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State of Technology for Rehabilitation of Wastewater Collection Systems

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by

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EXECUTIVE SUMMARY

Introduction

The variety of tools available to the sewer utility engineer today is remarkably different than it was during the 1960s. However, the average rate of system rehabilitation and upgrading within the U.S. is still not adequate to keep pace with increasing needs, quality demands, and continually deteriorating systems. The objective of this report is to summarize the current status of the development and application of repair, rehabilitation, and replacement technologies for wastewater collection systems. This report covers technologies applicable to sewer mainlines, laterals, manholes, and other appurtenances such as lift stations.

The emphasis of the report is on trenchless technologies, which do not require full excavation of the buried asset in order to carry out the work. These technologies have made a significant penetration into the U.S. market with estimates of the proportion of rehabilitation work carried out using trenchless techniques ranging up to 70% in the sewer sector (Carpenter, 2009). There is still considerable room for improvement in existing trenchless technologies and/or in the development of new trenchless technologies. Such improvements or new technologies offer the chance to make the investments in rehabilitation more effective and to extend the ability of utilities and local governments to fix larger portions of their systems with current funding levels. A secondary benefit is to increase the political and public will to spend additional money on fixing this problem.

Characteristics of Gravity Sewer Systems

In the U.S., there are approximately 16,000 sewer systems serving 190 million people and incorporating approximately 740,000 miles (1,190,660 km) of public sewers, plus 500,000 miles (804,500 km) of private lateral sewers. The term “sewer main” typically refers to the publicly owned collection lines that collect the sanitary sewage from individual properties, convey it to a treatment plant, and release it into a receiving body of water. Most sewer systems are laid out as gravity sewers, which transfer their flow under gravity in sloped sewers that are only partially filled under normal operating conditions.

Historically, many sewer systems were designed as “combined” systems that handled both sanitary sewage flow and stormwater drainage flows. The advantages were that storm flows would help to flush the system clean. The disadvantages were that during periods of high rainfall, it was necessary to allow excess flows to discharge into waterways through overflow structures. These overflows, known as combined sewer overflows (CSOs), were untreated, but diluted sewage. Over time, it became an unacceptable pollutant to the receiving waters. Such overflows are no longer permitted as a normal operating practice and many newer systems have been designed as “separated” systems with separate pipe networks for sanitary and stormwater flows. In cases where a combined system existed, new “interceptor” sewers have been designed to capture the overflows from combined systems and convey, store, and treat these flows, as appropriate, in the particular sewerage system.

The historical layout of gravity sewer mains has been strongly tied to topography, with sewers starting at the high points of a catchment area and following the natural drainage paths to a larger body of water where the sewage treatment plant was placed. In cities with a flat topography, a gravity sewer system has typically been designed with pipe sections installed to gradient via open-cut construction until the depths of excavation became uneconomical. At this point, a pump or lift station is installed to lift the sewage into a new pipe section, starting at the minimum depth of burial and flowing again via gravity either to the treatment plant or to another lift station.

Sewer laterals are the portion of the sewer network connecting individual properties to the public sewer network, but with some features (e.g., size of pipes, materials used, construction practices, and particularly ownership responsibility) that are different from the rest of the sewer collection system. Manholes are provided in sewer systems to help maintain and clean sewer pipes. Typically, they are provided at intersections of two or more mainline sewers, at changes in direction of sewer lines, and at regular intervals along a mainline. Manholes are typically spaced approximately 300 feet (91 meter) apart, but can be less than 100 feet (30.5 meter) or as far as 500 feet (152.4 meter) apart. Using these values, the number of manhole structures in the U.S. can be roughly estimated at over 12 million. Other structures that are part of a sewer collection system include pump/lift stations, valve or diversion structures, overflow structures, and drop shafts. There are also mechanical and sensor components, such as pump units, pump control systems, and flow monitoring stations, but these latter mechanical systems are not addressed in this report.

Renewal Technologies for Sewer Mainlines

In this report, the term "renewal" of a system is treated as the goal, while repair, rehabilitation, and replacement are methods to maintain performance and extend life to keep the system functioning at an acceptable level and at a minimum life-cycle cost for the foreseeable future. Repair actions are used either to restore the sewer to an operating condition or to deal with localized deterioration. Rehabilitation may include internal coatings, sealants, and linings used to extend operational life and restore much or all of the pipe's hydraulic and/or structural functionality. The focus of this report is on techniques used without an open-cut excavation to fully expose the sewer line. Replacement technologies essentially replace the existing pipe with a brand new pipe that provides a new conduit, but is not dependent on the existing host pipe for its structural performance.

Repair techniques include internal and external repair sleeves, short sections of cured-in-place liners and robotic repairs using in-pipe robots. Rehabilitation techniques include lining using sliplining, a variety of cured-in-place liner approaches and close-fit lining technologies, plus grouting approaches to seal leaky pipes that are otherwise structurally sound. Replacement techniques include pipe bursting and related techniques that will install a new pipe on the same alignment as the existing pipe, as well as conventional and trenchless methods to replace existing pipe on a new alignment.

The characteristics of renewal technologies for sewer mainlines, with emphasis on trenchless methods of rehabilitation, are described in this report. Appendix A provides general descriptions of each method, with detailed datasheets for representative technologies. The most commonly used technique for rehabilitation is cured-in-place lining, but several other technologies are available in order to provide solutions to a wide range of site constraints in the existing sewer system.

Renewal Technologies for Laterals, Manholes, and Appurtenances

Sewer laterals can be considered as merely additional pipe segments connecting building properties to the mainline sewers; however, laterals have a number of physical and administrative conditions that make both assessment and renewal programs more problematic than for the mainline sewers. The physical conditions include small diameters, frequent diameter changes, multiple bends, poor installation quality (especially at the junction with the mainline sewer), and blockage/damage caused by tree roots. Legal and administrative difficulties with the renewal of sewer laterals include the interaction between public funding and private property benefit, the liability issues of working on private property, and the development of incentive or enforcement programs that will encourage private and/or public action to renew this important component of the sewer system.

Likewise, sewer manholes and other sewer system appurtenances can all suffer from deterioration and thus degrade system performance as a whole. Manholes typically have many similar characteristics from structure to structure and various rehabilitation technologies have emerged to serve the manhole rehabilitation market. These include grouting and sealing approaches, spray or spin-cast liners, and grouted-in-place or cured-in-place liners. Similar approaches can be used in many ancillary structures although the rehabilitation approach may need to be tailored specifically for each structure, and the presence of flat surfaces means that liners cannot rely on ring compression to resist external groundwater pressures.

As indicated above for the renewal of sewer mainlines, the characteristics of renewal technologies for laterals, manholes and ancillary structures described in this report emphasize trenchless rehabilitation methods. General descriptions of each method are provided, with detailed datasheets for representative technologies provided in Appendix A. Manhole rehabilitation technologies can be considered well-established and widely used. For lateral sewers, a variety of technologies are available, but comprehensive lateral renewal programs are still emerging across the U.S. as municipalities consider the extent to which they need or wish to add lateral renewal to their mainline renewal programs. The variety in ancillary structures means that their renewal is significantly an ad hoc approach that uses techniques from the rehabilitation of manholes and other conventional structures.

Technology Selection Criteria

The criteria for technology selection can vary widely with the particular circumstances of an agency, sewerage system, or site configuration. However, certain key elements are usually desired in such a selection. These include capital outlay for the renewal works, a life-cycle assessment of the least costly approach (including both direct and indirect/social costs), and an assessment of the risk of technology failure in conjunction with the quality assurance and quality control measures to be applied. Other factors affecting the choice of technology include capacity issues (e.g., whether the pipe’s flow capacity needs to be increased at the same time the structures are being renewed), whether the flow can be removed from the existing pipe while it is being rehabilitated (need for a temporary bypass), the criticality of the sewer element (consequences of failure), and the accessibility of the pipe or site for the renewal work.

Design and Quality Assurance/Quality Control

A range of standards and design approaches exists for the rehabilitation of gravity sewerage systems. While these standards have been effective in that they have allowed the construction of large and varied renewal programs across the U.S., they do not represent an integrated approach to specifying renewal programs. Standards are frequently built around specific industry products rather than the performance desired from the rehabilitation or renewal activity. This makes it difficult to bid technologies against each other on a level playing field. This report identifies and briefly describes applicable standards for gravity sewer design and quality assurance and quality control (QA/QC). Some standards pertaining to the design of pressure pipes are also identified since gravity sewers may also occasionally (either by design or by mishap) become surcharged pipes operating under pressure.

Renewal technologies are not immune from failure. The principal failure modes for sewer rehabilitation technologies are construction/installation problems, structural failures, liner material degradation (leading over time to other failure modes), hydraulic inadequacy, failure to adequately address infiltration, and longitudinal liner movement after installation. Not all of these potential failure modes are directly addressed in current design and QA/QC standards. The high success rate of trenchless rehabilitation technologies (an assertion collected anecdotally by the authors from a variety of municipalities involved in trenchless rehabilitation) can thus be interpreted to mean that the application of design standards against specific failure modes (such as liner buckling) are also mitigating against failure caused by failure modes that are not specifically addressed in the design standards. This means that efforts to improve design analyses for specific failure modes should also include efforts to provide measures or guidelines to control against all likely failure modes. The evolution in the rehabilitation industry is bringing new technology providers and contractors to the marketplace as technology patents expire. In this regard, specifications and QA/QC procedures may need strengthening to compensate for the wider range of experience and “know how” of project bidders.

Operation and Maintenance

When portions of a sewerage system are renewed, the system elements that have been repaired, rehabilitated, or replaced must then enter the system’s normal operations and future maintenance/ replacement cycle. Many system owners have not fully addressed this area. Issues include the procedures for and frequency of cleaning and inspecting of relined pipes; monitoring of I/I reduction and flow performance over time; and noting any changes required in emergency procedures involving rehabilitated system components. Also, few municipalities have looked ahead to the time when they may need to renew a pipe component for the second time.

Findings and Recommendations

This report identifies some gaps between available technologies in the marketplace and technological developments that would offer significant improvements in practice. Technology gaps vary within the specific sectors of the wastewater collection system. Significant needs remain in matching design procedures to the actual loadings that technology will experience in the field. There is also a need to control the field processes to provide appropriate QA/QC of the finished product across a wide range of projects and contractors. Such technology advances would promote cost-effectiveness, increase performance of the rehabilitated product, and provide higher levels of quality assurance for the owner.

Most rehabilitation systems appear to be performing effectively to date, but a better understanding of expected life cycle and deterioration rates is important to properly use asset management systems. Some key gaps particularly exist in the availability of improved nondestructive inspection and condition assessment tools, including thickness and material property measurements for pipe walls and liners; identification of annular gaps and voids; data sharing among municipalities to allow improved prediction of deterioration rates and life-cycle costs; and the ability to tie the specifics of improved longevity created by rehabilitation to the management indicators used in asset accounting. In response to this identified need, EPA Task Order (TO) 58 was modified to include the development of protocols for evaluating previously installed rehabilitation technologies. Demonstration and evaluation of preliminary protocols for evaluating current liner condition and the expected lifetime of cured-in-place liners is already under way as this report is being finalized.

This report identifies nearly 100 different rehabilitation technologies. It includes 79 technology datasheets. Other technologies applicable to force main applications and water distribution networks are described in companion reports (EPA 2010a; EPA 2010b). Some of these technologies have been used internationally for nearly 40 years and in the U.S. for around 30 years; other technologies are either just being developed or just introduced into the U.S. after substantial use overseas. The EPA demonstration program provides the opportunity to demonstrate models for the acceptance of new products, the definition of QA/QC procedures, and the creation of protocols that will capture the as-installed condition of rehabilitation technologies, thus providing the basis for tracking their life-cycle cost and performance. In addition to demonstrating practical protocols for retrospectively evaluating previously installed rehabilitation technologies, this program will help to create a fuller understanding of the role of trenchless rehabilitation in the management and operation of wastewater systems.

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FOREWORD

The U.S. Environmental Protection Agency (EPA) is charged by Congress with protecting the nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building the science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory (NRMRL) is the Agency's center for investigation of technological and management approaches for preventing and reducing risks from pollution that threaten human health and the environment. The focus of the Laboratory's research program is on methods and their cost-effectiveness for prevention and control of pollution to air, land, water, and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites, sediments, and groundwater; prevention and control of indoor air pollution; and restoration of ecosystems. NRMRL collaborates with both public- and private-sector partners to foster technologies that reduce the cost of compliance and to anticipate emerging problems. NRMRL's research provides solutions to environmental problems by developing and promoting technologies that protect and improve the environment; advancing scientific and engineering information to support regulatory and policy decisions; and providing the technical support and information transfer to ensure implementation of environmental regulations and strategies at the national, state, and community levels.

This publication has been produced as part of the Laboratory's strategic long-term research plan. It is published and made available by EPA's Office of Research and Development to assist the user community and to link researchers with their clients.

Sally Gutierrez, Director
National Risk Management Research Laboratory

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DEFINITIONS

Cured-in-place pipe (CIPP) – A hollow cylinder consisting of a polyester- and/or glass-reinforced plastic fabric tube with cured thermosetting resin. The CIPP is formed within an existing pipe and takes the shape of the pipe.

Folded pipe – Pipe that has been manufactured and calibrated in a round shape, and then subsequently cooled and deformed into a folded shape for insertion into the existing pipe.

Formed pipe – A folded pipe that has been inserted into an existing pipe and expanded with steam heat and pressure and, if required by the manufacturer, with a squeegee device or “pig” to provide a close fit with the existing pipe.

Partially deteriorated pipe – The existing pipe can support the soil and surcharge loads throughout the design life of the rehabilitated pipe, but the soil adjacent to the existing pipe must provide adequate side support.

Fully deteriorated pipe – The existing pipe is not structurally sound and cannot support soil and live loads, or it is expected to reach this condition over the design life of any rehabilitation. This condition is evident when sections of the existing pipe are missing, the existing pipe has lost its original shape, or the existing pipe has corroded due to the effects of fluid, the atmosphere, or soil.

Renewal – The application of infrastructure repair, rehabilitation, and replacement technologies to return functionality to a drinking-water distribution system or a wastewater collection system.

Repair – A repair technique is used when the existing pipe is structurally sound, provides acceptable flow capacity, and can serve as the support or host of the repair method.

Rehabilitation – Internal coatings, sealants, and linings used to extend operational life and restore much or all of the pipe’s hydraulic and structural functionality.

Replacement – An existing pipe is usually replaced when it is severely deteriorated, collapsed, or increased flow capacity is needed.

Sliplining – The installation of a smaller-diameter replacement pipe inside an existing pipe, leaving an annular gap between the two. The replacement pipe can be continuous or made up of discrete segment lengths.

Trenchless technology – A family of techniques that allow installation and rehabilitation of buried utilities without the need to excavate a continuous trench to access the utility.

Open cut – Excavation from the surface to install or rehabilitate a buried utility.

ACRONYMS AND ABBREVIATIONS

ASCE	American Society of Civil Engineers
ASTM	American Society of Testing and Materials
AWI	Aging Water Infrastructure
AWWA	American Water Works Association
CBO	Congressional Budget Office
CCFRPM	centrifugally-cast fiber-reinforced polymer mortar
CCTV	closed-circuit television
CGA	Common Ground Alliance
CIGMAT	Center for Innovative Grouting and Materials, University of Houston
CIPM	cured-in-place manhole liners
CIPP	cured-in-place pipe
CSO	combined sewer overflows
DB	Design-build
DBB	Design-bid-build
DBO	Design-build-operate
DBOT	Design-build-operate-transfer
DIRT	Damage Information Reporting Tool (Common Ground Alliance)
DOT	Department of Transportation
DR	dimension ratio
EPA	U.S. Environmental Protection Agency
EPB	earth-pressure-balance
EPDM	ethylene propylene diene M-class
ESCR	environmental stress crack resistance
ETV	Environmental Technology Verification
FRP	fiberglass-reinforced plastic
GASB	Government Accounting Standards Board
GIS	Geographic Information Systems
GPR	ground penetrating radar
GPS	Global Positioning System
GRP	glass reinforced plastic
HDB	hydrostatic design basis
HDD	horizontal directional drilling
HDPE	high density polyethylene
HDS	hydrostatic design stress
ID	inner diameter
I/I	inflow and/or infiltration
IJS	intermediate jacking stations
IPL	International Pipeliner Technologies
ISO	International Organization for Standardization
MACP	Manhole Assessment Certification Program
NASSCO	National Association of Sewer Service Companies
NASTT	North American Society for Trenchless Technology
NRMRL	National Risk Management Research Laboratory
NSF	National Sanitation Foundation
O&M	operations and maintenance
OD	outer diameter
PACP	Pipeline Assessment Certification Program
PE	polyethylene

PPI	Plastics Pipe Institute
psi	pounds per square inch
psig	pounds per square inch gage
PU	polyurethane
PVC	polyvinyl chloride
PVCO	molecularly-oriented polyvinyl chloride
QA	quality assurance
QC	quality control
RDI/I	rainfall-derived inflow and/or infiltration
RT	radar tomography
SDR	standard dimension ratio
SOT	state-of-technology
SSO	sanitary sewer overflow
TBM	tunnel boring machine
TO	task order
TTC	Trenchless Technology Center, Louisiana Tech University
uPVC	unplasticized PVC
UV	ultraviolet
VCP	vitrified clay pipe
WEF	Water Environment Federation
WERF	Water Environment Research Foundation
WRc	UK Water Research Centre
WWTP	wastewater treatment plant

UNIT CONVERSION FACTORS

1 meter = 3.2808 feet
1 km = 0.62 mile
1 millimeter = 0.03937 inch
^{o}F = 1.8(^{o}C) + 32
MPa = 145 psi
1 bar = 14.503 psi
Psig = psi +14.7
mm = 39.37 mil
1 mile = 1.609 km

1.0 INTRODUCTION

1.1 Project Background

This report was prepared as part of the research being conducted under the U.S. Environmental Protection Agency's (EPA's) Sustainable Water Infrastructure Initiative. Under this program, research is being conducted to improve and evaluate innovative technologies that can reduce costs and increase the effectiveness of the operation, maintenance, and renewal of aging drinking water distribution and wastewater conveyance systems (EPA, 2007). The outputs from this research are intended to help EPA's program and regional offices implement Clean Water Act and Safe Drinking Water Act requirements; to help states and tribes meet their programmatic requirements; and to assist utilities in more effectively implementing comprehensive management of drinking water distribution and wastewater conveyance systems. This initiative is aimed at encouraging the introduction of new and improved technologies into the U.S. marketplace for water and wastewater rehabilitation, which will help utilities provide reliable service to their customers and meet their statutory requirements. As part of this research, the EPA National Risk Management Research Laboratory (NRMRL) awarded Task Order (TO) No. 58, entitled *Rehabilitation of Wastewater Collection and Water Distribution Systems*, under Contract No. EP-C-05-057. This research includes preparation of a series of reports on the state of technology (SOT) for rehabilitation of gravity wastewater systems (mains, laterals, and manholes), sewer force mains, and water mains. This report presents a comprehensive review and evaluation of existing and emerging technologies to define the current state-of-the-practice and state-of-the-art for sewer mainlines, laterals, manholes, and other appurtenances, such as lift stations.

This report follows a previously released interim report covering all three areas of the *Rehabilitation of Wastewater Collection and Water Distribution Systems: State of Technology Review Report* (EPA, 2009a). This interim report provided a brief overview of the current state-of-the-practice and current state-of-the-art for rehabilitation of pipes and structures within the wastewater collection and water distribution systems and discussed the common issues needing improvement that cut across both water and wastewater applications. In addition, the TO 58 project convened an international technology forum on September 9-10, 2008, at which the findings of the interim report were discussed and additional input was solicited from a wide range of utility owners, industry, and researchers who attended the forum.

During the preparation of the interim SOT report (EPA, 2009a), the conduct of the technology forum, and the preparation of the current SOT reports, the research team identified promising technologies that are in the early stages of adoption into U.S. practice. These technologies are considered appropriate for inclusion in a field demonstration program. The demonstrations will include not only a well-documented application of the technology, but also a demonstration of the approach to accept a novel or emerging technology and to capture design and installation data that will be important later in tracking deterioration rates of the rehabilitated structure.

The interim SOT report and the technology forum also reinforced a key need in applying asset management principles to water and wastewater systems – the need to track how the rehabilitation system is performing in terms of structural deterioration and functionality, and hence to assess the expected life cycle of the rehabilitated structure. Since several major rehabilitation technologies have been used in the U.S. for over 15 years (up to 33 years for cured-in-place pipe [CIPP] [Lucas, 2009]), a detailed and quantitative evaluation of older rehabilitated systems would provide an important dataset to confirm or revise estimates of expected life. Following the technology forum, additional work to develop protocols for retrospective evaluations of rehabilitation technologies and to test these protocols in selected applications was added to scope of this research.

1.2 Project Objectives

The objective of this report is to provide a status report on the U.S. development and application of wastewater collection system rehabilitation. The focus of the report is to review a wide range of applicable technologies that could be used to rehabilitate wastewater collection systems, including manholes and appurtenances. The text of this report provides an overview of the various technologies, with more detailed technology profiles included in Appendix A. This report also identifies gaps between available technologies in the marketplace and technological developments that would offer significant improvements in practice.

1.3 Project Approach

Recognizing that there would be some crossover among technologies used for water distribution systems, wastewater collection systems, and sewer force mains, a technology-specific datasheet was created for each identified technology, regardless of end use. Appendix A provides those technology profiles applicable to gravity wastewater systems. This information was gathered by researching the technology (through published literature, Web sites, trade shows, case studies, and magazine articles) and completing the technology-specific datasheet with as much publicly available information as possible. Each datasheet was then sent to the vendor to review and comment on the contents and to provide additional information, as needed. As discussed in Section 8, an effort was made to collect representative cost information, but often only limited cost data were available. Using the technology datasheets as a core reference, a written analysis of the SOT was prepared to identify application issues, market issues, and technology gaps.

1.4 Organization of the Report

The report is organized according to the following subjects:

- Section 1 provides the report introduction.
- Section 2 provides background on current utility practices, market issues for rehabilitation technologies, and the methods available for rehabilitating existing wastewater collection systems.
- Section 3 discusses the characteristics of wastewater collection systems, including the system components (mainlines, laterals, manholes, and ancillary structures) and the typical materials used for each component.
- Section 4 describes renewal technologies for sewer mainlines grouped into repair, rehabilitation, and replacement approaches.
- Sections 5, 6, and 7 extend this discussion to cover renewal technologies for laterals, manholes, and appurtenances, respectively.
- Section 8 highlights additional technology selection issues affecting rehabilitation of wastewater systems, including inspection and condition assessment.
- Section 9 deals with design parameters, product/material standards, design documents, installation standards, and quality assurance/quality control (QA/QC) requirements for both short- and long-term performance of rehabilitation systems.
- Section 10 discusses operation and maintenance (O&M) issues that affect both system performance and rehabilitation needs.

- Section 11 provides the findings and recommendations of the report in terms of technology gaps and suitable criteria for selecting technologies for EPA-funded demonstration projects.
- Appendix A contains datasheets for 79 rehabilitation technologies used to rehabilitate mainlines, laterals, manholes, and appurtenances.
- Appendix B lists ASTM standards pertaining to the rehabilitation of wastewater collection systems.
- Appendix C lists non-ASTM standards that are referenced in the report.

2.0 BACKGROUND

2.1 Current Utility Practices

The vast majority of agencies responsible for wastewater collection systems are public bodies administered under a municipal or regional government structure. They depend on a system of appointed and elected officials for their operating budget, which may be supplemented by special grants or loan programs from the state or Federal government. The maintenance and scheduled replacement of wastewater collection systems has historically been underfunded and can be an easy place to save money during fiscal crises without any immediate or noticeable effects on quality of life. However, over decades, this neglect and an increasing public unwillingness to accept wastewater pollution of waterways have led to a concerted effort to "catch up" and put the financial and operational organization of wastewater collection systems on a sound asset management basis. The objective of these renewal efforts is to provide the most cost-effective system operations and to reduce pollution caused by wastewater releases to a minimum practical level that will enhance environmental quality.

Some components of the U.S. wastewater infrastructure are well over 100 years old. The combination of age, neglect, and mishaps give rise to at least 40,000 sanitary sewer overflows (SSOs) per year, along with the resulting illnesses and environmental degradation (EPA, 2009d).

The latest 2009 infrastructure report card issued by the American Society of Civil Engineers (ASCE) provides a "D minus" grade for wastewater infrastructure – unchanged from its grade in the last assessment in 2005 (ASCE, 2009). In accompanying comments, ASCE indicated that as much as 10 billion gallons of raw sewage are released yearly because of the state of wastewater infrastructure.

Through a combination of enforcement activities, public education activities and technology development support, the EPA has been a primary driver in helping cities to confront the problems in their wastewater collection systems. Today, very few cities in North America have not at least thought about the current condition of their wastewater system, how its operation might be improved over time, and how to approach its rehabilitation and replacement. However, being aware of the problem and being able to assemble the financial and technical wherewithal to solve the problem over a defined time period are vastly different. Unless agencies are under a court order or consent decree to fix system problems, they still struggle to assemble the funds needed to make significant improvements over a moderate timeframe of 10 to 20 years.

In the technology arena, the experience level with rehabilitation technologies that provide an alternative to dig-and-replace varies widely. Some cities now have one to three decades of experience with rehabilitation approaches; others (especially smaller communities) have yet to try even one form of rehabilitation technology. Awareness that rehabilitation techniques exist appears to be quite widespread, but the confidence to apply a technique within a system or to select appropriately among the variety of solutions available for a particular problem is still more problematic.

2.2 Current Market

EPA estimates that wastewater collection in the U.S. is composed of 16,000 sewer systems serving 190 million people; they incorporate 740,000 miles (1,190,660 km) of gravity sewers and 60,000 miles (96,540 km) of force mains (EPA, 2009d; EPA, 2009e). There is an estimated 500,000 miles (804,500 km) of private lateral sewers (EPA, 2006).

The current annual financial market for rehabilitation and new construction in the water and sewer sectors within the U.S. is shown in Figure 2-1 (Carpenter, 2009). However, the sewer rehabilitation market was estimated at $3.3 billion in 2009, maintaining the same level as in 2008. The water rehabilitation market is smaller, with $1.3 billion projected for 2009. New construction was estimated at $4.3 billion for sewer and $2.8 billion for water. Both these estimates are less than in 2008, reflecting the slowdown of new building construction during the current economic crisis. The total U.S. market, in financial terms within the water distribution and wastewater collection systems, is therefore estimated to be about $12 billion per year. As noted in the TO 58 interim SOT report (EPA, 2009a), the U.S. market is often considered to be approximately 50% of the worldwide market; this provides a very approximate estimate of $24 billion as the total worldwide annual spending, in U.S. dollars, on water and sewer piping systems. Rehabilitation represents approximately 40% of U.S. total spending on water and sewer systems, but this percentage may vary in other parts of the world, depending on whether the region is dominated by older cities or by rapidly enlarging and emerging cities. The proportion of trenchless rehabilitation in the sewer market, as noted in the 2009 survey, shows that approximately 70% of the sewer or stormwater rehabilitation work uses trenchless methods. This percentage is lower for water systems, with approximately 32.5% of the rehabilitation work expected to use trenchless methods in 2009.

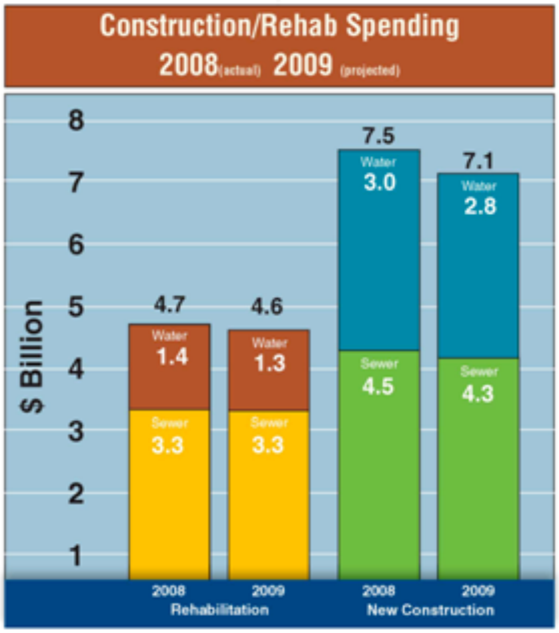

Figure 2-1. Construction and Rehabilitation Spending on Water and Wastewater Systems in 2008 and 2009 (Carpenter, 2009)

Annual expenditures for rehabilitation can be compared with the 20-year estimate of the investment needed to restore the water and wastewater infrastructure to a properly functional system. For wastewater systems, which are the topic of this report, the annual estimated investment required is between $12 billion and $21 billion (see Figure 2-2) (CBO, 2002) compared to the $3.3 billion annually reported as being spent in 2009 in the *Underground Construction* magazine survey.

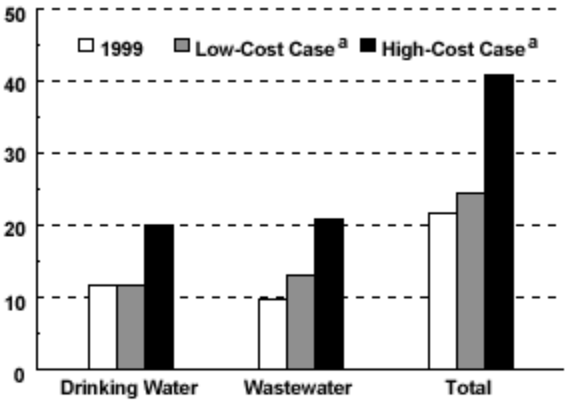

Figure 2-2. Estimated Annual Average Investment Costs ($ billions) for 2000-2019 for Water and Wastewater Infrastructure (CBO, 2002)

Changes in the market resulting from the targeting of infrastructure investments in the economic stimulus package passed by Congress in early 2009 are still somewhat unclear. Depending on how the stimulus funds are actually distributed and spent and whether the infrastructure emphasis continues into regular budget cycles, the financial picture for investment in wastewater infrastructure could improve substantially. However, it is very unlikely to be completely addressed in the foreseeable future.

2.3 Renewal – Repair, Rehabilitation, and Replacement

The terminology used in connection with infrastructure maintenance and renewal is not fully standardized, which can lead to some overlapping of terminology and potential confusion among those trying to get an overall picture of the industry's structure.

In this report, system renewal is the goal, while repair, rehabilitation, and replacement are methods to maintain performance and extend life to keep the system functioning at an acceptable level and with minimum life-cycle costs for the foreseeable future. Individually, the terms "repair," "rehabilitation," and "replacement," as used in this report, signifies the following:

- **Repair** actions are used either to restore the sewer to an operating condition or to deal with localized deterioration. The repair can be temporary until a more complete rehabilitation or replacement, or a long-term fix of a localized problem can be carried out.
- **Rehabilitation** may include internal coatings, sealants, and linings used to extend operational life and restore much or all of the pipe's hydraulic and structural functionality. The focus of this report is on techniques used without an open-cut excavation to expose the sewer line.
- **Replacement** technologies essentially replace existing pipe with new pipe, which provides a new conduit that does not depend on the existing host pipe for its structural performance. In this report, if the existing pipe is replaced in the same location (i.e., on the same line and grade), the replacement is referred to as an "on-line" replacement. If the replacement is made on a new alignment and perhaps with a new grade, the replacement is referred to as an "off-line" replacement.

The issue of terminology for asset management and renewal activities also is being addressed by the American Society for Testing and Materials' (ASTM) Committee F36 on Technology and Underground Utilities. ASTM E2135-07 provides a published standard related to terminology for property-related asset management (see Appendix B for a list of the relevant ASTM standards).

3.0 CHARACTERISTICS OF WASTEWATER COLLECTION SYSTEMS

3.1 System Components

In the U.S., there are approximately 16,000 sewer systems serving 190 million people. These systems incorporate 740,000 miles (1,190,660 km) of public sewers, plus 500,000 miles (804,500 km) of private lateral sewers. This section briefly describes the typical system components within a wastewater collection system to provide a background for the subsequent discussions of rehabilitation and replacement methods. A variety of references offer further information on the historical development, layout, and renewal of sewer systems, including: Bizier (2007), Grigg (2003), Read, et al. (1997), Read (2004), Stein (2001, 2005), WEF/ASCE (2007), and Schladweiler, et al. (2009).

3.1.1 Sewer Mains. The term “sewer main” typically refers to publicly owned collection lines that collect sanitary sewage from individual properties and convey the sewage to a treatment plant for treatment and release into a receiving body of water. The network of sewer mains leading to a treatment plant forms a tree-like structure, with the flow starting at the smallest branches and progressing into increasingly larger conduits as the merged flows continue to increase. Most sewer systems are laid out as gravity sewers, which transfer their flow under gravity in sloped sewers that are only partially filled under normal operating conditions.

Historically, many sewer systems were designed as “combined” systems that handled both sanitary sewage flow and stormwater drainage flows. The advantages were that storm flows would help to flush the system clean and that one pipe system could do double duty. The disadvantages were that during periods of high rainfall, excess flows discharged to waterways through overflow structures. These overflows, known as combined sewer overflows (CSOs), were untreated; however, the frequent release of diluted sewage, became an unacceptable pollutant in the receiving waters.

Such overflows are no longer permitted as a normal operating practice, and many newer systems have been designed as “separated” systems with separate pipe networks for sanitary and stormwater flows. In cases where a combined system existed, new “interceptor” sewers have been designed to capture the overflows from combined systems and convey, store, and treat these flows, as appropriate, for that particular sewerage system.

Gravity sewer gradients are designed to lie between minimum gradients, which provide self-cleaning flow velocities, and maximum gradients, which limit erosion damage to the sewer pipe. The pipe geometry and size, combined with the gradient, determine the pipe’s design flow capacity. However, as a municipality grows and flows increase or as the pipe deteriorates or becomes partially blocked, the pipe may become surcharged under either normal service or high-rainfall conditions. In this case, overflows may occur and pipes may become damaged by internal pressures for which they were not designed.

The historical layout of gravity-sewer mains has been strongly tied to topography, with sewers starting at the high points of a catchment area and following the natural drainage paths to a larger body of water where the sewage treatment plant was placed. This layout has meant that many sewers follow creeks, streams, and rivers to take advantage of the natural gradients, so there is minimal need for deep-cut excavation or tunneling. Another layout choice in a number of cities has been to locate sewers along backyard or alley easements away from the streets. Both of these layout choices have resulted in the public sewer being located either in a natural recreational environment (along a creek) or in an easement in private property that may have become inaccessible or built upon over time. As these sewers need rehabilitation or replacement, the lack of access or the potential damage to the natural environment through open-cut excavation can severely limit available renewal options. Furthermore, a sewer running below ground along a valley bottom is likely to have a groundwater level that will encourage infiltration into the sewer system as the pipe deteriorates.

In cities with a flat topography, a gravity sewer system has typically been designed with pipe sections installed to gradient via open-cut construction until the excavation became too deep to be economical. At this point, a pump or lift station is installed to lift the sewage into a new pipe section, starting at the minimum depth of burial and flowing again via gravity either to the treatment plant or to another lift station. Trenchless installation methods have altered the relative economics between the installation and operation costs of lift stations and changed the costs of installing longer and deeper lines via pipe jacking and microtunneling. However, many cities have large numbers of lift stations whose continued operations have energy and maintenance requirements.

Impacts of these layout issues on network renewal are:

- Mainline sewers are seldom very shallow pipes (especially in northern climates) and may be tens of feet belowground so as to overcome local topographic variations or before placement of a lift station in a flat-lying area.
- Deteriorated sewers may act as groundwater drains, contributing significantly to inflow and/or infiltration (I/I) problems.
- Deep sewers may be subject to significant external groundwater pressures once they are lined and sealed against infiltration.
- Once sealed, the groundwater level near the mainline sewer may rise, causing I/I problems in adjacent sewer laterals and flooding basements. This means that fixing the sewer mains may be less effective in reducing I/I than anticipated until the laterals also are fixed; additional measures may be needed to protect homeowners from basement flooding during rehabilitation actions.
- Whether under a major roadway or under a creek parkway, replacement of a sewer by open cut is a very disruptive operation, with high direct costs and potentially even higher indirect or social costs due to environmental damage, traffic delays, reduction in pavement life after reinstatement, and business losses.

3.1.2 Sewer Laterals. Sewer laterals are the portion of the sewer network connecting individual properties to the public sewer network, but have some features (e.g., size of pipes, materials used, construction practices, and particularly ownership responsibility) that differ from the rest of the sewer collection system. Laterals are very often in bad condition, having defects that cause serious problems; however, the owners may be unaware of these problems or unwilling to fix them if the consequences do not directly affect them. Even when the system-wide impact of I/I is not an issue, defective laterals can cause sewer backups and sanitary sewer overflows (SSOs), and can be an important issue of concern in public works agencies.

Figure 3-1 illustrates the division of private and public ownership for communities surveyed; this information resulted from a comprehensive study on sewer laterals conducted for the Water Environment Research Foundation (WERF) (Simicevic and Sterling, 2005). Distribution of ownership and attitudes toward the responsibility of public agencies to help solve a lateral's problem vary widely even within the same metropolitan area.

One concern related to private property issues and sewer laterals, but not directly connected to pipe rehabilitation is the need to remove sources of inflow into the sanitary sewer system from private property. These inflow sources can include connections to roof and driveway drains and connections to basement sump pumps. These inflows were once permitted in many communities, but are now typically prohibited. In general, removal of inflow sources represents one of the most cost-effective ways of removing a portion of the I/I from collection systems. However, the policing and actual removal of these sources is not always aggressively pursued due to the reluctance to take on private property issues.

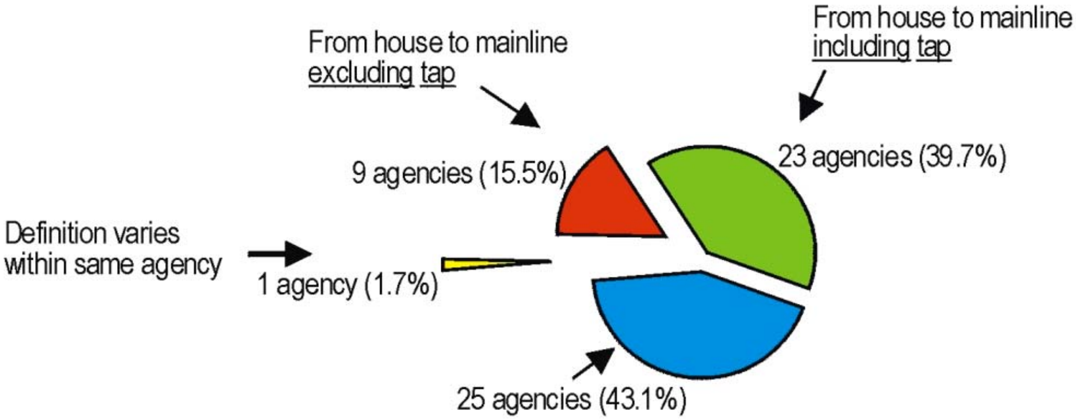

Figure 3-1. Private Ownership of Sewer Laterals (Simicevic and Sterling, 2005)

3.1.3 Manholes. Manholes are provided in sewer systems to help maintain and clean sewer pipes. Typically, they are provided at intersections of two or more mainline sewers, at changes in direction of sewer lines, and at regular intervals along a mainline. Manholes are typically spaced approximately 300 feet (91.4 meter) apart, but can be less than 100 feet (30 meter) or as far apart as 500 feet (152 meter). Using these values, there are roughly over 12 million manhole structures in the U.S. This typical spacing of manholes coincides quite well with the typical lengths of urban or suburban "blocks." Junctions for the connections to individual private properties are not provided with individual manholes, making them inaccessible except by open-cut excavation or robotic access through the mainline or lateral. In a few cities overseas (e.g., Berlin), connections to properties are made radially to several properties at a time from regularly spaced manholes. This configuration allows use of trenchless installation methods for both the mainline and the service lateral connections (see Figure 3-2).

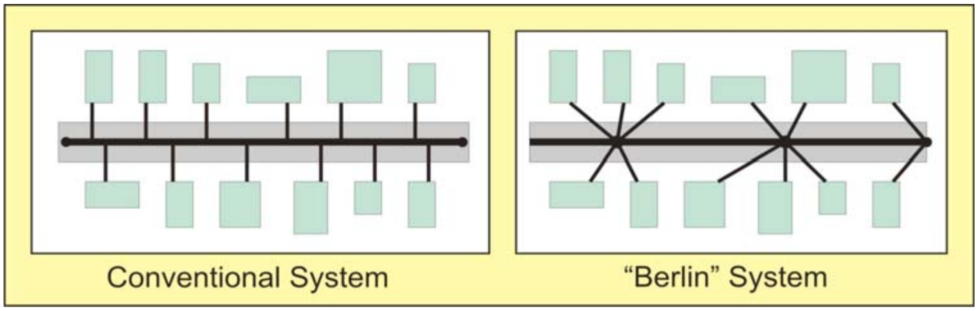

Figure 3-2. Comparison of the Conventional Lateral/Mainline Connection System Versus the "Berlin" System

Being able to inspect, repair, rehabilitate, or install at least one segment of sewer line from manhole to manhole is thus an important criterion for using trenchless methods on sewer systems. Manholes placed at moderate separations and at straight segments of sewers between manholes are the norm in sewer networks; however, road layouts and sewer depths have led to the use of curved sewer alignments between manholes and, in some cases, less frequently spaced manholes. These configurations limit the choices for rehabilitating these segments. The large-diameter segments of old sewer systems can present special problems in such a case. They are often deep segments, perhaps installed by tunneling. Because of their large diameter and depth, frequently spaced manholes would have been very costly and were not considered necessary due to the sewer's person-entry size. However, these segments of sewer systems now tend to have continuous moderate to high depths of flow, with flow quantities that are very expensive to bypass.

Older manholes are typically brick or concrete structures and may suffer from a variety of deterioration mechanisms:

- Hydrogen sulfide releases may attack concrete manholes and the mortar in brick manholes.
- Manholes may leak, allowing soil fines from the surrounding ground to enter, causing soil voids and surface settlement adjacent to the manholes.
- In cold climates, the upper portion of the manhole may be lifted by frost heave in the soil, thus fracturing the manhole and providing an infiltration path into the manhole.
- Newer plastic manhole materials avoid some of the corrosion issues, but some have been inadequately designed to prevent excessive deflections due to ground loadings.
- Corrosion of ladder access or cast-in-place rungs can be an important safety problem in manholes. Some utilities remove such fixtures during rehabilitation work.

Many agencies rehabilitate manholes as they rehabilitate an area's mainline sewers (unless urgent action is needed on manholes in other areas). Effective techniques for manhole rehabilitation exist, and full manhole replacement is an option if the structure is too badly deteriorated for rehabilitation.

3.1.4 Ancillary Structures. Ancillary structures that are part of a sewer collection system include pump/lift stations, valve or diversion structures, overflow structures, and drop shafts. Other mechanical and sensor components are pump units, pump-control systems, and flow-monitoring stations, but these mechanical systems are not addressed in this report.

The number and type of these ancillary structures varies widely among systems, depending on the area's topography, the system's history of development, the combined or separated nature of the system, and whether interceptor sewers have been added to an existing system via special structures. For example, in 1996, the Miami/Dade collection system was reported to comprise three regional treatment plants, 886 pump stations, 56,600 manholes, 2,228 miles (3,585 km) of gravity sewers, and 642 miles (1,033 km) of force mains. At the same time, the much larger Los Angeles wastewater and conveyance system, serving a population of 3.7 million people in a 535 square mile service area comprised 6,500 miles (10,459 km) of pipelines with 135,000 manholes, but only 55 pumping stations (Thomas, 1996).

What is deemed a pump station versus a lift station is not always consistent, since a lift station is a form of pumping station. In many cases, the term "pump station" is associated with force mains and is used for pumps that move sewage flows against gravity for some distance. The term "lift station" is used when gravity sewage lines become too deep for economical installation, and it is necessary to lift the sewage by pumping, so that a new section of gravity sewer line can be installed at a shallower depth. Particularly on smaller-diameter lines, lift station requirements are quite similar from one location to another, so standard or prepackaged designs may be used. Typically, however, a site-specific configuration and design are used for force main pumping stations or for lift stations on large-diameter sewers.

Drop shafts are used in wastewater systems to connect a shallow storm sewer or sanitary sewer with a deeper sewer or an interceptor tunnel system. Depending on the design of the drop shaft, the flow may be piped to the lower level within the shaft structure, or it may be allowed to drop freely within the shaft. Piping the flow allows for smooth directional transitions and minimizes turbulence that can cause excessive hydrogen sulfide release and corrosion/erosion in sanitary systems. In some cases, spiral drop (vortex) structures are used to reduce velocities. Rehabilitation issues for drop shafts will need to be determined on a case-by-case basis, depending on the depth of drop, the internal structures present, and the degree of deterioration.

Overflow structures remain in many systems and were designed to limit the flow in downstream sections of the sewer to a certain multiple of the expected dry weather (sanitary sewage) flow. The overflow was then discharged to a nearby waterway. To capture this diluted sewage during high-flow periods, the overflow structures were left in place and a drop shaft and interceptor sewer were used to capture the sewage on the overflow discharge line.

Valve chambers are used to shut off flow in a particular pipe and/or divert flow into a parallel line. In a gravity line, weir structures (or, on a temporary basis, inflatable plugs) may be used; valve chambers are more likely to be used on pressure pipe applications for water supply, siphons, or force main sewers.

While the majority of a sewer collection system may function as a non-pressurized gravity flow line, some circumstances require transmission of sewage flows under pressure. For example, a sewer line crossing a river may use a siphon structure to pass the sewage beneath the river. As an additional example, the decommissioning of an old sewage treatment plant may require transfer of the sewage collected at that location via a force main to a new treatment plant in another location. Overall, these pressurized sections represent approximately 7.55 of sewerage systems in the U.S. and typically use materials that are not used elsewhere in the sewer system, such as steel, cast iron, and ductile iron. They represent a special set of challenges for sewer rehabilitation. While siphons may have redundancy for cleaning and inspection, most force mains do not have a bypass flow line and hence are difficult to take out of service for inspection or rehabilitation. The combination of corrosion potential, lack of inspection, and severe consequences for a failure make force mains a particular issue of concern. The state of technology for the rehabilitation of force mains is dealt with in a companion report (EPA, 2010a).

4.0 MAINLINE RENWAL TECHNOLOGIES

4.1 Introduction

This section summarizes the range of technologies available for the repair, rehabilitation, and replacement of gravity sewer mainlines. Figure 4-1 illustrates these categories within the overall goal of sewer system renewal. The technologies described are not exhaustive, but are intended to reflect the major current options for renewal of mainline sewers. A technology-specific datasheet was created for most of the technologies discussed in this SOT report (Appendix A). Vendor contact information can be found on each datasheet, along with relevant case study information, as available. Where multiple providers offer the same or very similar technology, only datasheets from one or a few of the major providers are included. Groups of technologies also are described in general terms in this section, along with a summary of typical advantages, limitations, and applications.

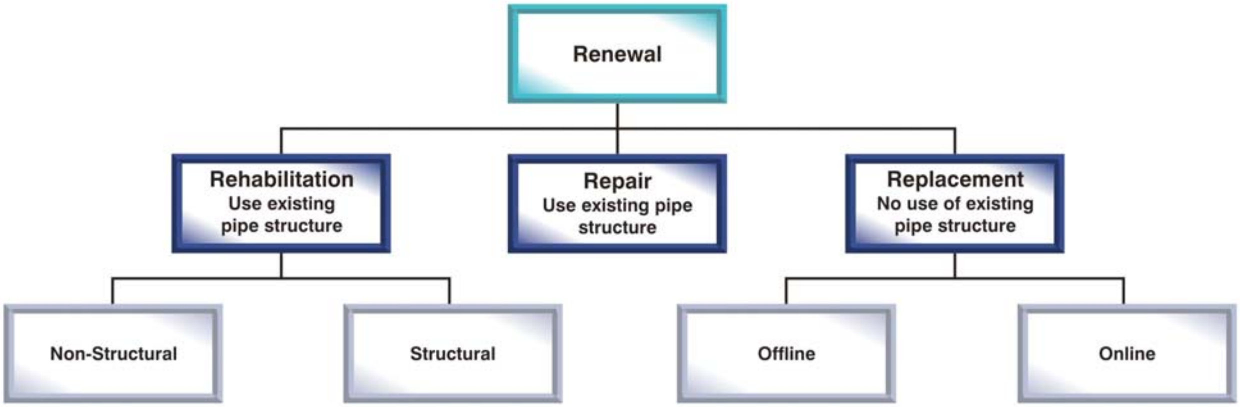

Figure 4-1. Renewal Approaches for Sanitary Sewers

4.2 Repair

Repair of sewer mainlines may result from gradual deterioration in some localized areas of the sewer line, external damage, or some other unexpected and rapid deterioration of conditions within the sewer. The focus of repair actions is either to restore the sewer to an operating condition or to deal with localized deterioration. The repair can be temporary until a more complete rehabilitation or replacement can be carried out. In-house crews can often conduct repair work, although agencies may use “on-call” contracts, or they can contract for groups of repairs with local contractors.

Repair of a failure or a deteriorated section of pipe generally focuses on taking only remedial action for one or two sections of pipe. This work is often done under emergency conditions. The first objective is to prevent any overflow or damage to the environment, and the second objective is to restore service as quickly as possible. Figure 4-2 illustrates the various repair approaches applicable to gravity sewer mainlines.

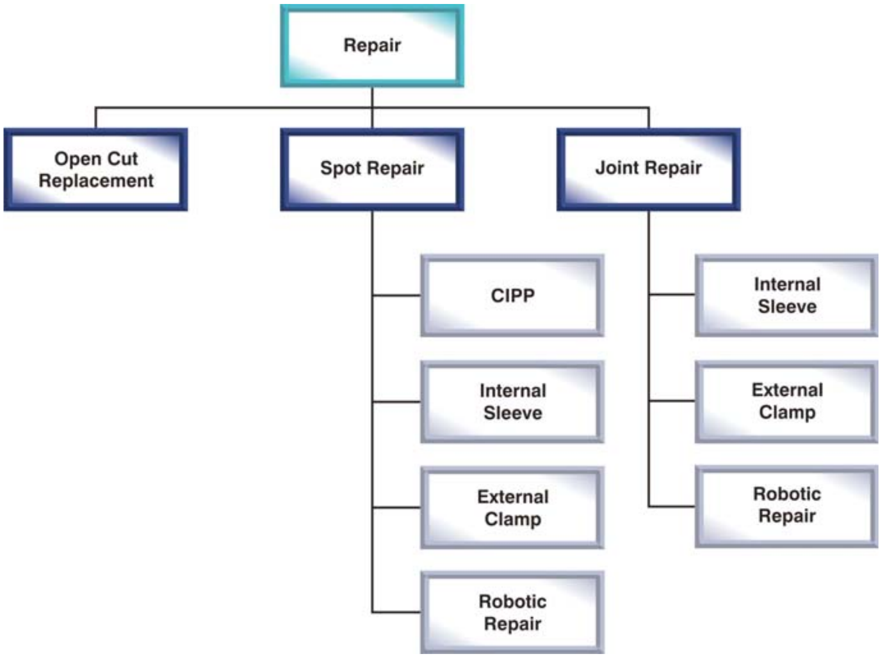

Figure 4-2. Repair Approaches for Gravity Sewer Mainlines

4.2.1 Open-Cut Repair and Replacement. For many decades, this was the principal repair approach for sewer mainlines. It can be used both for repair activities and for systematic replacement of deteriorated mainlines (see Section 4.4.2.1). The principal disadvantage of the external repair process is the need to make an open-cut excavation to expose the pipe. Costs and disruption increase when the sewer line is deep, below the water table, under a paved surface, or in either environmentally sensitive or heavily trafficked areas.

4.2.1.1 External Repair Clamps and Couplings. Making an external repair requires an open-cut excavation to reach the sewer line and, if necessary, to cut out the damaged section, replace it with a new pipe section, and reconnect the new section to the existing pipe with external couplings. A weakened or damaged section of pipe may also be reinforced by installing an external clamp around it. These are common techniques and are not discussed in Appendix A. The repair clamps must extend far enough along the pipe to bridge onto structurally sound sections of pipe. Figure 4-3 shows an example of an external clamp that can be used for repair.

Figure 4-3. Sewer Repair Clamp (Courtesy of Romac Industries)

4.2.1.2 External Joint Repairs. External joint repairs involve the same or similar techniques to those described in Section 4.2.1.1.

4.2.2 Internal Spot Repairs. Internal spot repairs can be divided mainly into two types of application:

- Short lengths of internal liner with appropriate termination and sealing arrangements
- Localized repairs using pipe robots that involve removing obstructions, sealing, and grouting.

4.2.2.1 CIPP Short Liners. One option for repairing damaged sections of sewer mainline is to use a short section of CIPP (see Section 4.3.4 for a description of the CIPP process), rather than relining the whole mainline segment from manhole to manhole. For these applications, the CIPP liner is pulled into place, rather than inverted, and is pressed against the host pipe, using an internal bladder, until the liner is cured. The length of the individual liner repair can be matched to the needs of the damaged pipe, and more than one "short" liner can be used within a mainline section. In most cases, a maximum of two CIPP spot repairs within a mainline segment would be made, since for more than two repair sections, it would be preferable, and have similar costs to reline the entire segment from manhole to manhole.

4.2.2.2 Internal Sleeves and Joint Repair. Techniques for joint repair and spot repair are quite similar. Where the internal pipe surface is reasonably smooth and round, joint repair techniques can also be used for spot repairs. Some internal repair sleeves (e.g., Link Pipe) can be ganged together to form longer sections of pipe repair. Three common internal joint-sealing techniques are the Weko-Seal®, AMEX 10®, and NPC internal joint seals, which are used in pressure pipes as well as gravity sewers. The repair section is expanded against the host pipe, and seals are compressed at each end of the section to provide a leak-tight seal. A stainless-steel insert maintains the compression once the seal is in place. Access is required to complete the expansion and to lock it in place. This type of seal currently has application in the 16 inches (406 mm) to 20 feet (6 meter) diameter range. For wastewater or water applications, the sleeve is made of ethylene propylene diene M-class (EPDM) rubber. These sleeves can also be used to seal a radial crack in a pipe wall or to transition between two different pipe materials. With its ability to span an extended longitudinal length by stacking the sleeves, the AMEX 10® Vario (Figure 4-4) can be used to seal a longitudinal crack. The sleeves have enough flexibility to allow some additional joint rotation without leakage after installation.

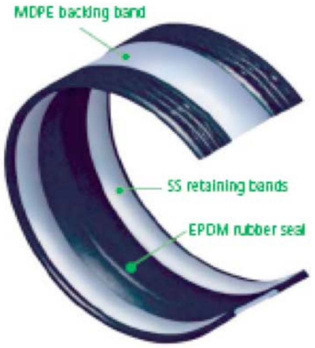

Figure 4-4. AMEX 10 Mono Seal (Courtesy AMEX)

Another form of joint or spot repair is the Link Pipe® system (Figure 4-5). Both stainless-steel and polyvinyl chloride (PVC) sleeves are available; applicable internal pipe diameters range from 4 to 54 inches (100 to 1,372 mm). Standard sleeve lengths are 12, 18, 24, and 36 inches (300, 450, 600, and 900 mm). The sleeve is expanded against the host pipe with a sealing compound, typically between the sleeve and the host pipe (or the sleeve can be grouted in place). The sleeve is locked in place by a ratchet-type interlock and placement, and locking does not require person-entry. The ends of the sleeve are tapered to reduce flow restrictions and maintenance issues. To ensure that the sleeves lock in place properly, they are manufactured specifically for the measured internal diameters of the sections to be sealed.

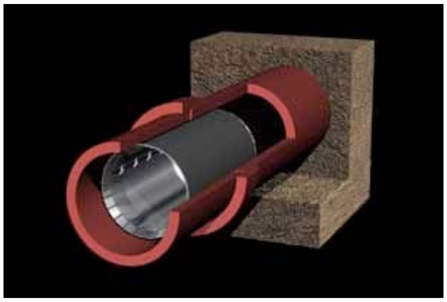

Figure 4-5. Internal Mechanical Sleeve (Courtesy Link Pipe)

4.2.2.3 Application Issues for Short Liners and Internal Sleeves. It is possible to use other internal repair solutions in short sections, but all short liner options present issues:

- Protecting the ends of the repair section from damage during future cleaning operations
- Bonding or interlocking the repair section to the host pipe so that it does not become dislodged during high flow or cleaning operations
- Spreading of initially localized damage beyond the repair zone, thereby requiring a new spot repair or relining the full manhole-to-manhole segment.

For these above reasons, agencies may use only limited internal spot repair, restricting its use mainly to isolated areas of damage that are not likely to propagate to the rest of the mainline segment and where a dig-up and repair would be costly and disruptive.

4.2.2.4 Robotic Repair. Pipe robots can perform a wide range of tasks within a sewer mainline. Their use in gravity sewers is greatly facilitated by the frequent spacing of manholes, which is not present in sewer force mains or water mains. Various pipe robots can remove (by grinding) flow obstructions such as protruding lateral pipes. They can also remove local areas of existing pipe and force a structural polymer into the pipe wall and surrounding void space. They are often used to repair and seal the connections of laterals to the mainline sewer (discussed in more detail in Section 5).

4.2.3 Summary of Repair Options. Table 4-1 summarizes repair and maintenance procedures for mainline sewers, together with their main advantages, limitations, and most suitable application conditions.

Table 4-1. Repair and Maintenance Procedures for Gravity Sewer Mainlines

Advantages	Limitations	Most Suitable Conditions for Application
External Repair Clamps and Joint Sleeves		
• Commonly used and well-understood • Robust and easy to apply	• Extensive surface disruption and disturbance • Cost of street replacement	• Open area without obstacles • Shallow pipe • Completely damaged pipe
Robotic Repair		
• Provides local repair • No excavation required • Minimal disturbance	• Repair limited to mainline wall defects and lateral defects within the first 2 feet from the mainline • High cost relative to length of pipe rehabilitated	• Localized defects suitable for robotic removal or repair • Only lateral connection and short distance into lateral need repair • Break-in or protruding laterals
CIPP Spot Repair		
• No excavation required • Local structural repair possible • Long-term repair	• High cost relative to length of pipe rehabilitated • Possible interference with future maintenance activities	• Single defects in otherwise sound pipe segments • Deep lines that are difficult to repair with open-cut methods
Internal Joint Seals and Mechanical Spot Repairs		
• Locking mechanism to provide positive seals • Can withstand internal pressures	• Access required for some technologies • Accurate measurements of internal diameter required • High cost relative to length of pipe to be rehabilitated • Possible interference with future maintenance activities	• Single defects in otherwise sound pipe segments • Deep lines that are difficult to repair with open-cut methods

4.3 Rehabilitation

Rehabilitation of mainline sewers represents a more extensive or deliberate effort to renew portions of a sewerage system. The focus of this discussion is on techniques that can be carried out without an open-cut excavation to expose the sewer line. As shown in Figure 4-6, rehabilitation methods will include the use of CIPP, close-fit linings, grout-in-place, spiral-wound linings, panel linings, spray-on/spin-cast linings, and chemical grouting. Sections 4.3.4 through 4.3.10 discuss technologies within each of these rehabilitation categories.

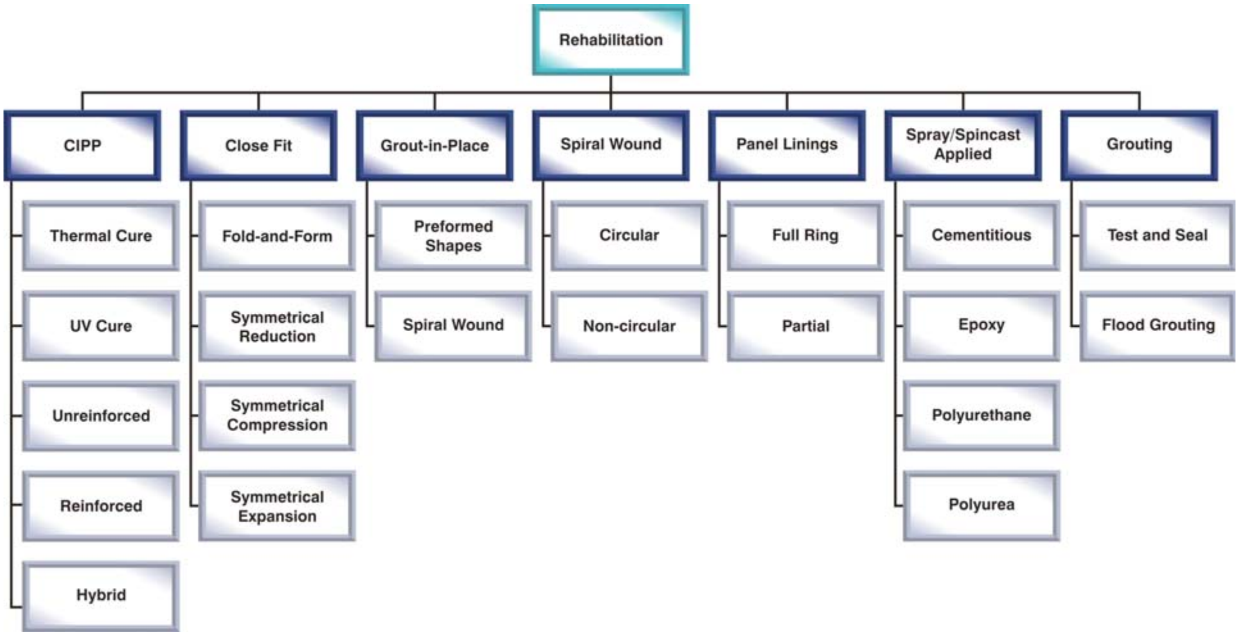

Figure 4-6. Rehabilitation Approaches for Sewer Mainlines

4.3.1 Host Pipe Condition Requirements. Rehabilitation and trenchless replacement technologies vary significantly in their applicability to various aspects of host pipe condition. Examples of typical issues are:

- Extent of cleaning required (e.g., high level of cleaning required for spray coatings and close-fit lining systems; low level needed for pipe bursting)
- Sensitivity of method to minor variations in pipe's internal diameter
- Adaptability of the method to cope with pipe-diameter changes within a rehabilitation segment.

The discussion of rehabilitation type describes special issues regarding individual rehabilitation systems, as do the datasheets in Appendix A.

4.3.2 Bypassing Requirements. Technologies also vary significantly in their requirements for sewage flow interruption or bypassing of the sewer line. The significance of this requirement increases as the sewer diameter increases, reflecting larger and more continuous sewage flows and more critical backup requirements for the bypass operations. In large-diameter sewers with high flows, bypassing can be a critical technical and cost element of the work. Only a few rehabilitation techniques, such as sliplining, can be installed in live sewers with no flow removal. On the other hand, in small sewers with low flows, it may be possible to simply block the flow from sewer laterals and an upstream mainline during the rehabilitation. In such cases, residents may be asked not to discharge liquid wastes for a few hours. Methods that allow a quick return to service not only increase direct productivity, but also may mean the difference between having to provide a bypass and being able to avoid this expense.

4.3.3 Non-Structural Linings. Some sections of a sewer system may be in good overall structural condition, but have leaking cracks or joints that allow excessive I/I into the system. Pipes that are susceptible to corrosion in a sewer environment might also benefit from non-structural coatings or linings that will provide corrosion protection principally to the sewer pipe. However, adequate preparation of surfaces for adhered coatings is very difficult in a non-person-entry sewer pipe, which will typically preclude this approach. Section 9 discusses the variation of structural capacity that a lining system needs according to groundwater condition and soil or traffic loading.

4.3.4 Cured-In-Place Pipe. A CIPP product was first installed in 1971 in a 230 feet (70m) length of 3.85 feet × 2 feet (1,175 mm × 610 mm) brick sewer in Hackney, East London. It is estimated that about 40,000 miles (64,360 km) of CIPP liners have been installed worldwide. It is by far the leading method for rehabilitating gravity sewers. After the original CIPP patent expired, new variants were introduced. Figure 4-7 highlights the main differences in CIPP technologies based on tube construction, method of installation, curing method, and type of resin. The original CIPP product was a needled felt tube impregnated with polyester resin that was inverted into a sewer through a manhole and cured using hot water. This product is still used for gravity sewers.

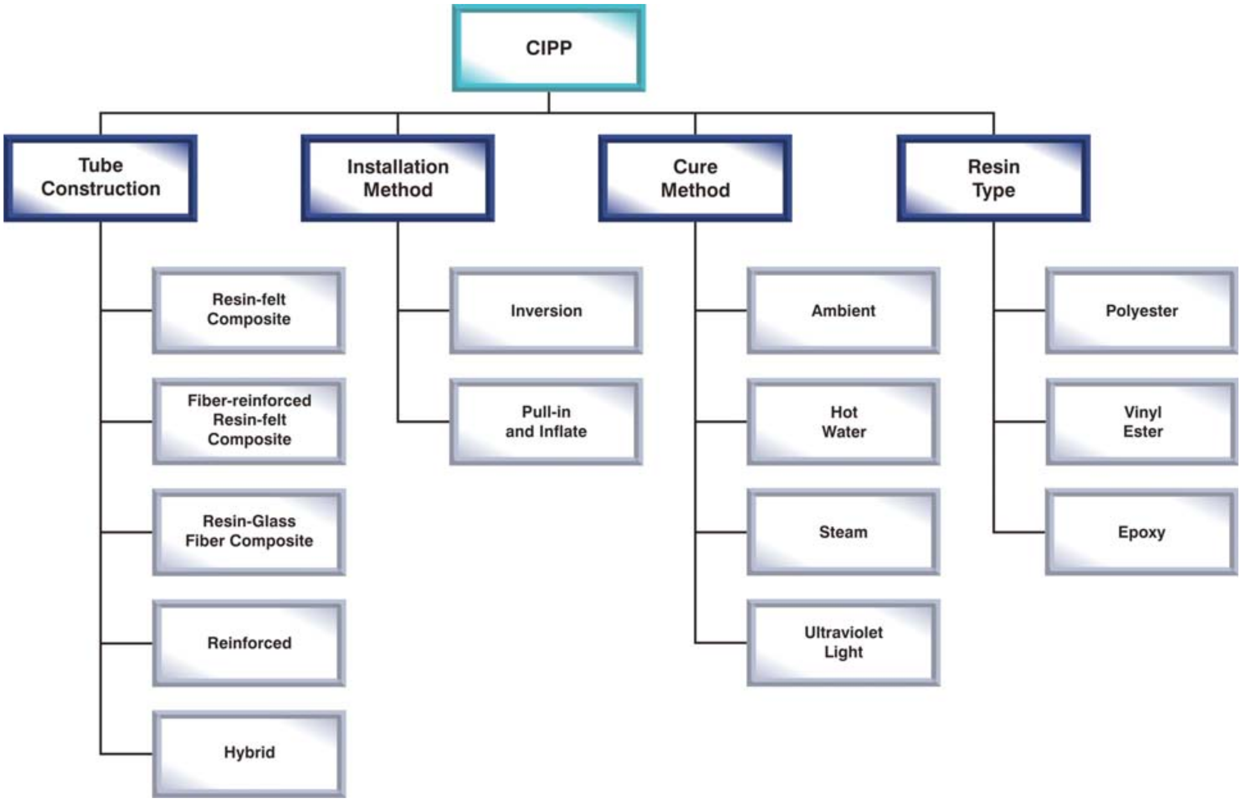

Figure 4-7. Summary of CIPP Technologies

The following sections describe the major generic technology variants for CIPP rehabilitation in terms of the tube construction, installation method, cure method, and resins used. Appendix A provides datasheets provided by some of the most established vendors for specific products representing these variants. Due to the wide range of manufacturers and contractors offering CIPP rehabilitation, it is not possible to represent all products with individual datasheets.

4.3.4.1 Hot Water/Steam Cured Liners. In 1976, the first Insituform® liner was installed in the U.S. in a 12-inch (300-mm) diameter line in Fresno, California. Since then, approximately 17,000 miles (27,353 km) of CIPP liner have been installed by U.S.-based Insituform contractors (Lucas, 2009). The original installations involved an inverted resin-felt composite liner impregnated with polyester resin and cured with hot water. Other companies also started installing CIPP liners in the U.S. through the 1980s and 1990s. These include the Inliner® system (first introduced in 1986); over 9 million feet have been installed since then. Other long standing liner suppliers include National Liner® and Masterliner®.

CIPP is generally available in diameters of 4 to 120 inches (100 to 3,048 mm), depending (especially in the larger diameters) on the supplier’s and contractor’s capabilities and experience. Liner thicknesses may vary from around 0.12 inch (3 mm) in small-diameter shallow pipes to over 2 inches (50 mm) in large-diameter deep pipes. Smaller mainline CIPP liners are typically prepared to the appropriate diameters and impregnated (“wet out”) with resin in the factory. They are then shipped in a refrigerated truck to the job site for insertion and curing. Lateral liners (3 to 4 inches [75 to 100 mm] diameter) are frequently impregnated by hand onsite. Large-diameter liners are also wet out onsite; special wetout facilities are used due to the high weight of the impregnated liner for transportation. The most commonly used resin is polyester, which provides good economy for most normal applications and good corrosion resistance to normal sewage conditions. Resin modifications include using “filled” resins, which incorporate inert fillers to increase the stiffness of the cured resin, but may sacrifice some strength and chemical resistance. Vinyl ester resins and epoxy resins provide greater chemical resistance, when needed, but increase cost. The felt tube is most commonly made of a non-woven needled felt fabricated with polyester fibers. The non-woven felt has little reinforcing capability, so the strength of a CIPP liner can be increased by using fiber-reinforced liners and woven liners.

One installation method uses liner inversion (see Figure 4-8), in which the impregnated, but uncured liner is forced by water or air pressure to turn itself inside out along the host pipe section to be lined. The advantage is that this liner can be impregnated with a handling/sealing layer outside the felt tube. When the liner is inverted, this layer becomes the inner surface of the CIPP liner. The uncured resin can then flow into cracks and openings in the host pipe to lock the liner in place. For structural purposes, a small amount of excess resin ensures that sufficient resin is available to give the required liner thickness. However, too much resin may cause problems such as blocking sewer laterals. A second advantage of the inversion approach is that the liner is not dragged, relative to the host pipe, as it is installed; rather, the liner unfurls itself along the pipe, reducing the potential for damage.

The other principal installation method is to pull the uncured liner into position without inversion. In this case, an outer layer confines the resin during impregnation and pull-in. This layer remains between the CIPP liner and the host pipe, which reduces the amount of interlock, but has the advantage of confining the resin, thus avoiding the potential for blocked laterals and washout of the resin by high groundwater inflows. Typically, an internal hose (called a calibration hose) inflates the liner within the host pipe and holds it under pressure until the liner is cured.

Variations of each method are used, depending on the circumstances. For example, a polyethylene (PE) tube may first be inverted into the host pipe and the liner then inverted inside the first tube. This will eliminate concern about resin washout if high groundwater inflows are present.

Figure 4-8. CIPP Installation Options: Liner Inversion (left) and Liner Pull-in (right) (Courtesy Insituform Technologies, Inc.)

Selection of the liner's curing process depends on job circumstances. This section discusses thermal curing of CIPP liners. Ambient curing of a liner is possible, but is seldom used for sewer mainlines because the liner takes longer time to cure; this reduces productivity and increases the sewer's out-of-service time. Hot-water curing was the original curing method and is still the most widely used. Steam curing offers a faster cure, but also has some operational and safety drawbacks. In both cases, temperature measurements are taken as the liner cures to track the exothermic reaction and to ensure complete cure of the resin. The same basic technology is used for whichever thermal curing option is chosen, but the installation procedures and QA/QC requirements will change according to the curing method chosen. The ultraviolet cure process (described below) uses specially formulated resins to respond to ultraviolet (UV) light to initiate the cure; this method has somewhat different installation processes.

4.3.4.2 Ultraviolet Light Cured Liners. A German company, Brandenburger GmbH, was an early developer of resin pre-impregnated, UV-light-cured laminates for sewers. In 1997, Brandenberger began promoting their technology outside Germany and now has over 10 million ft installed in 25 countries. The U.S. licensee, Reline America, Inc., was established in 2007 to distribute the Blue-Tek CIPP liner to licensed contractors. Blue-Tek™ is a UV-cured, glass-reinforced CIPP liner. A seamless, spirally wound, glass-fiber tube is impregnated with polyester (ortho) or vinylester resins. The seamless liner has both an inner and outer film; the outer film blocks UV light. The inner film is removed after curing. The shelf life of the impregnated liner is approximately 6 months. Blue-Tek is available in diameters from 6 inches (150 mm) to 48 inches (1,219 mm) and can be used in circular, oval, and egg-shaped pipes. Reline America reports that up to 60 inches (1,524 mm) liners will be available in the near future. Application of Blue-Tek can achieve rehabilitation of up to 1,000 feet (305 meter).

Blue-Tek is winched into the existing pipe and inflated with air pressure (6 to 8 pounds per square inch [psi]) and then cured using a UV light train (see Figure 4-9). For QA/QC purposes, in addition to CCTV inspection of the line before and after curing, a record of the liner's

Figure 4-9. UV Light Train for Curing CIPP Liner (Courtesy Reline America, Inc.)

inner air pressure during curing, the curing speed (ft/min), and resin reaction temperatures (infrared sensors) are all monitored. In the U.S., International Pipeliner Technologies (IPL) also offers a fiberglass-reinforced UV cure liner.

4.3.4.3 Emerging and Novel CIPP Technologies. One of the latest glass-reinforced CIPP liners to enter the U.S. market is Berolina Liner® from BKP Berolina Polyester GmbH in Germany. CIPP Corporation is the U.S. licensee. The liner was first used in Europe in 1997 and outside Europe beginning in 2001. At the time of this report, there have not been any U.S. installations, but the liner has been used in Canada (Hamilton, Ontario). The liner is composed of glass fiber and/or polyester webs impregnated with polyester or vinylester resin. Uniquely, the layers are overlapped and staggered giving the tube variable stretching capability. After placement of a protective film sleeve covering the lower half of the host pipe, the liner is installed by pulling it in place, which can be accommodated by the axial strength of the glass fiber. The tube, which is expanded by inflating it with compressed air, can be inspected with a closed-circuit television (CCTV) camera before polymerization. Once it is confirmed that the liner is correctly placed, it is then UV-cured. The liner has a protective inner film and a UV-resistant outer film. The inner film is removed after installation. The outer film prevents resin from migrating into laterals, as well as from entering cracks in the host pipe. The outer film also prevents significant styrene emissions. A rehabilitated length of up to 1,200 feet (366 meter) is reportedly possible. The Berolina Liner is available in diameters of 6 to 40 inches (150 to 1,000 mm), with thicknesses ranging from 0.08 to 0.47 inch (2 to 12 mm).

The **Aqualiner®** technology is undergoing development trials in Europe and has not yet been commercially released. It has been developed for the water rehabilitation market, but could also have application to the sewer market. Since it is not yet applied to the sewer market, no datasheet has been included in Appendix A. The developer, Aqualiner, is a consortium of three United Kingdom water companies, a Danish contractor, and a plastics consultant. All field trials have been with Wessex Water in the United Kingdom. Aqualiner involves winching a glass-fiber-reinforced polypropylene sock into a deteriorated pipe; once the sock is in place, a heated pig with a silicone rubber inflation tube is pushed through the thermoplastic sock to melt it against the pipe wall. The inversion bag presses the molten thermoplastic composite sock against the pipe wall, where it cools to form a solid, glass-reinforced thermoplastic liner. Pressure in the inflation bag is kept at 45 psi (3 bar) until the liner cools; the bag is then deflated and removed. There is no mixing of chemicals and no environmental releases. Aqualiner will be available in diameters 6 to 12 inches (150 to 300 mm) (eventually 18 inches [450 mm]) and will have a 150 psi (10 bar) pressure rating. A rehabilitated length of up to 500 feet (152 meter) for a 12-inch (300-mm) pipe is expected. An advantage of this technology is that no liquid resin is used.

Insituform I-Composite™ is a thermal curing liner developed to reduce the need for high liner thicknesses in large-diameter pipes and/or with high external groundwater pressures. The liner cross section includes fiber-reinforcing layers at the liner's top and bottom surfaces. These give the liner a very high strength and stiffness, allowing the liner's overall thickness to be reduced.

4.3.5 Close-Fit Lining Systems. The use of close-fit liners is often called modified sliplining. It involves the use of a PVC or PE liner whose outside diameter is similar to the host pipe's inside diameter. The key to installing the liner is to temporarily reduce the liner diameter to facilitate its insertion into the host pipe. Once the liner is in place, it is reverted to its original outside diameter, forming a close fit to the host pipe. As shown in Figure 4-10, close-fit liners can be classified into three broad categories, including those that achieve temporary diameter reduction through (1) a symmetrical reduction process, (2) a fold-and-form process, and (3) symmetrical expansion. In the case of the symmetrical-diameter reduction process, the liners can rely on either axial tension or radial compression to reduce the diameter. Fold-and-form liners, depending on their diameter, can be pre-folded and coiled into spools at the factory or can be deformed onsite.

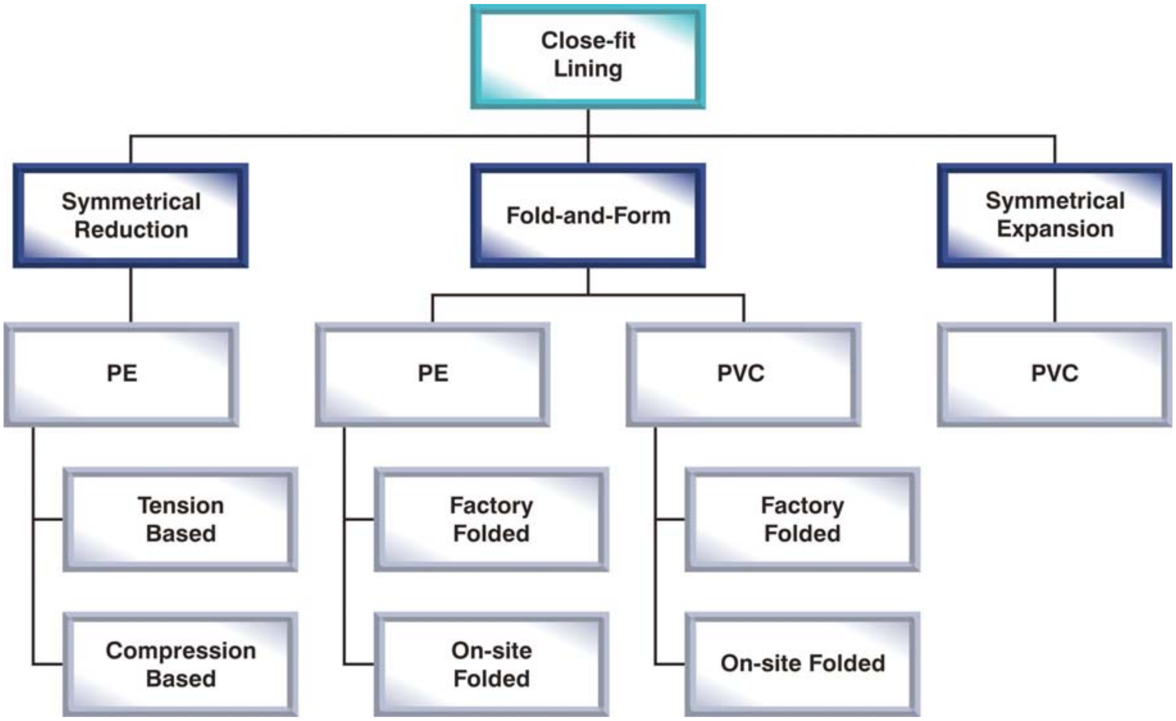

Figure 4-10. Summary of Close-Fit Lining Technologies

Symmetrical expansion essentially stretches the wall of the inserted pipe until it achieves a tight fit against the inside of the host pipe.

The installation of a close-fit liner is similar to sliplining (discussed in Section 4.4.1.1), except that additional stages are needed for diameter reduction prior to insertion and/or for reversion or expansion after insertion. Also, the host pipe must be cleaned more extensively than for ordinary sliplining, given the close fit of the liner. Some additional potential issues can occur during installation of these liners:

- Accuracy in pipe alignment for butt fusion welding is more critical.
- Tensile forces during pull-in of the liner must be monitored and controlled.

Although all of the approaches illustrated in Figure 4-10 have potential application to gravity sewer lines, only fold-and-form and symmetrical expansion are actively being marketed for this application in the U.S. Most applications for the symmetrical reduction approach are for relatively thin liners designed for sealing pressure pipes. For this reason, Appendix A does not include datasheets for symmetrical reduction liner technologies.

4.3.5.1 Fold-and-Form Close-Fit Lining – PVC (Alloy). Ultraliner PVC Alloy Pipeliner™ was first introduced in 1994 by Ultraliner; since then, the company has installed over 4.5 million feet (1.4 million meter) of liner. The use of Ultraliner appears to be equally dispersed across its diameter range of 4 to 30 inches (100 to 750 mm). PVC Alloy Pipeliner™ has been used in 36 states and is approved by 30 state Departments of Transportation (DOTs) – one of Ultraliner's largest markets – for use on drainage culverts. Ultraliner PVC Alloy Pipeliner is a solid-wall PVC pipe manufactured from virgin PVC homopolymer resin with no fillers; it is modified with special additives to improve ductility and toughness. The Pipeliner™ is collapsed flat (12 inches [300 mm] and less) and coiled on a reel in continuous, jointless lengths. Larger diameters (15+ inches [375+ mm]) are deflected to a smaller profile (approximately 50%) at the manufacturing plant. Figure 4-11 shows the folded and final installed shapes, plus the field insertion process. When properly installed, the PVC Alloy Pipeliner™ does not shrink longitudinally or radially after installation (memory is reset by heat and by stretching to new dimensions), achieving a tight fit. The material has very high abrasion resistance and ductility.

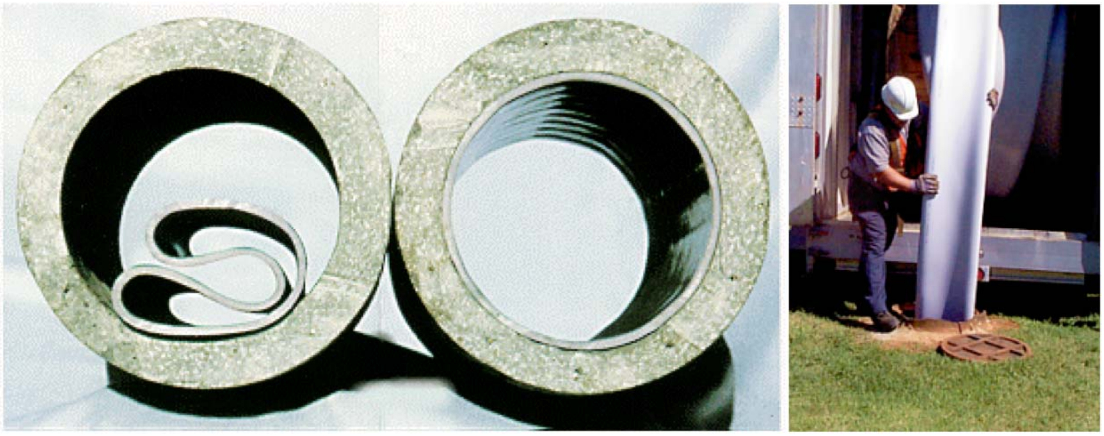

Figure 4-11. Fold and Form Process: (a) Folded and Final Close-Fit Shapes (b) Insertion of Folded Liner (Courtesy Ultraliner)

For gravity applications, the PVC Alloy Pipeliner™ can be considered a fully structural, independent liner with flexural modulus ranging from 145,000 psi (1,000 bar) (F1871) to 280,000 psi (19,310 bar) (F1504). Like most PVC products, the modulus and long-term properties must be rerated downward at temperatures above 80°F. The design of the liner is based on Appendix X1 in ASTM F1216.

For installation, access is required at both ends. The host pipe is cleaned and the Pipeliner™ is pulled into the existing pipe. Once in place, both ends are plugged, and the Pipeliner™ is expanded with steam and air pressure to reset the PVC alloy's memory. Installation and processing of the liner takes 4 to 5 hours, excluding any time needed to reinstate connections and for demobilization.

PVC Alloy Pipeliner™ tends to be more competitive on small-scale projects (short lengths, small diameter) because of its low mobilization and set-up costs, as compared to other trenchless rehabilitation methodologies (e.g., CIPP).

Miller Pipeline offers a fold-and-form PVC pipe called EX Pipe™. EX Pipe is a high-strength, unplasticized PVC (uPVC) manufactured to meet ASTM F1504. EX Pipe is only installed by Miller Pipeline crews. The EX Pipe is softened with heat in a pipe-warmer trailer and then continuously inserted into the host pipe via manholes or other access points using a winch. After insertion, the pipe is expanded approximately 10%, using steam and air pressure, to fit tightly within the existing pipe. Pressure is maintained until the liner cools to 100°F. The liner can be installed through 90° bends and small diameter changes. The pipe has a flexural modulus of 340,000 psi (23,450 bar) and a tensile strength of 6,000 psi (414 bar), which is only 25% below that of standard PVC pressure pipe.

Produced by American Pipe & Plastic, AM-Liner II® has been installed in over 100 miles (161 km) of gravity sewers. AM-Liner II is available in diameters from 6 to 12 inches and SDRs from 26 to 32.5. It conforms to ASTM F1871 (Type A Folded/Formed PVC Liner).

4.3.5.2 Fold-and-Form Close-Fit Lining – PE.

Another method of achieving a close-fit PE liner is to fold the PE pipe into a “C” or heart shape to facilitate the liner’s insertion into the host pipe, and then revert the liner to its original round shape by heat and/or pressure to form a close fit. When the liner is folded after extrusion as a round pipe, the process also can be referred to as “deform-reform.” The folding process can be carried out in the factory or onsite, depending on the PE liner’s diameter. Whether the reversion uses heat to help re-round the PE pipe is another distinction that can be made for factory-folded liners.

Most PE fold-and-form technologies are aimed at pressure pipe rehabilitation. The “U-liner” process was previously active in the sewer market in the U.S., but is not currently available in this market. The process is used internationally (see datasheet in Appendix A) for this approach, but it is principally marketed today for pressure pipe applications.

4.3.5.3 Symmetrical-Expansion PVC Close-Fit Lining.

The only current product in this category is a patented, standalone structural liner manufactured by Underground Solutions and sold under the name Duraliner™. This product is made of PVC and is available in diameters of 6 (150 mm) to 30 inches (760 mm). The outside diameter of the starting PVC pipe stock is sized smaller than the inside diameter of the host pipe. Sections of the Duraliner pipe are then butt-fused to form a continuous pipe. The pipe is then inserted into the cleaned and previously inspected host pipe. Special end caps and temperature sensors are fitted to the ends of the pipe. The PVC pipe is heated with steam, and pressure is applied to expand the material tightly against the walls of the host pipe. It takes approximately 90 minutes to fully expand the stock pipe. After cooling, the end fittings are removed, and the expanded new pipe is cut to length. Insertion lengths ranging from 700 to 1,500 feet (213 to 457 meter) are possible. The expansion of the PVC reorients the molecular chain in the circumferential direction, thereby increasing the tensile strength. Molecularly-oriented polyvinyl chloride (PVCO) pipe has been used in Europe for over 20 years.

4.3.6 Grout-in-Place Linings.

Grout-in-place linings are installed, with installation complete when the annular space is grouted. Once grouted, the liner functions as a composite liner, with each element providing its own contribution to the overall performance. Following installation, the interior liner element typically becomes anchored into the grout once the grout has cured. This anchoring prevents the internal lining from being separated from the grout by external water pressure. The structural capacity of the whole liner system may be based on the structural ring formed by the grout or on a composite action between the internal liner and the grout. Since cementitious grouts are typically used, it is important that the internal liner provide a full seal to separate the grout from corrosive conditions within the sewer.

The form of the linings may depend on the internal shape of the sewer (e.g., circular vs. oval); the diameter of the sewer (e.g., person-entry vs. non-person-entry); the distance between access points; and the ability to carry out lining work during live flows. Types of internal liners include:

- Liner panels placed by hand (e.g., Danby, Hobas)
- Pre-manufactured liner segments jacked into place and grouted (similar to sliplining, e.g., Angerlehner)
- Spiral-wound PVC liners (e.g., Danby and Sekisui [see Figure 4-12])
- Pull-in high density polyethylene (HDPE) studded liners inflated against the host pipe (e.g., Trolining) (can be carried out in non-person entry sized pipes)

In most cases (excluding Trolining), structural bracing is required to hold the internal liner in position during the grouting process. Because of the placement considerations and/or the thickness of the grout that needs to be installed, loss of pipe diameter can be significant. One system used in Europe, but not yet applied in the U.S., (Angerlehner) uses a “road header” - type excavating machine to remove a predetermined thickness of the existing host pipe before sliding into place the preformed segments, which are then grouted. Thus, the final dimensions of the lined pipe can be similar to the pipe’s original dimensions. In the Sekisui system, the winding is carried out around a specially configured frame, and the steel strips are used to hold the liner in a non-circular shape prior to grouting. The liner can also be installed under low-flow conditions within the sewer.

Figure 4-12. Grout-in-Place Spiral-Wound Liner in a Rectangular Cross Section (Courtesy Sekisui SPR Americas, LLC)

4.3.7 Spiral-Wound Linings. Spiral-wound linings may be used as grout-in-place linings (see Section 4.3.6). However, they can also be used as stand-alone liners that support the host pipe and help seal against infiltration into the sewer mainline. In the simplest version, a spiral winding machine is set up opposite the end of a sewer segment. Narrow PVC strips are fed into the machine and press-sealed together to form a continuous spiral-wound pipe whose diameter is significantly smaller than that of the host pipe. As the spiral pipe is produced, it extends along the pipe to be lined. Once it reaches the end of the segment, the far end of the pipe is gripped; the machine rotation is reversed, causing the spiral winding to expand. When the liner contacts the internal surface of the host pipe, the expansion is stopped and a continuous liner is now inside the existing pipe. Openings for laterals are not marked by dimples as in most CIPP installations, so they must be cut based on recorded position or some other form of marking. The ribbed profile of the lining provides a continuous annular groove following the spirals of the liner, but the flow path is small and very long when the liner makes continuous contact with the host pipe. A complete seal can be provided by grouting/packing at lateral connections and at the liner’s manhole terminations. Variations on the basic procedure include using a mobile winding machine that travels along the host pipe as the liner is wound. This allows the liner to be directly wound to contact the host pipe. It also allows changes in the liner dimension along the host pipe segment to accommodate changes in the host pipe’s diameter. In larger-diameter pipe where additional liner stiffness is required, steel inserts can be used in the PVC liner strips.

4.3.8 Panel Linings. Panel linings have many similarities to the grout-in-place liners, but rather than being anchored by the annular grouting process, the panels are chemically-bonded to the wall of the host pipe to form a composite structure. The panels must have an interlocking and/or sealing capability between the panel edges to ensure complete corrosion protection. Reliance on the panel’s adhesion for at least part of their performance also means that surface preparation is critical. Panel linings are only practical in person-entry diameters. Figure 4-13 shows a field installation in process. In some large-diameter sewers where the principal corrosion is in the upper portion of the cross section (above the flow surface) and when bypassing the sewage flow would be extremely costly, panel liners are used to reinforce and protect only the upper

Figure 4-13. Linabond Panel Lining Installation (Courtesy Linabond)

portion of the cross section. In this case, work is typically done during low-flow periods at night, working from temporary platforms. A special termination detail is used to protect the lower edge of the liner (e.g., Linabond).

4.3.9 Spray-On/Spin-Cast Linings. Spray-on linings available for sewer rehabilitation are either cementitious or polymer-based. Figure 4-14 shows the basic divisions of spray-on/spin-cast lining technologies for pipe systems. As discussed in the sections below, not all of these divisions have significant application to sewer main conditions.

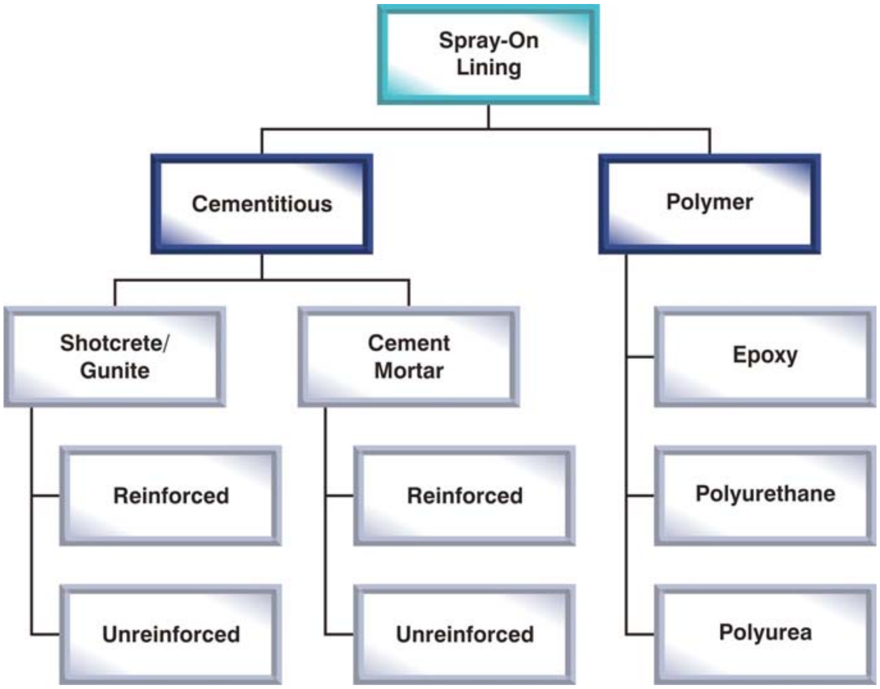

Figure 4-14. Summary of Spray-On Lining Technologies

4.3.9.1 Cementitious Linings. Cement mortar linings are very common in water main rehabilitation in the U.S. to control metal corrosion and taste problems. Cementitious linings also can be applied to gravity sewers; however, the corrosive environment in a sewer makes the application of ordinary cement or concrete materials prone to deterioration. Shotcrete or gunite applications are useful under a variety of conditions. The term “gunite” typically refers to a spray-applied dry cement mortar mix with the water added at the nozzle. The term “shotcrete” refers to any spray-applied concrete mix and is the term more often used in current practice. Shotcrete can be applied over a reinforcing mesh or can include reinforcing fibers. Such linings are usually applied by hand in a person-entry-sized space or pipe; however, robotic spray or spincast equipment is available for smaller-diameter pipes (e.g., Shotcrete Technologies). Unless special cementitious materials are used, the application of sprayed cementitious materials is likely to be restricted to areas of sewer systems that have low corrosion potential. They provide a rigid, low-cost lining material that can be applied in large thicknesses (shotcrete linings in tunnels can exceed 1 foot thick). They can also be used as filler material or as a base structural layer that is covered by a corrosion-resistant lining material. Application of sprayed cementitious linings is more common in drainage pipes, stormwater pipes, and culverts.

***4.3.9.2	Epoxy Spray-On Linings.*** Epoxy spray-on linings are widely used for water main rehabilitation, manhole rehabilitation and person-entry tunnels (see Figure 4-15). They are also used in small-diameter gravity sewer main applications, but special provisions for adequately preparing the surface in a non-person-entry sewer environment must be made to obtain a dependable bond. The relevant epoxy materials are two-component materials containing 100% solids by volume and are capable of adhering to dry and moist surfaces. Often, epoxy linings alone are not applied in a thick enough layer to function as a structural ring, and, in this case, they must properly adhere to the host pipe to function adequately. Thicker (high build) layers can be applied with proper formulations and expertise, but these applications currently are more limited because of cost and curing time considerations.

Figure 4-15. Spray-Applied Epoxy Lining in a Brick Sewer Tunnel (Courtesy Warren Environmental)

***4.3.9.3	Polyurethane Spray-On Linings.*** In the United Kingdom's water sector, use of polyurethanes (PUs), which are two-part poly-isocyanate formulations, has virtually replaced the use of epoxy liners. The majority of water main applications are for corrosion protection and taste improvement, and only a thin coating is applied (approximately 0.04 inch [1 mm]). The main advantage of PU over epoxy is the fast (30-minute) cure time. The equipment and application are essentially the same. For gravity sewer main applications, the same issues apply as for epoxy coatings. Sewer pipes typically have more degraded interior surfaces than water pipes, so it is difficult to clean and prepare surfaces adequately; the coatings cannot resist external water pressures without an adequate bond.

To overcome the inadequacies of thin polymer lining applications, high-build PU applications have been developed to function as a structural liner that is less dependent on the quality of bond to the host pipe and that can bridge over holes in an internally pressurized host pipe. The first commercial product was introduced by E. Wood in the United Kingdom for the water market. This product was called Copon Hycote 169HB. This emerging material has potential for use in a gravity sewer, if the inner surface of the sewer can be sufficiently cleaned to allow proper adhesion for application.

***4.3.9.4	Polyurea Spray-On Linings.*** A new family of polymer spray-on linings, based on the use of polyurea, is finding acceptance for lining manholes, wetwells, and other structures exposed to corrosive environments. One of the principal benefits of using polyurea is a very fast cure, with gel times in 5 to 40 seconds and 80% cure in just 5 minutes. Structures can be returned to service 30 minutes after applying the polyurea. Full cure is achieved in 24 hours. The other primary benefit is the ability to spray-apply a thickness from 0.25 inch (6 mm) to 2 inches (50 mm). A California-based company, Innovative Painting and Waterproofing, has developed a robotic delivery system that allows polyurea to be sprayed on pipes as small as 8 inches (200 mm) in diameter. They have recently completed several projects, including applying 60 mils (1.5 mm) to nearly 2,420 feet (732 meter) of 96 and 72 inches (2,400 and 1,800 mm) steel pipe using a robotic unit. Hunting Specialized Products produces three lines of polyurea spray-on linings, which range from flexible to stiff, based on the flexural modulus of elasticity.

**4.3.10	Chemical Grouting.** Chemical grouting of sewer mainlines in non-person-entry diameters is typically performed as a test-and-seal procedure using inflatable packers (Figure 4-16). The packers isolate one short section of pipe at a time for the test-and-seal procedure. The procedure is to move the packer section to the desired location along the mainline, inflate the packers to

4-16. Mainline Grouting Packer (Courtesy Logiball)

seal that section of mainline pipe, test the section under low pressure for leakage, and, if leakage is present, pump grout into the section. The grout exits through joints and cracks into the soil surrounding the pipe and forms a gel-type seal around the pipe. Either resistance to further flow of grout or a repeated pressure test can indicate that the seal has been completed before the packer moves to the next location. Specific locations where leakage or damage has been identified can be treated individually, or an entire segment can be tested and sealed in sections. Grout packers for mainline use can be designed as "flow-through" packer systems that permit continued sewer flow during grouting operations. The most common grouting materials are acrylamide, acrylic, and acrylate gels.

Pipe robots can be used to drill holes and inject grout in leaking pipe sections or at lateral connections. The pipe drilling and sealing activities can be viewed by cameras from within the pipe, but data on the grouting packet's pressure test ability are not available. Large voids or interconnected networks of voids within the ground may be uneconomical to seal with either method.

Because grouting is used to eliminate infiltration, but does not provide structural repair, it is only suitable for structurally sound pipes. The longevity of repair has been reported to be quite short in some ground conditions (less than 5 years); however, case studies have been identified where the grout was in good condition after much longer periods of time (for example, 20 years in the City of North Vancouver, Canada [Thompson, 2008] and 10 years in the Village of Genoa, WI). One factor often identified as impacting a grout's sealing longevity is the fluctuation of moisture conditions in the ground. The gel-type grouts typically used in sewer applications perform better when they do not dry out under service conditions. A paper by Romans (2001) discusses grout longevity.

Since grouting is relatively inexpensive and its design and preparation requirements are low, it can be a very useful component of a sewer rehabilitation program. It can reduce I/I and help to prevent structural deterioration due to loss of soil into the sewer system. Pilot studies to determine the performance of grouting systems in local conditions can provide indications about sealing characteristics. Contractor experience and quality control are also important to a grouting program's success (Lee, 2008). Grouting can be used as a short-term measure to meet I/I reduction goals while a longer-term pipe-lining program is carried out.

4.3.10.1 Flood Grouting. Sanipor® offers flood grouting in the U.S. In this approach, one segment of a sewer system, including at least one manhole, is isolated (using mainline packers and lateral packers near building exit points). Figure 6-2 illustrates the process. A sodium silicate-based solution serves as grouting and is introduced as two separate components. First, the sewer segment is flooded with Solution A through the manhole, and the solution permeates through defects in the pipes and manhole into the surrounding ground. This solution is then quickly pumped out of the pipes, and Solution B is used to re-fill the system. As Solution B comes into contact with Solution A in the ground outside the pipes, it forms a hard sodium silicate seal around the pipe network in areas where it had defects. The principal advantage is the ability to seal laterals, mainline, and manholes in a single setup. As indicated above, large voids or interconnected networks of voids within the ground may be uneconomical to seal by grouting. An exfiltration test is typically conducted in new or questionable areas before starting the flood grouting process.

4.3.11 Summary of Rehabilitation Options. Table 4-2 summarizes the rehabilitation technologies for mainline sewers, along with their main advantages, limitations, and most suitable application conditions.

Table 4-2. Characteristics of Rehabilitation Technologies for Mainline Sewers

Advantages	Limitations	Most Suitable Conditions for Application
CIPP Thermal Cure		
• No excavation required • Long history of application	• Field quality control important	• Applicable to a wide range of conditions
CIPP UV Cure		
• No excavation required • Rapid cure • Long shelf life for impregnated liner	• Limited thickness of liner that can be cured using UV • Limited diameter range	• Applicable to a wide range of conditions • Small- to medium-diameter pipes
Close-Fit Fold and Form PVC Liners		
• No excavation required • Factory-prepared liner pipe • Folding allows easy insertion	• Limited diameter range	• Applicable to a wide range of conditions • Small- to medium-diameter pipes
Close-Fit Symmetrical Reduction PE Liners		
• Factory-prepared liner pipe	• Not applicable to sewers with significant geometric imperfections • Liner can become stuck if tension lost during installation • Insertion pits required	• Not currently used for gravity sewers in the U.S.
Close-Fit Symmetrical Compression PE Liners		
• Factory-prepared liner pipe • Liner stays in reduced diameter until reverted	• Not applicable to sewers with significant geometric imperfections • Insertion pits required	• Not currently used for gravity sewers in the U.S.
Close-Fit Fold-and-Form PE Liners		
• Factory-prepared liner pipe • Folding allows easy insertion	• No diameter adjustment during installation to fit host pipe • Insertion pits required in larger diameters	• Not currently used for gravity sewers in the U.S.
Symmetrical Expansion PVC Liners		
• Factory-prepared liner pipe • Thinner wall installations than PE	• Insertion pits required in larger diameters	• Pipes with smooth interiors • Small- to medium-diameter pipes
Cast-in-Place Lining		
• Factory-prepared inner lining • Adaptable to a wide range of conditions • Rigid grout provides long-term performance	• Greater loss of diameter than most close-fit lining methods • Access pits required, depending on method • Lengthy site operations	• Person-entry sewers for most systems • Small- to medium-diameter for PE liner system

Table 4-2. Characteristics of Rehabilitation Technologies for Mainline Sewers (Continued)

Advantages	Limitations	Most Suitable Conditions for Application
Spiral-Wound Lining		
• Factory-prepared lining material • Low mobilization for small-diameter circular pipes	• Remaining annular gap if not grouted	• Wide range of applicability across systems • Large, non-circular sewers
Panel Lining		
• Factory-prepared lining material • Partial circumference installation possible to avoid bypassing	• Need to ensure adequate bond to host pipe • Access for panels required	• Person-entry sewers
Sprayed Lining (Cementitious)		
• Inexpensive liner material • Reinforcement can be incorporated	• Not as corrosion-resistant as polymer material alternatives	• Person-entry sewers for hand application • Rebuilding highly damaged areas • Low-corrosion potential sewers
Sprayed Lining (Polymer)		
• High-build polymers available for sewer rehabilitation • Bond not as critical for high-build applications	• Difficult to clean and prepare surfaces in non-person-entry diameters • Cost of liner materials can be high	• Thin corrosion protection layers not as applicable in sewer mains • High-build applications have potential for use in a wide range of conditions
Chemical Grouting (Test and Seal)		
• No excavation required • Repairs only where needed • Inexpensive	• No structural repair • Sometimes can't be completed • Longevity of grouting performance may vary	• Many leaking defects in structurally sound pipes • When inexpensive and quick repair is desired
Flood Grouting		
• No excavation (lateral cleanouts required) • Repairs mainlines, laterals, and manholes	• No structural repair • Access to private property required	• Many leaking defects in structurally sound pipes • Deep pipes, complex layouts • Cleanouts already exist

4.4 Replacement

Replacement technologies essentially change out the existing pipe with a brand new pipe. The new pipe provides a new conduit that does not depend on the existing host pipe for its structural performance. In this report, if the existing pipe is replaced in the same location (i.e., on the same line and grade), the replacement is then referred to as an "on-line" replacement. If the replacement is made on a new alignment, and perhaps with a new grade, the replacement is referred to as an "off-line" replacement. It should be noted that in the literature, "on-line" and "off-line" may also refer to the ability to carry out repairs or rehabilitation without interrupting service.

Figure 4-17 illustrates the major divisions of replacement technologies. The emphasis of this report is on sewer rehabilitation technologies, so the ones described in more detail are the on-line replacement technologies that more directly complement and compete with the rehabilitation technologies. "Off-line" technologies are essentially new construction technologies and a detailed description of each of the potential methods is beyond the scope of this report.

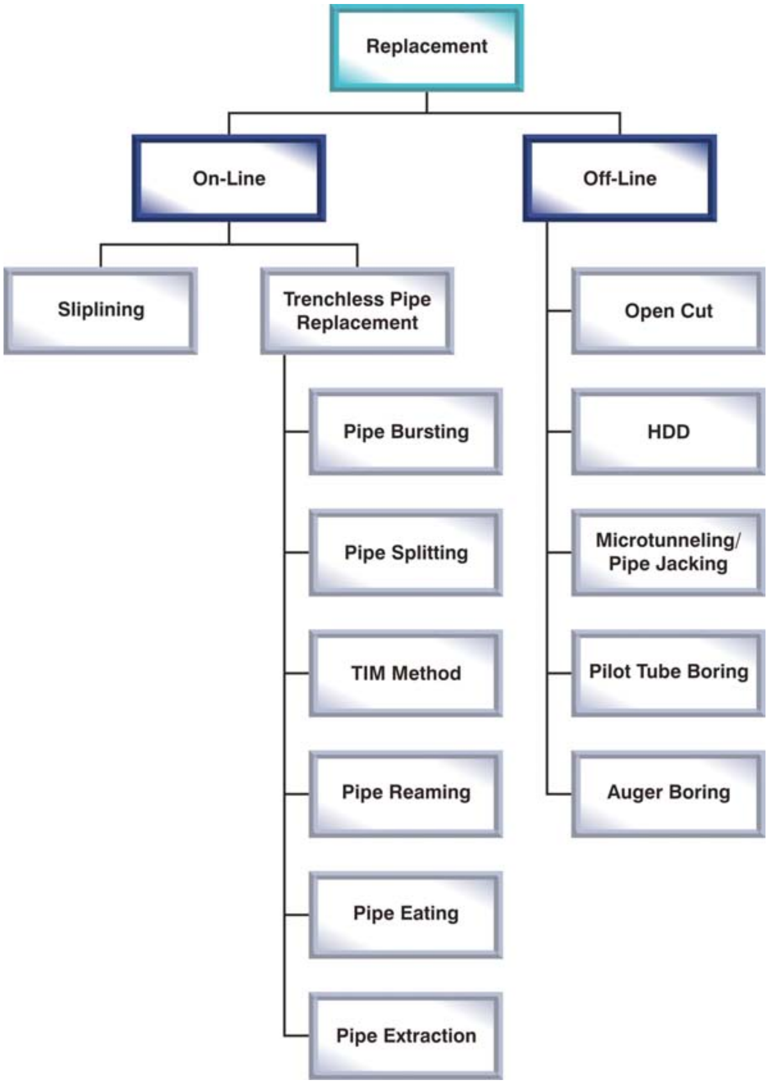

Figure 4-17. Summary of Replacement Technologies for Mainline Sewers

4.4.1 On-Line Replacement. In this context, on-line replacement refers to replacement of a mainline-sewer segment on the same line and grade as the existing pipe. In a dig-up-and-replace scenario, the existing pipe is removed and a new pipe constructed in its place. With on-line replacement, bypass of the existing pipe is needed during the replacement construction. Other techniques provide a new pipe in the same location that can function as a standalone pipe. This approach can also be considered replacement, even if the old pipe is not removed. Such techniques can include sliplining and various forms of trenchless pipe replacement.

The advantages of “on-line” replacement over a parallel or “off-line” replacement are:

- No new right-of-way is required for the replacement, and any additional space required is limited to the amount required for any pipe upsizing.
- Existing lateral connections and connections to other portions of the collection system are only minimally affected.

The advantages of “off-line” replacement are:

- Upsizing of any degree is feasible unless existing neighboring utilities limit the space available.
- Grade or layout problems associated with the existing pipe can be corrected during replacement.
- No bypass of the existing line is needed during the replacement.

4.4.1.1 Sliplining. Sliplining is an important sewer replacement or rehabilitation technique. It is related to the close-fit lining techniques that use a deformed manufactured pipe for insertion into the existing sewer. However, in the case of sliplining, a brand new pipe is inserted in an undeformed condition into the existing pipe. When the sliplining replacement pipe is relatively small in diameter and its material is flexible, the slipline may be installed as a continuous pipe. For larger-diameter sliplining and for sliplining with more rigid materials, discrete pipe lengths are used; the pipe sections are mated in an insertion pit before being pushed or pulled through the host pipe. The pit requirements for sliplining may be significant if long pipe sections or large diameter fused pipe lengths are used. For discrete pipe lengths, the pit length needs to be just longer than the pipe length chosen. For continuous pipe, the pit length depends on the depth of the host pipe and the rigidity of the replacement pipe. Typically, the upper portion of the host pipe’s section is removed to provide access for sliplining.

A key advantage for sliplining applications is the ability to insert the pipe lining under live-flow conditions (see Figure 4-18). This removes the need to bypass flows and the risks associated with storms during bypass operations.

Figure 4-18. Live Insertion Sliplining (Courtesy Hobas Pipe USA)

The host pipe alignment and interior geometrical variation are important in assessing the suitability of sliplining. It is difficult or impossible to push sliplining pipes around sharp changes in direction, so access pits may be needed at significant alignment deviations. It is easier to pull a sliplining pipe around a curve in the host pipe, but this requires use of a flexible pipe with fused or tension-resisting joints. The pipe materials typically used to slipline gravity sewers are HDPE and Fusible™ PVC for use in long, continuous, fused-pipe lengths. Materials used for discrete pipe lengths include PVC and glass-reinforced plastic (GRP). Flush-joint pipes are preferred, because they allow a smaller annular gap and hence less flow reduction; however, pipes with shallow bells can be used if circumstances allow.

PE with butt-welded joints has been used extensively as a sliplining method of replacement. A recent addition to sliplining pipes is fusible PVC pipe. Some pipe materials have joints that can be mechanically locked together. When this feature is available, the pipe string can be advanced by either pulling or pushing, or a combination of the two, thereby increasing the length that can be sliplined from one access pit to the next. One limitation of using discrete pipe lengths is that rubber-ring joints will normally only allow angular rotations ranging from about 0.5 to 3.5 degrees, depending on material and diameter. Therefore, any deviations in the host pipe's joints that exceed these values may require special attention. Also, pipe lengths may have to be non-standard to accommodate short radius curves. Hobas Pipe USA, US Composite Pipe (Flowtite™), Ameron, and Future Pipe manufacture large-diameter, GRP/fiberglass-reinforced plastic (FRP) pipe for sliplining both pressure and non-pressure wastewater lines. Pipe diameters from 12 to 144 inches (300 mm to 3.66 m) are available. In smaller diameters, available restrained-joint PVC pipes available include the Certa-Lok™ joint, which uses a spline locking configuration and the Terrabrute joint that uses a ring and dowel pin system.

Typically, the new pipe's outer diameter (OD) is approximately 5% less than the existing pipe's inner diameter (ID) (with a minimum of 2 inches [50 mm] difference). This can be relaxed for smaller diameters, straight runs, and when there are no offset joints that could interfere with movement of the new pipe. For instance, a 30-inch (750-mm) nominal, 32-inch (800-mm) OD, centrifugally cast, fiber-reinforced polymer mortar (CCFRPM) pipe was installed in a 33-inch (825-mm) clay host pipe in Los Angeles (a 3% reduction in diameter).

The annular gap remaining after sliplining is grouted after insertion of the liner pipe. Grouting locks the slipline in place, with respect to the host pipe, to prevent thermal and flow-related movements. It also allows the slipline to provide structural support to the host pipe. In large-diameter sewers, improved flow characteristics of the sliplined pipe can mean no or minimal loss of flow capacity; however, the flow implications become more important in small-diameter, gravity-flow pipes.

4.4.1.2 Trenchless Pipe Replacement. Trenchless pipe replacement includes a family of methods that break up and/or remove the existing pipe without excavation. A new pipe is pulled or pushed into the void created by this operation. The replacement pipe can be a continuous pipe string using fused joints (HDPE or Fusible PVC™) or using pipes joined with connectors that provide a tensile load capacity (e.g., PVC pipes with Terrabrute™ or Certa-Lok™ joints). Figure 4-19 illustrates the flush or low-profile PVC restrained-joint options for trenchless pipe replacement. It is also possible to use discrete pipe lengths, when tensile capacity joints are not available or when the replacement pipe is jacked into place (see Sections 4.4.1.7 and 4.4.1.8). When pulling a sectional pipe without restrained joints, the pipe string is pulled from the back of the string. This keeps the pipe string in compression, but requires additional steps to disconnect and reconnect the pulling arrangement as new pipe sections are added.

As shown in Figure 4-17, trenchless pipe replacement can be divided into several categories of methods. The most common family of methods is referred to as "pipe bursting," which is used to burst brittle pipes in a wide range of diameters. "Pipe splitting" is a method variant adapted to slice open more ductile pipes that are resistant to bursting. In both pipe bursting and pipe splitting methods, the remnants of the original pipe remain in the ground and are sufficiently displaced to enable the replacement pipe to be pulled or jacked into place. Some methods can also remove material from the existing pipe during the replacement process. "Pipe reaming" uses an HDD-drill-operated reaming head to fragment and remove pipe pieces via drilling mud flow, while concurrently pulling in the new pipe. "Pipe eating" is a microtunneling-based process that excavates the old pipe while the cutting head is being jacked on the front of the replacement pipe string. Pipe extraction pushes the host pipe to a removal pit while the replacement pipe is jacked into place. These methods are described in more detail in Sections 4.4.13 through 4.4.18.

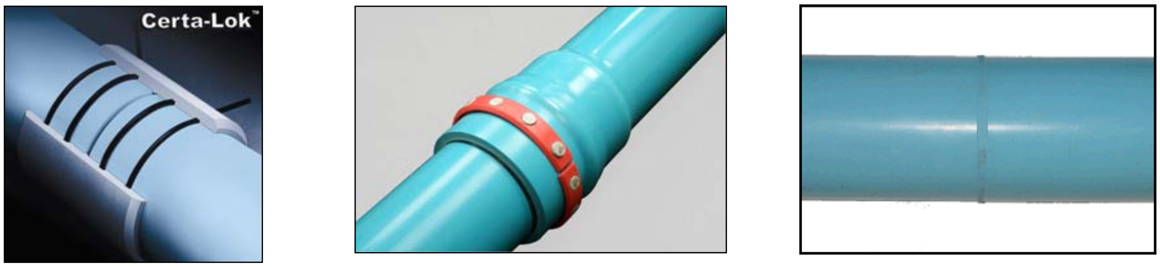

Figure 4-19. Tensile Capacity PVC Joints: (1) Certa-Lok™, (2) Terrabrute™, (3) Fusible PVC™ (Figures are used with permission: Certa-Lok™ is a Trademark of CertainTeed Corporation; Terrabrute™ is a Trademark of IPEX, Inc.; Fusible PVC™ is a Trademark of Underground Solutions, Inc.)

4.4.1.3 Pipe Bursting. British Gas developed pipe bursting in the 1970s for an extensive replacement program of small-diameter gas lines in the United Kingdom. It has since been adapted to a variety of trenchless pipe-replacement scenarios.

Static bursting is the simplest bursting technique. It involves creating large tensile hoop stresses within the existing pipe by means of a cone-shaped bursting head. Figure 4-20 illustrates the process. Fins may be added to the bursting head to promote fracturing. Pipe diameters from 2 to 60 inches (50 mm to 1.5 meter) can be burst using the static method, although most bursting is carried out in diameters of less than 36 inches (914 mm). Unreinforced brittle pipe materials are the easiest to burst, but lightly reinforced concrete or deteriorated reinforced materials may be able to be burst. Lengths up to 400 feet (122 meter) typically can be burst using the static approach, although much longer lengths can be burst under the right combination of ground conditions and bursting equipment. For mainline sewer bursting, the tensile pull generally uses sectional rods that either snap together or are screwed together. TT Technologies' Grundoburst® and Hammerhead Hydroburst® are two examples of equipment designed for static bursting. Some manufacturers combine an on-demand hammering action with a static-based system (e.g., Jabar). In another approach, an HDD rig provides the tensile pull, and a hydraulic hammer (operating from the drilling fluid pressure) fractures the existing pipe (e.g., Impactor).

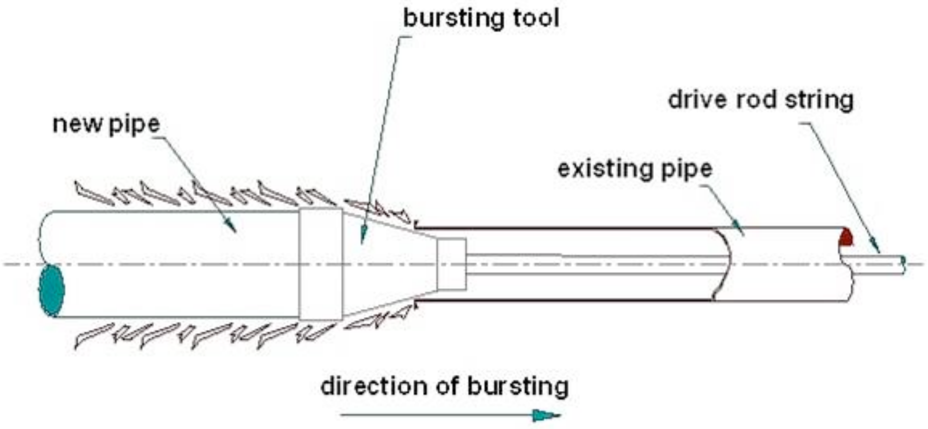

Figure 4-20. Schematic of Static-Bursting Technique

Pneumatic bursting uses an air-operated hammer that shatters the old pipe through the impact of the bursting head being pulled through the line. A tensioned cable advances the bursting head through the existing pipe and keeps the bursting head in contact with the host pipe; however, it does not provide the tensile load necessary to fracture the pipe without the pneumatic impact. Pneumatic bursting works well with the same materials as the static method and is effective in bursting existing PVC pipe. Diameters from 4 inches (100 mm) and lengths up to 500 feet (152 meter) are typically burst with the pneumatic method. The maximum single length of pipe burst recorded is over 2,500 feet (762 meter), but this is not considered a feasible or economical length of burst under most conditions, because bursting progress slows with greater burst lengths. TT Technologies's Grundocrack® is an example of pneumatic pipe bursting equipment.

Pneumatic pipe bursting equipment varies in the geometric configuration of the specific components. One important distinction is the configuration of the bursting/expander head. In a rear expander head, the main expansion and the displacement of the fractured pipe pieces occur at the rear of the bursting head. This provides greater stability and tracking of the bursting head, in order to follow the existing host pipe alignment. An alternate arrangement is the front expander head, where all expansion occurs at the front of the tool. Since only a cable winch is required at the receiving manhole, the front expander can be detached when it arrives and the pneumatic hammer portion of the tool retracted through the replacement pipe to the starting pit. This minimizes the excavation associated with this type of pipe bursting operation.

Hydraulic bursting uses hydraulic pressure to expand mechanical leaves within the bursting head. This expansion breaks the old pipe and pushes the pieces into the surrounding soil. The bursting head is then retracted and slid forward before repeating the process. An expansion cone can also be accommodated for upsizing. The hydraulic method can be used with the same pipe materials as the static method and in diameters from 6 to 20 inches (150 to 500 mm); however, it has been reported to encounter difficulties in sandy soils, which can affect the expansion/retraction movement of the expander components. It is not widely used when compared to static and pneumatic bursting. Xpandit™ is an example of equipment designed for hydraulic pipe bursting.

The **Tenbusch Insertion Method (TIM™)** pipe bursting method is based on thrust from jacking, rather than a tensile pull. The leading element is a heavy steel guide pipe, which maintains alignment within the center of the old pipe. Behind the lead element is the cracker, which fractures the old pipe, followed by a cone expander that radially expands the fractured pipe into the soil. This is followed by the front jack, which is a hydraulic cylinder that serves as an intermittent jacking station to provide the axial thrust to the leading equipment. The front jack bears against the replacement pipe (via an adapter) that is also being jacked into the void. Lubricant is introduced at the adapter to minimize friction. The lead equipment is designed to be disassembled at a 4 feet (1.22 meter) diameter receiving manhole and then removed. With the Tenbusch method, only rigid pipes that can withstand high axial jacking loads are used for the replacement, mainly clay and ductile iron pipe.

Pipe slitting is a variation of the static pipe bursting method for ductile host pipes incorporating scoring/cutting wheels in advance of the bursting head. The existing pipe is progressively scored and then slit by a series of cutting wheels before the tail of the bursting head opens and expands the slit pipe. Pipe slitting has been used on pipes 6 to 24 inches (150 to 610 mm) in diameter.

4.4.1.4 Application Considerations for Pipe Bursting. Pipe bursting can replace the existing pipe size-on-size, or the process can be used to insert a larger-diameter pipe. With the right soil conditions and adjacent structures far enough away to avoid damage, upsizing to 50% can commonly be achieved for diameters of 12 inches (300 mm) and under. For diameters over 12 inches (300 mm), upsizing is more commonly limited to around 25%. Upsizing by over 50% has been done, but needs careful evaluation. It should be noted that even in a size-on-size replacement, the bursting head has a larger diameter than both the existing pipe and the replacement pipe and will cause some soil displacement. This extra diameter provides an annular gap behind the bursting head to lower friction on the replacement pipe and allow injection of a lubrication mud into the annular space, if required.

The bursting method works best on friable pipes, including cast-iron, asbestos-cement, non-reinforced concrete, PVC, and clay pipes. The type of soil affects the bursting head's ability to expand the hole and therefore the amount of upsizing. Bursting is not possible in rock or for pipes that are concrete-encased. Also, shallowly buried pipes pose some risk of surface displacement. Generally, the minimum depth of the existing pipe should be 10 times the difference in diameters of the existing pipe's outer diameter (OD) and the expander's OD. With increasing depth of soil burial, the force needed to expand the hole also increases. The foundation of adjacent structures and other utilities can be damaged if they are too close to the bursting activity. The distance should be a minimum of 18 inches (450 mm) for normal bursting and larger for upsizing. Expansion pits or trenches can be dug adjacent to structures or utilities to relieve the soil pressure.

Since the original pipe is destroyed in the bursting process, the new pipe is designed to carry all of the operational loads, including internal pressure, external soil pressure, and traffic loads. After insertion of the new pipe behind the bursting head, the soil will tend to close back on the pipe. This will tend to reduce the loads actually experienced by the replacement pipe because much of the overburden load will arch over the loosened ground around the pipe. Because the extent and longevity of this arching action is difficult to predict, the design approach is similar to that used for direct burial pipe, based on soil-pipe interaction. Also, some of the most demanding loads may be exerted on the new pipe during installation. The new pipe will experience flexural loads as it enters the launch pit, axial tensile loads due to friction and pipe weight, external buckling pressure due to soil fill and groundwater, and possible surface damage from contact with shards of the old pipe.

4.4.1.5 Drive and Pull (Tight-in-Pipe). This is a novel system in the North American market and has been adapted from European applications. It is intended to provide a new replacement pipe with minimal loss of internal diameter and without the need for open-cut excavations. The system uses short lengths of PVC replacement pipe that will fit within a normal 4 feet (1.22 meter) diameter manhole. The "bursting" head is not intended for significant displacement of the existing host-pipe fragments, but rather just to create an opening sufficient to pull in the replacement pipe in a relatively tight fit. A special gripping arrangement is used to pull the new sections of pipe as they are added to the insertion string. The system is being offered in the U.S. by TT Technologies in conjunction with PVC pipe manufactured by Ipex, Inc.

4.4.1.6 Pipe Reaming. In this system, an HDD rig provides a tensile pull and rotational torque capability for the replacement process. A drilled entry path allows the drill rod to enter the section of pipe being replaced. The drill rod is then pushed along the existing pipe to the insertion pit and is connected to a reaming head with cutting teeth. The replacement pipe is attached to the rear of the reaming head, and the HDD rig is then used to ream out the existing pipe as the drill rods are retracted. Drilling mud is used during the process to flush the reamed pipe fragments forward to the initial entry end of the replacement section. Thus, no ground displacement is necessary to create the void for either same-size replacement or upsizing, and the pipe fragments are removed from the soil.

4.4.1.7 Pipe Eating. The "pipe-eating" process uses excavation heads that can cut through and fragment existing pipe material. In this case, a microtunneling-style excavation head is jacked along the existing pipe alignment, with the replacement pipe supplying the jacking thrust. The system is most applicable to unreinforced or lightly reinforced existing pipes. Depending on the circumstances, the existing pipe may be filled with a weak concrete mix prior to excavation and replacement, or the excavation head may have a front extension that assists the excavation head in following the existing pipe alignment. In the former case, alignment of the replacement pipe can be controlled by the normal guidance mechanism for microtunneling and hence can correct alignment or profile deficiencies in the existing pipe. This system has very seldom been used in North America, if at all. Systems are available in Japan and Europe, but the only manufacturer offering such a system and with a presence in the U.S. is Herrenknecht.

4.4.1.8 Pipe Extraction. Pipe extraction is typically a site-adapted pipe jacking process in which the old pipe is pushed ahead of the new pipe and is removed or broken up as it enters the receiving pit. The circumstances for using this method include having an existing pipe that is competent enough to be jacked to the receiving pit, having low enough adhesion/friction to allow the existing pipe to be slid through the soil, and having no lateral connections or repair clamps that would anchor the existing pipe.

4.4.2 Off-Line Replacement. As the name implies, off-line replacement simply involves installation of a new pipe without regard to the existing pipe's line and grade. Normally, the deteriorated pipe being replaced is kept in service while the new replacement pipe is installed. Once the new pipe is in place and inspected or tested, as appropriate, a switch-over is made. These methods are not within the scope of this report, so they are only briefly described below, with references provided for further reading. General references for new installation approaches are Najafi (2005); NASTT (2008a and 2008b); and Stein (2005).

4.4.2.1 Open-Cut Replacement. The conventional method of open-cut replacement may be the cheapest direct-cost option when sewers are relatively shallow and road pavement replacement costs are low. However, open-cut replacement becomes less desirable where mainline sewers are deeper, around environmentally sensitive areas, at areas where traffic disruption is important, and in circumstances where high-structural-capacity road pavements must be cut and replaced. Since the latter circumstances cover much of the replacement needs in urban areas, alternatives to open-cut replacement are very desirable and may offer direct cost savings, as well as a reduction in social and indirect costs.

4.4.2.2 Impact Moling. Impact moling uses a pneumatic hammer to advance a torpedo-shaped cylinder through the ground to create an opening into which a pipe can be inserted (Figure 4-21). The typical diameter range for impact moling is 1.75 to 8 inches (44 to 200 mm), with the bulk of the installations occurring in the smaller-diameter ranges. While steerable impact moling equipment has been introduced into the marketplace, it is not in general use due to size and operating constraints; hence, impact-moling is a non-steerable installation process that requires periodic pits to check and adjust the installation alignment. Impact-moling is most commonly used for small-diameter, pressure-pipe installations for building service connections. Research is under way to develop a steerable and trackable small-diameter impact mole, but it is not yet commercially available.

Figure 4-21. Impact-Moling Process (Courtesy TT Technologies)

4.4.2.3 Pipe Ramming. Pipe ramming also uses a pneumatic hammer, but in this case, the hammer is used to drive a steel pipe through the ground. In all except very small diameters, the pipe is driven open-ended with a cutting shoe ring attached to the pipe's leading edge. The pipe cuts its way through the ground with minimal positive ground displacement while the soil remains inside the pipe during driving, thereby eliminating soil flow into the open end of the pipe, except in extremely poor soil conditions. The method can be used in a wide range of pipe diameters, including diameters in excess of 10 feet (3 meter). It is typically used for pipe crossings of roads and railways, since it is non-steerable and requires a large area or pit for the pipe and ramming-head layout. The soil is typically removed after the pipe is fully rammed through to the receiving pit, but intermediate soil removal can be used if soil conditions permit.

4.4.2.4 Pipe Jacking. Pipe jacking has been used for installing pipe sections since the late 1800s. In standard pipe jacking, the soil is removed at the leading pipe's working face (often by hand), and the pipe is jacked forward through the ground as the soil is removed. In contrast to a conventional tunneling process (in which a lining is constructed in place as the tunnel advances), the thrust requirements for pipe jacking increase as the distance from the launching shaft increases (see Figure 4-22). The thrust is provided by jacks at the launching shaft and in the case of very long distances between shafts, intermediate jacking stations (IJSs) can be used so that only part of the pipe string is moved at a time. Various excavation shields and partial face-support mechanisms can be used with pipe jacking to provide steering capability, powered excavation, and enhanced ground support. The excavated soil is removed through the jacking pipes by wagon or a conveyor belt. Conventional pipe jacking is restricted to person-entry sizes and to depths that do not extend significantly below the groundwater table.

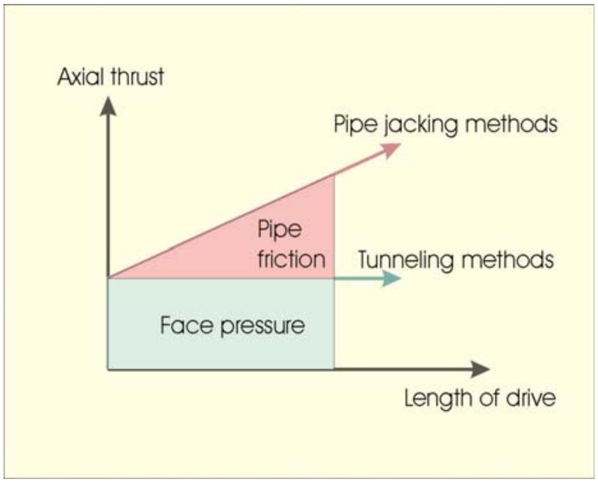

Figure 4-22. Comparison of Thrust Versus Distance for Tunneling and Pipe Jacking Methods

4.4.2.5 Auger Boring. Auger boring also is a pipe jacking method that has been used since the 1940s. In auger boring, the ground is excavated by a cutterhead that is rotated by a spiral-flighted auger string extending from the cutterhead to the launching pit. Rotating the auger simultaneously excavates the ground and moves the excavated spoil toward the launching pit. In its original form, the method had limited steering capability and could not operate in very poor ground conditions or substantially below the water table. However, the equipment cost is relatively low and the operation is fairly simple. Since the development of microtunneling techniques, a number of ground-control and steering advances have been combined with auger-boring methods.

4.4.2.6 Microtunneling. Microtunneling is a pipe jacking-based method that incorporates the following elements:

- An excavation head that provides face support during excavation so that excavation can be carried out below the water table and in running ground
- A guidance system to provide accurate grade and alignment control
- Pipe jacking system for propulsion
- Ability to be remote-controlled from the surface

The name "microtunneling" was originally used to denote a tunneling operation too small for person-entry (e.g., less than approximately 3 feet [1 meter] in diameter). However, the method-based definition described above has been adopted in the U.S. so that microtunneling machines can be several meters in diameter if they are pipe-jacked and have the other features listed above.

Microtunneling machines can have a variety of excavation heads using spade bits, rock picks, roller cutters, and cobble/boulder crushing heads, as appropriate. Face support and excavated soil movement are typically linked in two major variants:

- A slurry-based machine in which pressurized slurry supports the face while it is being excavated, and the excavated spoil is removed by the slurry and separated from it in an aboveground separation unit.
- In an earth-pressure-balance (EPB) machine, the forward movement of the excavation head is coordinated with the rate of soil removal to maintain face support. The excavated spoil typically is removed from the pressurized chamber through a paired set of augers that maintain a soil plug. Once in the unpressurized portion of the pipe, the spoil can be removed by muck cars or by a conveyor. EPB machines are only feasible in larger-diameter microtunneling operations.

Diameter ranges from 12 to 120 inches (300 mm to 3,000 mm) represent the normal range of microtunneling diameters. Diameters smaller than 12 inches do not allow sufficient room for the guidance and excavation equipment, and diameters larger than 120 inches (3,000 mm) provide transportation difficulties for the jacking pipe. Curved alignments with joint deflections of up to 5% can be accommodated, although curved alignments currently are uncommon in the U.S. Selection of the right jacking pipe is very important, since jacking loads of up to 1,000 tons are possible. Flush-jointed pipe is typically used to avoid projections beyond the shield's OD and to minimize friction between the pipe wall and the soil. Bentonite slurry may also be introduced between the pipe barrel and the soil to minimize friction. As with conventional pipe jacking, IJSs may be used on long drives to extend the distance that can be microtunneled from a single setup.

4.4.2.7 Pilot Tube Method. The pilot tube method (also known as guided boring) is a hybrid installation approach that uses the slanted-head steering capability from HDD soil drilling to create an accurate, straight alignment. The final installation may be completed by microtunneling, auger boring, or even pipe ramming. In the pilot tube approach, a hollow drill rod with a sealed slanted displacement head is pushed into the ground. No soil is removed, but rather is displaced around the pilot tube. A camera theodolite is used to sight down the center of the pilot tube to a target at the rear of the displacement head. The target provides information on the head's deviation from the intended alignment and the rotational position of the slant face. By rotating the slant face to the proper direction to correct the alignment and then thrusting, the pilot tube can be kept on line and grade. Once the pilot tube reaches the target shaft, it is used to guide enlargement of the hole and installation of temporary or final jacking pipes, as necessary. The equipment has a much lower cost than a full microtunneling system, and the setup is quick. Figure 4-23 is an example of pilot-tube or guided-boring equipment. The method is relatively low-risk, since the pilot tube can be retracted easily if an obstacle is encountered and because the probability of installation success is increased once a pilot-tube connection is made between the launching and reception shafts.

Figure 4-23. Guided Boring Machine (Courtesy Akkerman, Inc.)

4.4.2.8 Utility Tunneling. Utility tunneling is the use of conventional tunneling techniques for utility-sized tunnel openings and distances between shafts. In hand-dug tunnels, workers excavate the soil at the face, and the spoil is transported back to the starting shaft in hand-pushed rail cars. Under most ground conditions, a cylindrical steel shield is used at the face of the tunnel to protect the tunnel workers. To provide continued support to the ground around the tunnel, a tunnel lining is built within the shield; new sections are built as the tunnel progresses. In conventional tunneling, this lining is not slid longitudinally through the ground, as in the case of pipe jacking methods; this is the major distinction between the methods. Conventional tunneling cannot be used in running ground or substantially below the water table. It has a low mobilization cost and can be useful for short utility tunnel lengths with diameters of more than 6 feet (2 meter). In poor ground conditions or below the water table, compressed-air tunneling can be used, but this is expensive and can pose a significant risk. For longer tunnel projects, shield tunnels or tunnel-boring machines (TBMs) incorporating slurry or EPB face support can be considered; however, in this case, the machines use the previously constructed tunnel lining as the basis for their thrust. Since there is no pipe to be slid through the ground, the limitations on tunnel length from a single shaft setup are principally related to excavation productivity, rather than physical limits based on jacking force and pipe-thrust capacity.

4.4.2.9 Horizontal Directional Drilling. HDD developed from approaches used to deviate oil well drilling. In a typical HDD installation, a pilot hole is drilled along a planned vertical and horizontal alignment by a drill rig sitting on the surface at the entry point of the drill path (Figure 4-24). In shallow soil installations, the drill bit is steered by using a slant-faced bit that drills relatively straight when rotated, but will deviate when pushed without rotation. A locating device (sonde) is situated behind the drill head and transmits signals allowing capture of the depth, slope, and o'clock position of the drill head. Using this information, the drill head can be manipulated to follow the designed trajectory (under roads, rivers, or railroads, or simply to avoid surface excavation and other utilities). When the drill head emerges at the target location, a reaming head is attached, and the reaming head is pulled back toward the HDD rig enlarging the hole. For small-diameter pipes, the pipe to be installed may be attached to the reamer at this stage, or for large-diameter or long pipe installations, several pre-reams may be carried out before the pipe is finally installed.

Figure 4-24. Horizontal Directional Drilling Rig (Courtesy Ditch Witch)

It is generally preferable to pull the pipe into the prepared hole in a single uninterrupted pull; hence, pipe strings are usually welded (steel) or fused (HDPE or Fusible PVC™). It is also possible to use sectional pipes with restrained joints (e.g., Certa-Lok™ or Terrabrute™ joints). This is advantageous where there is no room to lay out the full length of the pipe string prior to pullback.

In hard soil or rocky conditions, the spade type of excavation bit is replaced with a rock excavation bit powered by a downhole mud motor (adapted from oilfield drilling technology). Steering is still possible, but in deeper or inaccessible installations, the locational information about the drill path trajectory is typically obtained through a "wireline" steering package that references the drill-path trajectory to the earth's magnetic field.

Using HDD technology, anything from fiber-optic cables in residential subdivisions to oil and gas pipelines extending under major rivers can be installed successfully and unobtrusively. Maximum installation lengths currently exceed 8,000 feet (2.5 km), and diameters of up to 54 inches (1.37 meter) have been installed (although installation lengths are shorter for larger diameters). Costs tend to be lower than for microtunneling, but the alignment accuracy is lower. Special procedures to minimize deviations in HDD for gravity sewer applications have been developed and successful installations of gravity sewers with moderate minimum gradients have been achieved (minimum grades vary with depth, soil type, surface access, etc.).

4.4.3 Summary of Replacement Technologies. Table 4-3 summarizes the replacement technologies for mainline sewers, as well as their main advantages, limitations, and most suitable application conditions.

Table 4-3. Sewer Mainline Replacement Technologies

Advantages	Limitations	Most Suitable Conditions for Application
Pipe Bursting (Static, Pneumatic, Hydraulic, TIM, Pipe Splitting)		
• New pipe is installed • No pipe cleaning needed • Some upsizing capability	• Pits required • Difficult in hard clays, high groundwater table, or with past repair clamps • Access pits required for lateral connections • Must predict effect of ground movements and/or vibration	• Badly damaged pipe • Pipes with few lateral connections • Pipes where upsizing is needed or loss of diameter is not permissible
Drive and Pull (Tight-in-Pipe)		
• New pipe is installed • Can operate from within existing manholes	• Diameter reduction • Upsizing not possible	• Where surface disruption would present problems
Pipe Removal Techniques (Pipe Reaming, Pipe Eating)		
• New pipe is installed • No pipe cleaning needed • Large upsizing capability • Minimal ground movement	• Pits/access paths required to reach sewer depth • Pipe eating has expensive mobilization	• Where pipe upsizing is required and ground movements must be limited
Pipe Extraction		
• New pipe is installed • No pipe cleaning needed • Minimal ground movement	• Pit(s) required to reach sewer depth • Has limited application	• Pipe extraction is suitable only in limited circumstances
Open-Cut Replacement		
• New pipe is installed • Unlimited upsizing • Commonly used and well-understood	• Extensive surface disruption • Time-consuming • Often expensive	• Open area without obstacles • Shallow pipe • Large upsize needed
Trenchless Installation Techniques		
• Minimal or no surface disruption • Wide range of techniques available • May be less expensive in direct cost, as well as when	• May encounter unknown obstacles or geologic conditions • Can be more risky than open-cut installations • May be more expensive than open cut	• Areas where surface disruption must be avoided • Installations at moderate or higher depths (approximately 15 feet or more) • Sizes of contracts appropriate

Advantages	Limitations	Most Suitable Conditions for Application
social/indirect costs are included		to the mobilization cost of the method

5.0 SEWER LATERAL RENEWAL TECHNOLOGIES

5.1 Special Considerations for Laterals

While sewer laterals are only additional pipe segments connected from building properties to the mainline sewers, they have a number of physical and administrative conditions that make both assessment and renewal programs more problematic than for the mainline sewers. Figure 5-1 shows a typical layout for a sewer lateral connecting to a mainline in a street, together with some of the typical conditions and illegal drain connections that contribute to high I/I from laterals.

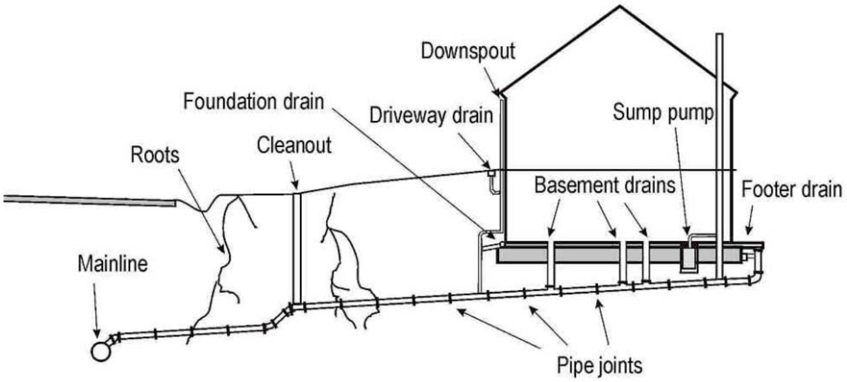

Figure 5-1. Typical Layout of Sewer Laterals (Simicevic and Sterling, 2005)

When compared to sewer mainlines, some of the unique physical features of laterals that affect activities such as pipe inspection or rehabilitation are (Simicevic and Sterling, 2005):

- Small diameters – These pipes are most often 4 or 6 inches (100 or 150 mm) in diameter.
- Diameter changes – There is commonly a diameter change at the foundation or property line (for example, from 4 to 6 inches [100 to 150 mm]).
- Multiple bends and multiple fittings for cleanouts, etc.
- Flat and shallow pipes – Laterals often have a minimum slope and are laid as shallow as possible in the existing topography until close to the mainline.
- Laterals are often constructed by local plumbing contractors with little or no inspection.
- Limited access to pipes – These pipes usually have no access points other than through the mainline connection or a cleanout. Sometimes they can be accessed from inside the house.
- Defective connections (Figure 5-2) with the mainline (e.g., “break-in” installation [“hammer tap”], or a broken connection to the mainline because of ground settlement over time).
- Misaligned and/or open pipe joints – Mortar used to seal the joints between pipe sections deteriorates or was not fully installed in the first place. Pipes may have been laid with loose fitting joints or with joints connected with duct tape.
- Many bells at the pipe joints are cracked and/or displaced.

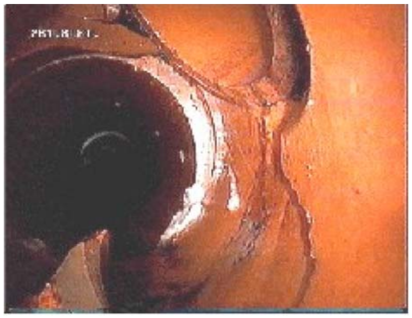

Figure 5-2. "Break-In" Connection to the Mainline (Courtesy of LMK Enterprises, Inc)

- Laterals often pass close to trees, either on private property or at the edge of the roadway and roots can follow the outside of the sewer pipe until they find a joint to enter.
- Previous repairs are often of poor quality.
- Materials previously used for sewer laterals may be unsuitable and undergoing widespread failure (e.g., Orangeburg pipe).

5.1.1 Ownership. As shown in Figure 3-1, according to a 2004 municipal survey conducted by Water Environment Research Foundation (WERF) (Simicevic and Sterling, 2005) as part of a study of lateral rehabilitation, private property is owned to the sewer main in the street in approximately 55% of the municipalities surveyed; however, there is a split regarding who owns the actual connection into the main (the sewer "tap"). Cleanouts at or near the property line are often used as the demarcation of private and public ownership, but again, not in all cases.

5.1.2 Layout, Materials, and Records. The location of a sewer lateral on private property depends on site conditions. Most laterals are in front of a house, but some agencies have over 80% of their laterals at the back of a house, and some have over 50% of their laterals at the side of the house. In the WERF survey, 19% of participating agencies reported that cleanouts are still not required, while the remaining 81% require at least one cleanout on their laterals. The agencies requiring cleanouts reported that local plumbing codes generally control the requirement for placing the cleanouts and that the cleanouts are required at different locations along the laterals. Participating agencies in the WERF survey reported that most private sewer laterals were vitrified clay pipe (VCP) (51.8 %), but that PVC pipes were already representing a large portion of pipes within their systems (26.6%) (Figure 5-3). The category "other" pipe types in the figure refers to Orangeburg pipes and asbestos-cement pipes, which are no longer installed.

In terms of pipe size for laterals, they also reported that most private sewer laterals in their systems were 4 inch (100 mm) pipes (62.6%) and 6-inch pipes (29.7%). Smaller diameters (3 inches or less) and larger diameters (up to 12 inches [100 mm]) were reported in smaller quantities (Figure 5-4).

Recordkeeping for sewer laterals is generally poor in many agencies. In the WERF survey, 24.1% of participating agencies reported keeping no records about the locations of sewer laterals in their systems. The rest of participating agencies reported having some kind of records about lateral locations, even though in some cases, it only involved the public portion of the lateral (the part between the mainline and the right-of-way, or only information about the lateral-to-mainline connection).

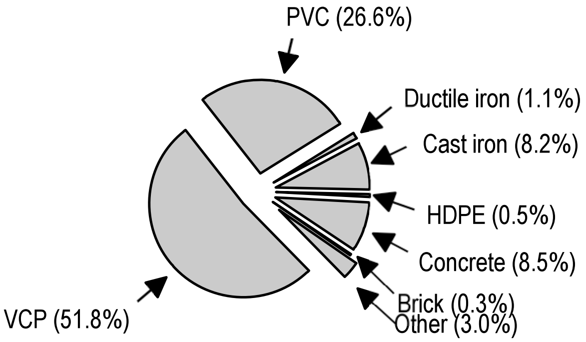

Figure 5-3. Pipe Types Used for Sewer Laterals (Simicevic and Sterling, 2005)

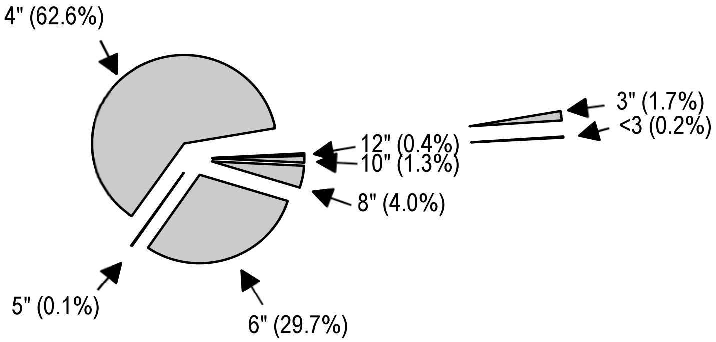

Figure 5-4. Pipe Sizes Used for Sewer Laterals (Simicevic and Sterling, 2005)

The participating agencies used different ways to keep records of sewer laterals. These included maps, electronic databases, and geographic information systems (GIS). There is expected to be a gradual trend toward combining all records relating to sewer laterals (layout, materials, maintenance records, inspection and assessment data, etc.) into GIS-based asset management systems, but the status of recordkeeping for sewer laterals is still poor in many agencies.

5.1.3 Private Property Issues. Even when municipalities have concluded that their sewer laterals present a problem that should be addressed systematically, they are still often reluctant to move ahead. Dealing with private property owners over sewer lateral repairs is a difficult issue. Most private property owners have little idea of the condition of their sewer. They will see little or no direct benefit from the usually significant repair and the rehabilitation costs. Linked to the legal issues of who owns which portion of the lateral, who should pay, etc., are also questions of legal right of access to the private property for inspection and repair work, as well as legal liability for accidents during inspection or repair work. Some key issues/options regarding legal and liability matters are:

- Some states prohibit spending public money for private gain (i.e., improving private property by paying for rehabilitation of private laterals). This issue has been addressed successfully in the courts by arguing that the private gain is only incidental to a larger public gain, resulting from fewer sewer overflows and decreased sewage treatment costs.
- Procedures for entering private property to conduct inspection and repair work vary widely across the U.S.

- Many municipalities regard taking any additional responsibility for private sewer laterals as a major concern in terms of additional work and public liaison. Other municipalities are more proactive, seeing themselves as being in the best position to do something about lateral problems by providing homeowner-friendly programs, even if they do not take financial responsibility for the work.
- Having the political will to force homeowner compliance is often an issue with elected city councils who have to approve the program.

5.1.4 Financing Issues. Programs can be much more successful with less public resistance if the financial aspects, as well as the legal aspects, are carefully considered. Some of these issues are:

- For wealthier neighborhoods, financing options can make it easy for the homeowner to agree to and proceed with the repair. For low-income neighborhoods, some kind of financial assistance or deferral of payment until property sale may be essential to pursuing a program.
- A few cities have decided that sewer lateral repair provides enough public good that they have put up all of the money for the program.
- Other cities use a warranty program approach where the homeowner essentially pays an insurance premium against the cost of a malfunctioning sewer system.
- Using a mandatory inspection at the time of sale and a requirement to have the lateral in proper condition before the property is transferred allows the cost of lateral repair to be paid at a time that money is available from the property sale. This is true for both low-income and wealthy neighborhoods.
- The city can use its program size to bid or negotiate uniform and low costs for the lateral repairs. A homeowner can opt to bid the work themselves, but a quick check on an individual price can often convince him/her that joining the city program is an opportunity to take care of the problem at a lower price and with little effort.

5.1.5 Lateral Renewal Decision-Making. After identifying problems related to the condition of sewer laterals or excessive I/I involving a significant contribution from sewer laterals, an agency needs to determine how or whether to address these problems. Criteria may include the direct cost-effectiveness of sewer lateral renewal in terms of the costs they avoid versus the costs they incur, but may also need to address more general considerations affecting public health, the environment, and quality of life.

Even when looking at the direct cost-effectiveness of lateral renewal, it is important to see it in a broader view. Repairing the laterals in one small basin may not appear cost-effective if the savings are calculated only by multiplying the reduction in total quantity of conveyed sewerage annually by the average cost of conveyance/treatment per 1,000 gallons of sewage. However, the same repair may be cost-effective if it prevents peak flows from exceeding design maximum flows at lift stations and at the wastewater treatment plants (WWTP), and if it eliminates the need to upsize parts of the collection system.

Because of the large investments required to bring most systems up to standard, rehabilitation and capacity-building efforts may take many years; hence, decisions must prioritize system improvements over time. System needs and prioritization will then guide development of a strategy to deal with sewer laterals (i.e., deciding whether the rehabilitation of private sewer laterals is necessary; deciding how lateral rehabilitation will fit within an overall renewal program; selecting the general approach of what laterals to repair and what part of selected laterals to repair; selecting the methods of financing the lateral rehabilitation that will be effective and acceptable for a particular agency; and deciding on how to deal with accessing private properties and related legal liabilities).

The use of pilot projects for lateral rehabilitation has proved useful in many cities that have adopted broad lateral rehabilitation programs. They provide site- and system-specific data and help to identify the rehabilitation techniques to be adopted, as well as their effectiveness.

5.2 Locating Technologies, Inspection Technologies, and Condition Assessment

5.2.1 Locating Technologies Table 5-1 summarizes the principal existing methods for locating or marking sewer laterals and cleanouts.

Table 5-1. Methods for Locating or Marking Sewer Laterals and Cleanouts

Method	Description
House-to-house survey	Locates cleanouts visible from the surface.
Smoke testing	Locates pipes that are not very deep and have defects. Used often and on a large scale.
Dye water flooding	Checks if the house is connected to the mainline. If so, another method can be used to identify the lateral layout, if necessary.
Mainline CCTV	Locates lateral-to-mainline connections along the mainline. Used frequently.
Walkover sonde (on lateral CCTV, rod, or cleaning hose)	Identifies layout and depth of the pipe on its entire length (where the camera can pass). The most accurate method after open-cut excavating.
Plumber’s snake	Identifies layout of the pipe on its entire length, but difficult to work with in noisy conditions. Used less as other methods became available.
Vacuum excavation	May be used to locate and check the depth of the pipe at selected points where the lateral is believed to be laid; mostly used for installation of cleanouts and opening small pits, where needed, during lateral rehabilitation. Has become very popular for its ease of use and small footprint.
Ground-penetrating radar (GPR)	Identifies layout and depth of the pipe where the soil conditions are favorable and access inside the lateral is difficult. Currently used rather infrequently, but use increasing as cost of equipment drops and ease of use improves. Research is improving the resolution of utilities at greater depths in difficult soil conditions.
Radar tomography (RT)	Can be used to locate sewer laterals (on a large scale) if the surveyed area is accessible to a vehicle pulling a pool-table-size attachment. Creates 3D images showing utility lines and other features at various depths.
Magnetic tapes	Installed in a trench at shallow depth during open-cut pipe installation or replacement. Easily detected with any metallic detector such as a simple wand-type detector.
Marker balls	Installed at shallow depth next to cleanouts or at intervals along the pipe before or during backfilling. Detected with special marker locators that create and detect radio signals in resonance with the marker balls.

5.2.2 Inspection Technologies. Table 5-2 summarizes the principal methods used for laterals inspection. More detailed discussions of these methods can be found in the WERF report (Simicevic and Sterling, 2005) and in an EPA report on the inspection of wastewater systems (EPA, 2009b).

Table 5-2. Methods for Inspection of Sewer Laterals

Method	Description
Building inspections	Identifies uncapped cleanouts and various connections to the laterals.
Smoke testing	Identifies various connections and defective service laterals.
Dye water flooding	Identifies defective laterals and various connections to the sewer lateral.
Mainline CCTV	Identifies "suspect" laterals and may be able to inspect first few feet of the lateral.
Lateral CCTV	Identifies location and size of active leaks and some inactive leaks (water stains); also identifies change in pipe material/diameter along the lateral, sags, bends, etc.
Pressure testing	Identifies existence of both active and passive leaks.
Electro scanning	Identifies existence of both active and passive leaks in non-conductive pipes.

5.2.3 Condition Assessment and Recordkeeping. Based on the inspection data from a sewer lateral, the condition of individual laterals or the average condition of laterals in a basin or sub-basin can be assessed. Decisions about whether the rehabilitation or replacement of a particular lateral is necessary can be made on the basis of this assessment, but may also be made according to other system criteria. For example, lower and/or upper laterals may be rehabilitated at the same time as mainline segments, as in Nashville and Davidson County, TN and all non-PVC laterals may be renewed in a sub-basin being rehabilitated, as in Sarasota, FL. However, in many agencies, only laterals proven to be defective qualify for repair, especially if the agency has to force the homeowner to do and/or pay for the repair.

The condition assessment will normally be based both on I/I conditions in the lateral and on the lateral's structural condition. Both the presence of I/I and, if possible, a measure of its severity are assessed, along with identification of various types of structural defects. Table 5-3 indicates the typical data sources and assessment parameters used for different aspects of condition assessment.

Standardization of defect codes is just as important for sewer laterals as for mainline condition assessment. It enables benchmarking of sewer pipe conditions within a single agency and also compares sewer pipe conditions among different agencies. For illustration, Table 5-4 shows partial examples of lateral codes created as a subset of Pipeline Assessment Certification Program (PACP) mainline observation codes (using Flexidata software).

5.2.4 Quantification of I/I from Laterals. A critical issue for many municipalities in considering development of a lateral rehabilitation program is whether they can justify the cost and effort of the program in terms of potential public benefit that will accrue from the program (e.g., financially through reduced treatment costs and, in the U.S., through avoidance of Federal government fines for sewage overflows). Public benefit also occurs through a general improvement in the environment. According to the WERF study (Simicevic and Sterling, 2005), a number of cities had completed monitored lateral repair programs, but the monitored data were quite variable in terms of extent and robustness.

Table 5-3. Basis for Condition Assessment

Assessment Type	Data Source	Basis of Assessment
I/I assessment	CCTV	Visible joint infiltration
		Evidence of periodic leaking
	Digital scanning	Evidence of periodic leaking
	Pressure testing	Exfiltration rates
Structural assessment	CCTV/digital scanning	Qualitative descriptions
		Quantitative scoring of individual defects and aggregated scores for pipe sections
Operating conditions	CCTV/digital scanning	Qualitative descriptions (e.g., tree roots, debris, blockages)
Other defects	CCTV/digital scanning	Qualitative descriptions (e.g., construction defects such as hammer tap lateral connections)

Table 5-4. Examples of PACP Lateral Condition Codes

Code	Description	Code	Description
B	Broken	HSV	Hole soil visible
BSV	Broken soil visible	HVV	Hole void visible
BVV	Broken void visible	ID	Infiltration dripper
CC	Crack circumferential	IR	Infiltration runner
CL	Crack longitudinal	JSM	Joint separated medium
CM	Crack multiple	OBR	Obstacle rocks
CS	Crack spiral	RBB	Roots ball barrel
D	Deformed	RBJ	Roots ball joint
DAE	Deposits attached encrustation	RFB	Roots fine barrel
DAGS	Deposits attached grease	RFJ	Roots fine joint
DNF	Deposits ingressed fine	SAM	Surface aggregate missing
DNGV	Deposits ingressed gravel	SAP	Surface aggregate projecting
FC	Fracture circumferential	SAV	Surface aggregate visible
FL	Fracture longitudinal	VC	Vermin cockroach
FM	Fracture multiple	VR	Vermin rat
H	Hole	XP	Collapse pipe sewer

The Oak Valley neighborhood of Nashville, TN, is one example with a strong dataset from pre-mainline rehabilitation, post-mainline rehabilitation, and post-lateral rehabilitation. A regression analysis was used on data from storms in each of the three periods; this allowed a comparison of I/I reduction from both the mainline and the combined programs (Kurz, 2002). As shown in Figures 5-5 and 5-6, rehabilitation of the laterals reduced rainfall-derived inflow and infiltration (RDI/I) as measured by the 24-hour flow volume from 75% to 90% of the pre-rehabilitation flow volume. The reduction in peak hour flow

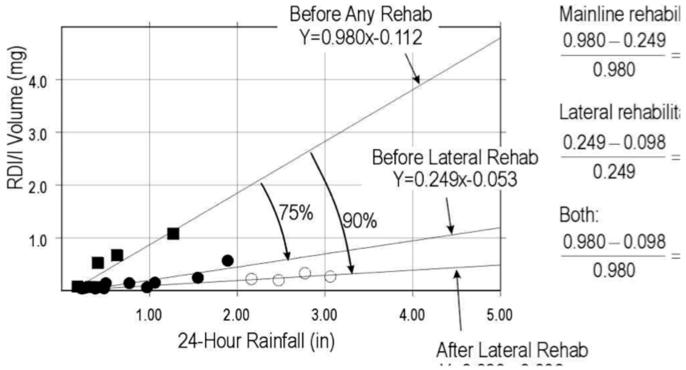

Figure 5-5. 24-Hour RDII Volume Reduction in Oak Valley (Nashville and Davidson County) (Simicevic and Sterling, 2005)

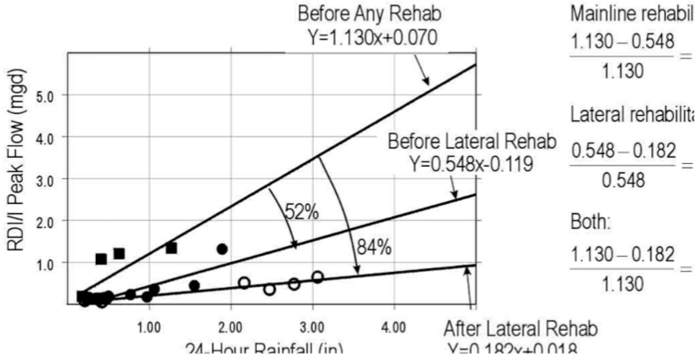

Figure 5-6. RDI/I Peak Hourly Flow Reduction in Oak Valley (Nashville and Davidson County) (Simicevic and Sterling, 2005)

from the lateral rehabilitation was more marked, improving the reduction in peak hour flow from 55% to 85% of the pre-rehabilitation flow.

Based on a calculated cost of sewerage conveyance and treatment of $0.76 per 1,000 gallons of flow, savings from the reduced costs in conveyance and treatment provided a 4.5-year payback for the mainline rehabilitation alone and a 5.5-year payback for the combined mainline plus lateral rehabilitation. This calculation makes no allowance for environmental value improvements or for improvement in asset value derived from the sewer system renovation.

Another example is a 2002 rehabilitation project focused on removing inflow sources in Tacoma, WA. The project involved disconnection of sump pumps and foundation drains from sewer laterals. The effectiveness in RDI/I reduction was estimated as a percent reduction of RDI/I volume and as a percent reduction of RDI/I peak flows for any rainfall. The rehabilitation successfully eliminated 35% of RDI/I volume and reduced RDI/I peak flows by 15%.

5.3 Methods for Inflow Removal

5.3.1 Inflow Removal. Inflow removal often represents a high return on investment as the first step in reducing I/I within the sewerage system, and most inflow sources within the system are found in connection with laterals and private building connections. While many of the methods for inflow source removal are straightforward in terms of physical application, the private property issues and the potential consequences of inflow source removal need careful consideration. Table 5-5 lists some of the common techniques involved in inflow removal, and Figure 5-7 illustrates the disconnection of a foundation drain and installation of a sump pump.

Table 5-5. Common Inflow Removal Techniques

Inflow Removal Approach	Variations	Description of Remedy	Potential Problems or Application Issues
Disconnection of downspouts	Direct discharge	Cut downspouts and redirect flow onto property	Erosion and local flooding due to poor surface drainage
	Rain barrels	Discharge flow into storage barrels	Empty before next storm event
	Bubbler pots	Discharge flow away from property	—
	Rain gardens	Provide absorption zone for flow	Maintain garden
Footing drain disconnections	Full	Divert all drainage flow from sanitary sewer	Pump failure; backup power; basement backup or flooding. Discharge problems due to surface contours, icing in winter, etc.
	Partial	Divert only during high-flow events	
Manhole inflow/open cleanouts	Removal during rain events	Lock or secure covers	Interferes with normal access
	Poor seals or inadvertent loss	Provide sealing inserts	—

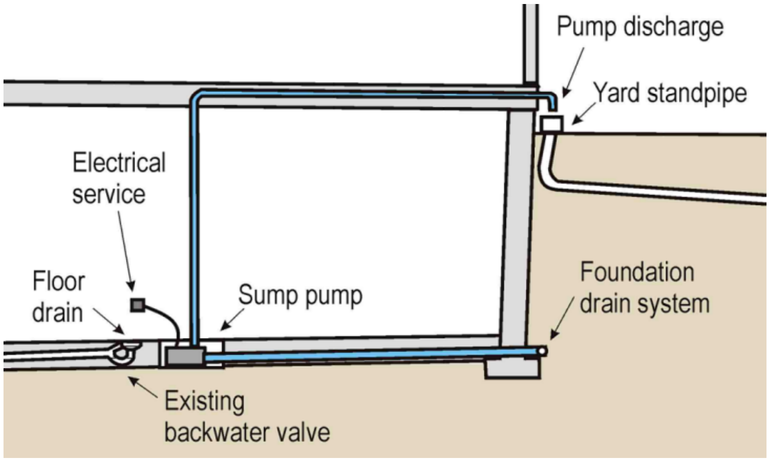

Figure 5-7. Foundation Drain Disconnection Setup in Duluth, MN

5.4 Methods for Renewal

Following the decision to begin a renewal program, it is necessary to decide which method(s) will be used or permitted in a bid selection process. The principal methods are briefly introduced below and their characteristics listed in Tables 5-6 to 5-8. Appendix A provides datasheets illustrating each technology category.

5.4.1 Repair Technologies and Maintenance Procedures. Open-cut repair is the traditional repair method. Using a backhoe for excavation requires significant size pits; for deep laterals, this may require shoring or sloping the sides of the excavation to allow person access into the excavation. Surface disruption can be limited by using vacuum excavation techniques; however, sewer line repair using a keyhole excavation is not as well developed as it is in the gas industry. The one-call procedure to locate and mark all other underground utilities near the excavation must be followed, even when the excavation is entirely on private property.

Robotic repairs can be carried out from within the mainline sewer, but are essentially limited to lateral-mainline junction repairs. Such repairs avoid the surface disturbance of an open-cut repair and eliminate the potential for damage to other utilities.

Maintenance actions may not be considered specific renewal options, but when sewer conditions have become poor over time, such actions may be required either for proper operation of the lateral or to permit a more extensive renewal action. The homeowner usually initiates cleaning of laterals only when a problem is experienced; however, if the lateral has a recurring root problem, regular root removal may be required to keep the lateral functioning. Root growths in a lateral are clear evidence of a leaky lateral that contributes I/I to the collection system.

Table 5-6 provides a summary of the repair and maintenance procedures for sewer laterals together with their main advantages and limitations and most suitable application conditions.

Table 5-6. Repair and Maintenance Procedures for Laterals

Advantages	Limitations	Most Suitable Conditions for Application
Open-Cut Repair		
• Permanent repair • Unlimited upsizing • No chemicals used • Commonly used and well-understood	• Extensive surface disruption and disturbance of homeowners • Access to private property required • Time-consuming • Often expensive	• Open area without obstacles • Shallow pipe • Pipes with severe offset joints • Completely damaged pipe • Large upsize needed
Robotic Repair		
• Provides structural repair • Removes infiltration, root problems • No excavation needed • Access to private property not required • Minimal disturbance	• Repair limited to first 2 ft from the mainline • Chemicals used (safety requirements)	• Only lateral connection and short distance into lateral need repair • Break-in or protruding laterals

5.4.2 Rehabilitation. The sections below provide a general description of the principal rehabilitation techniques for sewer laterals, and Table 5-7 summarizes attributes for each category of methods. Appendix A provides datasheets showing more detail on techniques offered commercially.

5.4.2.1 Chemical Grouting. Chemical grouting of sewer laterals is most often performed from the mainline (lateral-to-mainline connection and first several feet into the lateral are grouted); however, grouting can also be completed through cleanouts (the entire length of lateral is grouted in 3 to 5 feet [900 to 1,500 mm] long increments). The method is performed as a test-and-seal procedure. Because it eliminates infiltration, but does not provide structural repair, it is only suitable for structurally sound pipes. The longevity of repair can be rather short in some ground conditions (up to 5 years). However, case studies were identified where the grout was in good condition after longer periods of time (for example, 10 years in the Village of Genoa, WI). This is the least expensive of all rehabilitation methods, but grouting with long bladders (6 to 30 feet [2 to 10 meter]) is more expensive. It may be uneconomical to seal large voids or interconnected networks of voids within the ground.

5.4.2.2 Cured-in-Place (CIP) Lining. For CIP lining, there are many systems on the market. They vary in the types of fabric and resin used, the type of curing system, or simply in the delivery of the same basic technique by different providers. CIP lining approaches can offer a structural repair with minimal excavation and minimal diameter reduction. When optimized for lateral rehabilitation, CIP lining offers a fast repair (2 to 3 hours with heat cure) and three to four laterals/day can be rehabilitated. There are various classes of CIP lateral liner (Figure 5-8), depending on the treatment of the lateral-mainline connection and the lateral liners' extent of coverage. The standard CIP laterals approach does not address the lateral/mainline connection, and even when both the mainline and the lateral are rehabilitated, the junction between the two liners may not be adequately sealed.

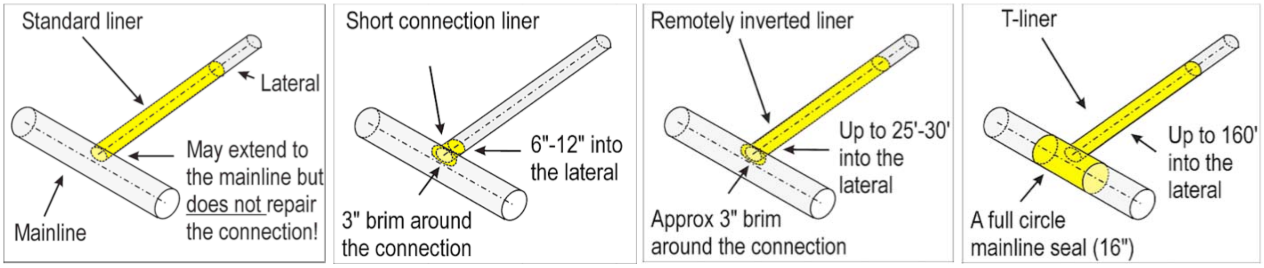

Figure 5-8. Types of CIP Lateral Lining Systems

Since the connection is often a weak link in the sewer lateral and is at the sewer lateral's deepest point, a number of systems have been developed that provide a seal for only the connection or seals of the connection, plus a short section of lateral. For this purpose, grouting can be used, as well as systems such as a "top hat"-style system with a flange inside the mainline and a short section of liner extending into the lateral.

Recently, these systems have been combined into a system (T-liner) that provides a full circle liner inside the main line, with a full CIP lateral liner that can extend up to 160 feet (50 meter) from the mainline. For CIP liners, the mainline should be lined first, unless the mainline does not require rehabilitation. With a connection seal with the mainline the lateral liner then completes the sealing process for the lateral and mainline system.

5.4.2.3 Flood Grouting. Flood grouting is offered in the U.S. by Sanipor®. In this approach, one segment of a sewer system, including at least one manhole, is isolated (using mainline packers and lateral packers near building exit points). Figure 5-2 illustrates the process. A sodium silicate-based solution is used for the grouting and is introduced as two separate components. First, the sewer segment is flooded with Solution A through the manhole, and the solution is allowed to permeate into the surrounding ground through defects in the pipes and manhole. This solution is then quickly pumped out of the pipes, and Solution B is used to re-fill the system. As Solution B comes into contact with Solution A in the ground outside the pipes, it forms a hard sodium silicate seal around the pipe network in the defective areas of the pipe network. The principal advantage is the ability to seal laterals, mainline, and manholes from a single setup. As indicated above, it may be uneconomical to seal large voids or interconnected networks of voids within the ground using a grouting procedure. An exfiltration test is typically conducted in new or questionable areas before starting the flood grouting process.

5.4.2.4 Sliplining. Because of the small diameter and frequent bends in sewer laterals, slipliners are used only infrequently. Typically, the slipline's capacity is not a major issue for a lateral sewer, but the installation can be problematic, except in straight sections of laterals. With CIP liners and pipe bursting options available, sliplining is rarely the preferred option.

5.4.3 Summary of Rehabilitation Technologies for Laterals. Table 5-7 summarizes rehabilitation technologies for sewer laterals, along with their main advantages, limitations, and most suitable application conditions.

Table 5-7. Rehabilitation Technologies for Sewer Laterals

Advantages	Limitations	Most Suitable Conditions for Application
	CIP Standard Liners	
• No excavation (cleanouts required) • Structural repair possible • Long term repair	• Repair up to 100 to 200 feet from cleanout • Connection with mainline not repaired • Can't upsize pipes, remove sags • Not for pipes with large offset joints, many bends, badly corroded • Root problems possible in future • Access to private property usually required	• Long lengths of laterals need to be repaired; cleanouts exist • Pits required for bursting are to be avoided • Deep laterals that are difficult to repair with some other methods
	CIP Short Connection Liners	
• No excavation (cleanouts required) • Minimal disturbance to homeowners • Access to private property not required • Structural repair possible • Long-term repair	• Repair limited to first 1 foot of the lateral from the mainline • Adhesion with existing CIP liners not fully proven (for some liners)	• Only lateral-to-mainline connections need to be repaired • Mainline and/or lateral have been CIPP-relined, but the annular space at lateral connection is not sealed

Advantages	**Limitations**	**Most Suitable Conditions for Application**
CIP Long Connection Liners		
• Connection with mainline repaired • No excavation (cleanouts required) • Short disruption to homeowners • Structural repair possible • Long-term repair	• Repair limited to about 25 feet from mainline • No upsizing • Root problems possible in future	• Longer lengths of lower lateral need rehabilitation • Mainline already CIPP-relined (if necessary)
CIP T-Liners		
• No excavation (cleanouts required) • Connection with mainline repaired • Repair extends into mainline • Root problems in future even less likely • Short disturbance to homeowners • Structural repair possible • Long-term repair	• Repair limited to 80 to 160 feet of the lateral from the mainline • No upsizing • Access to private property typically still required	• Extra protection against infiltration wanted near lateral-to-mainline connection • Mainline already CIPP-relined (if necessary)
Chemical Grouting		
• No excavation required • Repairs only where needed (pressure test performed first) • Removes infiltration, root problems • Minimal disturbance to homeowners • Access to private property usually not required • Inexpensive	• No structural repair • No upsizing • Sometimes can’t be completed (the section can’t be pressurized) • The longer the bladder, the more difficult the installation (from the mainline) • Grout may crack in some groundwater conditions • Chemicals used (safety requirements)	• Many leaking defects in structurally sound pipes • Groundwater table stable around the pipe defects throughout the year • Inexpensive and quick repair is desired • Cleanouts exist already
Flood Grouting		
• No excavation (cleanouts required) • Removes infiltration, root problems • Repairs both mainlines and laterals • Minimal disturbance to homeowners	• No structural repair, no upsizing • Access to private property required	• Many leaking defects in still structurally sound pipes • Deep pipes, many sharp bends • Cleanouts exist already
Sliplining		
• No special equipment needed • No chemicals are used	• Reduction in pipe diameter • Pits required • Time-consuming • Expensive	• Large lateral pipes

5.4.4 Replacement. The conventional method of open-cut replacement may be the cheapest option when lateral sewers are relatively shallow; however, it becomes less desirable in northern climates where laterals are at greater depths, for properties with well-developed landscaping elements, and where road pavement must be cut and replaced. For replacement of sewer laterals, trenchless techniques offer a much less disruptive option and may be directly competitive in price.

Another trenchless approach is to use specially designed small pipe bursting systems that are optimized for use in sewer laterals. Pipe bursting is good for badly damaged pipe or for pipes with insufficient hydraulic capacity (since the existing pipe can be upsized by one size during replacement). It provides a permanent structural repair and is reasonably fast, requiring as little as a few hours to replace a single lateral. Drawbacks are that pits are required, pipe bursting is not suitable for laterals with many bends, and cost considerations make it unsuitable for very short laterals.

Table 5-8 summarizes the replacement technologies for sewer laterals, along with their main advantages, limitations, and most suitable application conditions.

Table 5-8. Replacement Technologies for Sewer Laterals

Advantages	Limitations	Most Suitable Conditions for Application
Open-Cut Repair		
• Permanent repair • Unlimited upsizing • No chemicals used • Commonly used and well-understood	• Extensive surface disruption and disturbance of homeowners • Access to private property required • Time-consuming • Often expensive	• Open area without obstacles • Shallow pipe • Pipes with severe offset joints • Completely damaged pipe • Large upsize needed
Pipe Bursting		
• New pipe is installed • No (or minimal) pipe cleaning/root removal needed • Upsizing (one size) • Eliminates minor sags • Eliminates future root problems • Short disruption to homeowners (up to 1 day). • No chemicals used	• Pits required • Access to private property required • Difficult in hard clays, high groundwater table • Difficult in pipes with past metal-clamp repairs • Not for pipes with many sharp bends • Risk of damaging objects when bursting at shallow depths	• Not very deep laterals • Length to replace at least 20 feet • Badly damaged pipe, few bends • Roots are persistent problem

6.0 MANHOLE RENEWAL TECHNOLOGIES

6.1 Special Considerations for Manholes

Manholes are an integral part of wastewater collection systems. They are typically spaced approximately 300 feet (91 meter) apart, but can be less than 100 feet (30 meter) or as far as 500 feet (152 meter) apart. Using these values, the number of manhole structures in the U.S. is roughly estimated at over 12 million. Other estimates have put the number at over 20 million (Hughes, 2000). Manholes became a regular component of sewer systems only at the beginning of the 20th century. Thornhill (2006) refers to a 1914 paper describing opposition to the use of manholes based on odor releases from the sewer system. However, the use of manholes was adopted as a general practice in sewer construction, and the presence of manholes greatly facilitates the inspection, cleaning, maintenance, and rehabilitation of the sewer system.

Manholes are a significant contributor to I/I, but the cost of their rehabilitation is relatively low compared to rehabilitation of the remainder of the sewerage system. Since they extend to the surface, manholes are not protected by several feet of earth, as are sewer mainlines. Hence, they are more severely exposed to traffic loadings and to surface climatic and environmental impacts (e.g., frost action). Older manholes are typically brick or concrete structures and may suffer from a variety of deterioration mechanisms:

- Hydrogen sulfide release may attack concrete manholes and the mortar in brick manholes. Turbulence in manholes can contribute to additional hydrogen sulfide release, corrosion of concrete structures, and corrosion of the mortar in brick manholes.
- Manholes may leak, allowing soil fines from the surrounding ground to enter the manholes, causing soil voids and surface settlement adjacent to the manholes.
- In cold climates, the upper portion of the manhole may be lifted by frost heave in the soil during winter, thus fracturing the manhole and providing an infiltration path into the manhole.
- Newer plastic manhole materials avoid some of the corrosion issues, but some have been inadequately designed against excessive deflections due to ground loadings.
- Corrosion of ladder access or cast-in-place rungs can be an important safety issue in manholes. Some utilities remove such fixtures during rehabilitation work.

6.1.1 Layout, Materials, and Records. Despite the discrete nature of manholes and the surface access they give to the sewer system, records of the locations and layouts of manholes are not always correct or complete; as a result, finding manholes in the field can be difficult if they have been paved over, hidden in vegetation, or buried beneath soil cover. Unrecorded or hidden manholes can be found using CCTV inspection of the sewer mainlines or (for shallow covered manholes) by the thermal differences between the surface above the manhole and the surrounding ground. For example, a light snowfall can reveal circular patches of melted snow above manhole covers. Reconciling poor sewerage system records with actual physical locations in the field has been significantly eased in the past few years by the availability of survey-grade Global Positioning System (GPS) units and software specifically designed to capture field GPS data and convert them to documented GIS databases (e.g., Guardian Prostar). With manhole locations and the attached sewer lines and flow directions reconciled, the remainder of the recordkeeping should provide information on the manhole geometry, materials used, maintenance and rehabilitation history, and condition assessment data.

6.1.2 Manhole Renewal Decision-Making. Many agencies rehabilitate manholes as they rehabilitate the mainline sewers in an area (unless urgent action is needed on manholes located in other areas). Effective techniques exist for manhole rehabilitation, and full manhole replacement is an option if the structure is too badly deteriorated for rehabilitation.

6.2 Inspection and Condition Assessment

6.2.1 Inspection Technologies. Inspection of manholes is generally a straightforward process involving person entry into the manhole. However, confined-space entry procedures and personnel training must be followed; thus, costs for manhole inspections are much more than for inspection of a similar-sized structure aboveground. The same or similar camera setup used in the zoom-camera inspection of sewer mainlines can be used to inspect manholes from the surface, thus avoiding the need for confined-space entry. Further information on inspection technologies for sewer systems can be found in the report for a companion study (EPA, 2009b).

6.2.2 Condition Assessment and Recordkeeping. Further guidance on these topics can be found in the recent National Association of Sewer Service Companies (NASSCO) Performance Specification Guideline for the Renovation of Manholes Structures (Muenchmeyer, 2007); the earlier Manhole Inspection and Rehabilitation Manual #92 (ASCE, 1997); and various papers and articles in the water environment and civil engineering journals (e.g., Wade, 1991).

Condition assessment records of manhole defects suffer from the same problems as for mainline and lateral sewer pipes – inconsistency in coding defects and the difficulty of comparing the severity of conditions, even within a single agency. To help reduce such problems, NASSCO has developed the Manhole Assessment and Certification Program (MACP) as a companion to its standardized coding and certification training program for mainline and lateral sewers (e.g., PACP). The program was introduced in 2006. The manhole program drops some PACP codes that do not apply to manholes and adds others related to particular features (e.g., manhole rings) and typical defects in manholes. The reference location for defects is given as the depth below the top of the manhole frame, together with an o'clock position for the defect's lateral position. The outgoing sewer line position is taken to be the 6 o'clock position (Thornhill, 2006).

6.2.3 Quantification of I/I from Manholes. Inflow into a manhole generally occurs through holes or defects in the cover, frame, or frame seal, or from other defects in the upper portion of a manhole that are exposed to surface water ponding above. Defects contributing to inflow include:

- Open vent or pick holes in manhole covers
- Poorly fitting covers
- Covers that are cracked, broken, or missing
- Frames that are cracked, worn, offset, or deteriorated
- Missing gaskets
- Frost-related movements of upper manhole components.

There is no hard distinction as to whether leakage in a near-surface defect in a manhole is classified as inflow or infiltration. In general, the distinction is made on whether the response in terms of increased flow in the sewer is very rapid (inflow) or delayed as the rainwater percolates through the ground surrounding the structure (infiltration). Major sources of infiltration are cracked, loose, or missing mortar in brick manholes, joints between precast sections, and pipe-wall connections. Infiltration can also occur due to cracking or corrosion of the manhole structural materials or because the structural material itself is porous.

The structural evaluation of a manhole can be rated according to deformation, mortar loss, depth of corrosion, and quantity and size of visible cracks; however, structural defects do not always result in high I/I into the system if rainfall amounts or groundwater levels are low in the region.

6.3 Methods for I/I Removal and Renewal

6.3.1 Introduction. Based on the inspection and condition assessment process, together with broader system-wide planning directions, the purpose, extent, and methods for manhole maintenance and renewal can be evaluated. The purpose of the renewal work may be to:

- Reduce or eliminate I/I
- Address structural problems
- Reduce future corrosion
- Improve maintenance access.

The specific goals for an individual manhole or a series of manholes in a sub-basin will help to determine the rehabilitation methodology. The steps in choosing a rehabilitation method typically involve:

- Classifying the type of defects (e.g., structural defects, O&M defects, construction features)
- Based on the defined defects, classifying each manhole into the renovation technology or technologies to be considered (see descriptions of major technologies below)
- Selecting applicable solution(s) based on the problems identified and the cost-benefit ratios for each solution (to the extent that they can be determined)
- Considering whether techniques will be matched individually to different conditions or whether the set of techniques will be limited for simplicity.
- Consider whether equivalent techniques can be bid against each other in a performance specification.
- Evaluating the technical specifications and contractor capabilities for the selected technologies. This should include:
  - Compatibility of materials
  - Field constructability considerations
  - Contractor qualifications and experience (company, field supervisor, and applicator)
  - Evidence of field-proven success for the technology after a specified period of service under similar operational and climate conditions.

6.3.2 Repair Technologies. Within the level of effort that typically can be handled as a maintenance activity are simple I/I fixes that do not require street excavation or major rehabilitation work:

- Sealing holes in lids, replacing lids, or adding seals/pans to remove inflow
- Providing locking lids to prevent unauthorized removal
- Using patching and plugging compounds to stop minor leaks in the body of the manhole.

Other repair-type activities that may be handled as maintenance or as part of rehabilitation include:

- Sealing the chimney area of the manhole (typically containing multiple joints and rings) with purpose-made seals or sealants. Seals can be applied internally or externally to the manhole structure.

- Sealing joints in structurally sound precast manhole sections.
- Installing pre-cast bench and invert inserts.
- Replacing castings, adjustment rings, covers, and manhole steps.

The datasheets in Appendix A do not specifically include repair technologies.

6.3.3 Rehabilitation Technologies. The sections below provide a general description of the principal rehabilitation techniques for manholes and summarize attributes for each technology category. Appendix A provides datasheets with more detail on the techniques offered commercially. More information on the rehabilitation methods characteristics, and their selection, specification, and inspection can be found in Muenchmeyer (2007), ASCE (1997), and Hughes (2002).

For purposes of discussion, the technologies of the various rehabilitation approaches are divided into the following classes of techniques:

- Chemical grouting
- Flood grouting
- Spray- or spin-applied cementitious coatings and liners
- Spray-applied polymer coatings and liners
- Cured-in-place liners
- Cast-in-place liners
- Panel liners.

As indicated in Section 6.3.1 above, selection of the appropriate technologies is strongly dependent on the rehabilitation goals. The technology selection should also consider (Muenchmeyer, 2007):

- Accessibility
- Downtime available for rehabilitation process
- Existing and future conditions related to corrosion
- Existing structural deterioration
- Existing infiltration.

The classes of techniques listed above also vary in their dependence on bonding a liner to the existing manhole structure. When bonding is a critical issue, adequate preparation of the interior manhole surface prior to rehabilitation also becomes a critical issue (removal of deteriorated material and adequate cleaning to provide a clean, sound surface for bonding). Many field failures of coatings and adhered liners can be traced to inadequate surface preparation. Table 6-1 summarizes the importance of surface bonding according to the type of rehabilitation and the expectations for its performance. Many of the techniques listed above can be configured to be non-structural or structural and standalone or composite; hence, the classification below is not based on a specific rehabilitation technique.

Table 6-1. Surface Bonding Requirements by Rehabilitation Technique

Type of Rehabilitation	Performance Issue		
	Corrosion Protection	Hydrostatic Pressure	Structural Performance
Grouting	Not applicable	No surface bond required	Not applicable
Coatings and non-structural liners	Bond desired to eliminate annular space, but bonding requirements typically controlled by hydrostatic pressure resistance rather than by corrosion protection.	Most situations will provide some external hydrostatic pressure. The liner has minimal ring stiffness; hence, bond is critical to the performance of the liner.	Not applicable
Standalone structural liners	Bond desired to eliminate annular space, but structural bond not required.	No surface bond required	No surface bond required
Composite-action structural liners	Bond desired to eliminate annular space, but bonding requirements typically controlled by hydrostatic pressure or structural resistance rather than by corrosion protection.	Most situations will provide some external hydrostatic pressure. Bond or interlock is critical to the composite performance.	Bond or interlock is critical to the composite performance.

6.3.3.1 Chemical Grouting. Chemical grouting is generally used when the existing manhole is structurally sound, but has I/I problems. A variety of grout types are available; application is typically by drilling through or adjacent to joints or defects and/or in a pattern across the manhole wall. Typically, a spiral pattern is used for pattern drilling, and the grout is injected into the lowest holes first. Grout is injected until refusal or until a seal is formed. If large quantities of grout are pumped, it indicates that either there is a void outside of the manhole or that there is a connective passage that allows the grout to migrate from the manhole area. In the first case, the grout can fill the soil void to prevent future soil collapse and manhole deterioration. In the second case, the grout may migrate into undesirable locations (such as nearby sewer laterals) and cause plugging or surface heaving. It may be desirable or necessary to seal open cracks and joints from the interior of the manhole prior to injection grouting. A variety of products are available for this purpose, including the sealing of active flowing leaks (see Figure 6-1).

Figure 6-1. Grouting of Active Leaks (Courtesy Prime Resins)

ASTM F2414 provides a specification for chemical grouting of manholes and recommends inspection of grouted manholes at 12 months following grouting; any resealing necessary should be carried out at no cost to the owner. The most common grout types used for manhole grouting and sealing are:

- Acrylamide, acrylic and acrylate gels
- Hydrophilic polyurethane foam or gel
- Hydrophobic polyurethane foam or gel
- Oil-free, oakum-soaked polyurethane resin (for sealing joints and cracks).

Cementitious grouts and sodium silicate grouts may also be used, depending on the nature of the grouting program.

Grouting is not considered a structural solution, but is comparatively easy and inexpensive to apply. It can provide a successful reduction in I/I flowing into the system, as well as provide the opportunity to identify and fill external voids adjacent to the manhole. The length of time that grouting will provide acceptable performance in reducing I/I may depend on the type of grout used, the skill of the grouting team, and the site and groundwater conditions. Both successful and unsuccessful applications can be identified in case studies; this suggests that pilot projects with 12-month follow-ups can help to identify the expectations for local success.

6.3.3.2 Flood Grouting. Flood grouting is offered in the U.S. by Sanipor®. In this approach, as shown in Figure 6-2, one segment of a sewer system, including at least one manhole, is isolated (using mainline packers and lateral packers near building exit points). A sodium silicate-based solution is used for the grouting and is introduced as two separate components. First, the sewer segment is flooded with Solution A through the manhole; the solution is allowed to permeate through defects in the pipes and manhole into the surrounding ground. This solution is then quickly pumped out of the pipes and Solution B is used to re-fill the system. As Solution B comes into contact with Solution A in the ground outside the pipes, it forms a hard sodium silicate seal around the pipe network in the areas where the pipe network had defects. The principal advantage is the ability to seal laterals, mainline, and manholes from a single setup. Large voids or interconnected networks of voids within the ground may be uneconomical to seal using a grouting procedure. An exfiltration test is typically conducted in new or questionable areas before starting the flood grouting process. However, grouting is an effective way to seal small- to medium-sized voids; high grout use provides a useful indicator of void issues that may need further investigation.

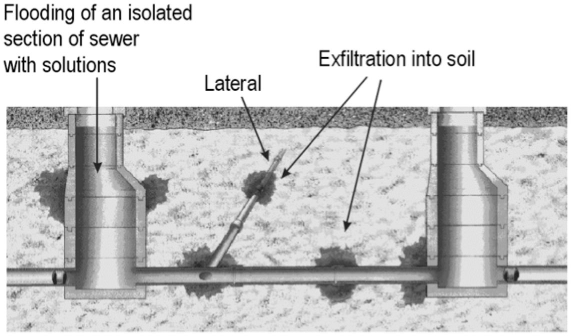

Figure 6-2. Flood Grouting Schematic (Courtesy Sanipor®)

6.3.3.3 Spray-On or Spin-Cast Cementitious Coatings and Liners. The types of cementitious materials typically used for manhole coatings and liners are:

- Standard Portland cement
- Calcium aluminates-based cement
- Polymer-modified Portland cement containing a dry, densified, microsilica powder admixture.

Standard Portland cement has relatively low resistance to corrosion in sewer applications, but may be used where the corrosion potential is low. Calcium aluminates and microsilica cements typically have a higher resistance to microbially-induced corrosion because they slow the growth of the acid-producing bacteria and can attain both a high structural strength and an early strength gain; this allows additional coatings to be applied much sooner than in the case of Portland cement.

Figure 6-3. Spin-Cast Application of a Fiber-Reinforced Cementitious Structural Liner (Courtesy AP/M Permacast)

Cementitious materials can be sprayed or spun-cast according to ASTM F-2551 (see Figure 6-3) or poured in place using forms (discussed in Section 6.3.3.7). These materials can provide either relatively thin coatings or thick structural liners. Their relatively low cost and rigidity when cured contribute to their suitability as a structural liner. They can also provide I/I reduction and a moderate level of corrosion protection, depending on the type of material used. For greater levels of corrosion protection, anti-bacterial additives may be incorporated into the liner mix to prevent the growth of acid-producing bacteria and thereby provide long-term protection. Cementitious materials may also be used to smooth irregular manhole surfaces and provide a base layer for application of the protective coatings needed for industrial-level corrosion conditions.

6.3.3.4 Spray-On or Spin-Cast Polymer Coatings and Liners. Epoxy, polyurethane, and polyurea coatings are the most common coatings. They provide a high resistance to corrosion attack when properly applied (see Figure 6-4). They can be applied as coatings to provide corrosion protection and I/I control; if applied in sufficient thickness, they can provide structural benefit or a full standalone liner. In coating or semi-structural thicknesses, the liners depend on the bond to the host structure. When using polymer coatings and liners, the following considerations are often important:

Figure 6-4. Rehabilitated Manhole Using a Spray-Applied Epoxy Liner (Courtesy RLS Solutions)

- Compatibility of coating/liner with host structure material and any chemicals or other preparation layers that are applied.
- Behavior of coating/liner in the presence of moisture – either surface dampness or moisture in cracks, even when the main surface is dry.
- Degree of curing for the host structure and/or previous layers at the time of application. Degree of curing may be important to obtaining adequate bond. Outgassing of the underlying material can cause pinholes in the new coating, with significant impacts on the corrosion coating’s/liner’s protection characteristics.

Epoxies can even be formulated to bond under damp conditions, but typically have slower set times than polyurethanes and polyureas. The strength, structural modulus, and creep properties of polymer coating can vary widely with the formulation used, but high-strength and high-modulus formulations are available. Proper safety procedures and applicator protection are important during application of polymer materials.

6.3.3.5 Cured-in-Place Manhole Liners (CIPM). CIP liners are typically designed to provide significant structural rehabilitation to a manhole in addition to I/I removal and corrosion protection. The basic process is similar to that used in CIPP systems except that the liner is not inverted into place (see Figure 6-5) and non-shrink VOC-free solids epoxies are used, which allow for strong adhesion of the lining system to the host substrate. A fabric liner “bag” is custom-designed according to the site conditions and the shape and dimensions of the individual manhole. The material is a composite of felt, fiberglass and PVC fabrics that is saturated with a two-part epoxy on site. There is some variation of materials layering between available products. Because the liner is not inverted into place, the epoxy is applied to the exterior of the bag to achieve saturation. Once fully saturated, the liner is lifted and lowered into the manhole and fixed in place at the manhole collar. The liner bag (and/or a separate inflation bladder) is inflated with uniform air pressure – pressing the liner against the manhole surfaces. Steam or hot water vapor is then circulated inside the liner until its cure cycle is complete and the liner is mechanically bonded to the substrate. The method of terminating the liner at the manhole invert and dealing with the flow line structures in the base of the manhole may vary according to the liner type or the specific application. The bottom termination of the liners is typically either at the bench-to-channel edge or in the case of invert-lining, at the flow line pipe connections and the adjacent invert. Once cured, any extra liner material used for installation purposes is removed, openings are cut to restore flow as necessary and the terminations of the liner are sealed as appropriate. The CIPM lining system provides significant standalone structural support to the manhole, but care should be taken to fill voids in the existing structure and to avoid reverse curvature or flat sections in the liner that could compromise its structural resistance.

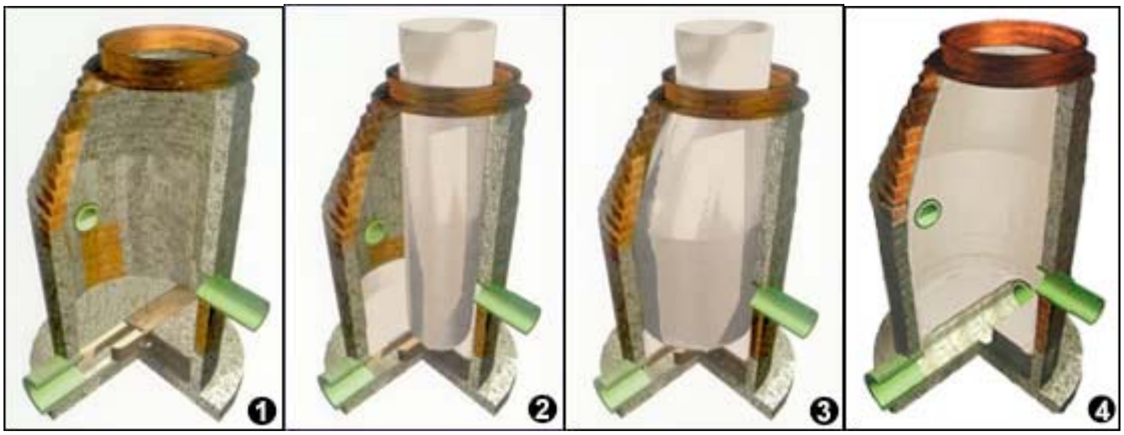

Figure 6-5. Sequence for Installation of a Cured-in-Place Manhole Liner (Courtesy Terre Hill)

6.3.3.6 Spiral-Wound Liners. Spiral-wound liners (e.g., Danby) can be used for manholes in a similar fashion as used for mainline sewer pipes. A PVC profiled strip is wound within the manhole, leaving an annular gap to be grouted. The PVC strips have T-shaped profiles that lock the PVC into the grout. The annular gap can be sized according to the lining design’s structural requirements. When grouted, the composite lining provides structural support, with the grout protected from corrosion by the internal PVC liner.

6.3.3.7 Cast-In-Place Liners. Cast-in-place liners typically use an internal “formwork” liner that allows insertion of a structural liner material. Corrosion protection can be provided by internal liner or by applying a polymer coating to the cast-in-place concrete. Typically, a 2 to 4 inches (50 to 100 mm) thickness of concrete is poured in the annular space, diminishing the manhole diameter by 4 to 8 inches (100 to 200 mm). The liner and formwork or the internal bracing must be capable of resisting the pressure of the wet concrete during installation. An internal thermoplastic layer should have fusion-welded joints to provide complete corrosion protection.

6.3.3.8 Panel Liners. Panel liners are typically thermoplastic materials and are generally used as non-structural liners for corrosion protection and I/I reduction. Panel liners usually have thermally welded seams and are glued to the manhole wall with a special adhesive. Typically, they lack the necessary ring stiffness to resist external water pressures or structural loads on their own and depend on the bonding for any structural support needed.

6.3.3.9 Geopolymer Materials. Geopolymer materials are being developed for sealing, corrosion protection, and structural applications in the wastewater industry and should find application for manhole rehabilitation. Geopolymers are created from power plant fly ash and can be polymerized when combined with an alkaline solution. They will polymerize at room temperatures, but the application of heat provides high early strength and better long-term properties. Geopolymers provide a high-strength, rigid material with high corrosion resistance as compared to Portland cement materials. The material can be poured or sprayed (using appropriate additives). Research is currently under way to determine the variability of properties according to fly ash source and to document the material properties in terms of different additives and curing conditions (Allouche and Steward, 2009). A major benefit of their use will be their extremely low environmental impact (i.e., low embodied energy and use of waste materials). Since, no commercial applications existed at the time this report was written, this technology is not represented in Table 6-2 or in Appendix A.

6.3.4 Summary of Rehabilitation Technologies for Manholes. Table 6-2 summarizes the rehabilitation technologies for manholes, along with their main advantages, limitations, and most suitable application conditions.

Table 6-2. Rehabilitation Technologies for Manholes

Advantages	Limitations	Most Suitable Conditions for Application
Chemical Grouting		
• No excavation required • I/I control • Can fill external voids • Repairs only where needed • Inexpensive	• No structural repair • Sometimes can't be completed (excessive grout quantities) • Chemicals used (safety requirements)	• Many leaking defects in structurally sound manholes • Groundwater table stable around the manhole throughout the year • Inexpensive and quick repair is desired
Flood Grouting		
• No excavation (cleanouts required on laterals) • Repairs both mainlines and laterals	• No structural repair • Access to private property required • Chemicals used (safety requirements)	• Many leaking defects in structurally sound manholes • Sealing complex and deep pipe and manhole systems • Cleanouts already exist on connected laterals
Sprayed or Spin-Cast Cementitious Coatings and Liners		
• No excavation required • Rigid structural materials • Corrosion resistance with applicable materials • Inexpensive materials • Easy application process	• Performance depends on surface preparation	• Low-moderate corrosion conditions • Some structural capabilities desired
Sprayed or Spin-Cast Polymer Coatings and Liners		
• No excavation required • High corrosion resistance with proper application • Easy application process	• Expensive materials • Performance depends on surface preparation	• High corrosion conditions • Suitable application conditions vary widely with type of polymer and application thickness
Cured-in-Place Manhole Liners		
• No excavation required • Structural repair possible • Long-term repair	• Termination/sealing of liner at base of manhole or connections • Chemicals used (safety requirements)	• Full structural repair needed • Deep manholes that are difficult to repair with some other methods
Cast-in-Place Liners		
• No excavation required	• Needs internal lining for	• Full structural repair needed

Table 6-2. Renewal Technologies for Manholes (Continued)

Advantages	Limitations	Most Suitable Conditions for Application
• Structural repair possible	corrosion protection • Loss of manhole diameter • Labor-intensive	• Heavily deteriorated manhole
Panel Liners		
• No excavation required • High quality control on liner quality	• More labor-intensive than sprayed or spin-cast applications • Depends on bond to existing structure	• High corrosion conditions

6.3.5 Replacement. Under some conditions, open-cut replacement of the entire manhole is the best option. Table 6-3 summarizes the main advantages and limitations associated with the dig-and-replace option.

Table 6-3. Open-Cut Replacement of Manholes

Advantages	Limitations	Most Suitable Conditions for Application
Open-Cut Repair		
• Permanent repair • Changes in size or configuration possible • Commonly used and well-understood	• Extensive surface disruption and disturbance of traffic or sewer easement area • Time-consuming • Often expensive	• Open area without obstacles or environmental restrictions • Shallow manholes • Heavily damaged manholes • Non-circular manholes requiring resistance to significant external groundwater pressure

7.0 RENEWAL TECHNOLOGIES FOR ANCILLARY STRUCTURES

7.1 Special Considerations for Ancillary Structures

The preceding sections discussed the rehabilitation of mainline sewers, sewer laterals, and manholes. While these components of the wastewater system comprise the vast majority of the system's physical components, there are ancillary structures with critical or important functions within the system. These cannot be treated for inspection, condition assessment, and renewal in the same manner used for the pipe network and standard manhole elements.

Force mains are a significant and important part of many systems. These are discussed separately in a companion report (EPA, 2010a).

The remaining ancillary structures in most systems include some or all of the following elements:

- Pump stations and lift stations
- Pump units, backup pump units, pump control systems
- Flow-monitoring stations
- Valve or diversion structures
- Overflow structures
- Drop structures.

These ancillary structures have quite diverse characteristics and include various components that need periodic inspection and renewal:

- Mechanical systems powered by electricity or fuel-driven generators
- Sensor and control systems for monitoring and controlling operations
- Physical structures with little in terms of standard elements and shapes, and frequent flat-wall, floor, and roof surfaces.

The following sections discuss special issues faced in terms of rehabilitating the physical structures. Issues relating to the inspection, maintenance, and renewal of pumps, mechanical systems, sensors, control systems, monitoring stations, etc., are beyond the scope of this report.

7.1.1 Pump Stations and Lift Stations. Pump stations are usually associated with force mains and are used to move the sewage flows against gravity for some distance. Lift stations are used where gravity sewage lines become too deep for economical installation, and it is necessary to lift the sewage so that a new section of gravity sewer line can be installed at a shallower depth. The changing economics of deep-sewer installation using microtunneling or directional drilling may eliminate some lift stations, either during construction of a new system or as a retrofit measure. This can have a significant impact on maintenance and rehabilitation needs of these ancillary structures and can be considered as a possible alternative to major retrofit or replacement of lift stations.

The issues concerning pump maintenance and replacement schedules are not addressed in detail in this report. It should be noted, however, that pump stations can "age" pipe through surge stresses. For the non-flow areas of pump and lift stations, normal structural rehabilitation issues will apply. The structures are often belowground and may suffer from some groundwater leakage and condensation during humid weather. Under damp and humid conditions, steel supports and frames may become corroded, and equipment may gradually deteriorate. Rehabilitation typically involves eliminating the groundwater leakage and providing new, easily maintained surfaces within the structure. Combinations of grouting, sealing, and coating of interior walls are the typical approaches for such rehabilitation. Section 7.3 describes typical available products. Since the shapes of the structures are often rectangular, it is not possible for liners to resist external groundwater pressure by arching action in curved sections; hence, most coating applications must be able to bond to the existing structure. Further complicating the ability to seal such structures fully are the internal supports for equipment that may be bolted to internal walls, penetrations for venting that pass through the walls, and any waterproofing or sealing layers. Providing a structure that is easy to maintain and keep dry is easiest during the initial design by:

- Keeping external and internal shapes as simple as possible for ease of construction and waterproofing
- Avoiding sharp, re-entrant corners wherever waterproofing or sealing layers are to be applied (e.g., using curved or angled fillet shapes that do not require waterproofing layers to conform to a sharp 90° bend)
- Laying out internal supporting members so that they preferably slope slightly toward the wall of the structure. The same applies to the floor-to-wall junction. Both of these measures will help keep any leakage water adjacent to the wall and reduce corrosion and water staining in the structure's interior. Systems that provide a drainage space behind wall and floor surfaces also are available (e.g., Badger, 2009).
- Providing an internal drain at the floor-wall junction to confine leakage issues and allow easy collection and disposal of leakage. Proprietary drain systems designed for this purpose are commercially available (e.g., Basement Systems, 2009).
- Analyzing pump operations, maintenance, and emergency procedures so that the facility can operate effectively and avoid damage to adjacent pipe sections.

Wet well areas of lift and pump stations are subject to erosion and corrosion concerns, depending on the structural materials used and the level of hydrogen sulfide produced by turbulence in the wastewater flow.

7.1.2 Drop Shafts. Drop shafts are used in wastewater systems to connect a shallow storm sewer or sanitary sewer with a deeper sewer or interceptor tunnel system. Depending on the design of the drop shaft, the flow may be piped to the lower level within the shaft structure, or it may be allowed to drop freely within the shaft. Piping the flow allows for smooth directional transitions and minimizes turbulence, which can cause excessive hydrogen sulfide release and corrosion/erosion in sanitary systems. In some cases, spiral drop (vortex) structures are used to reduce velocities.

Rehabilitation issues for drop shafts will need to be determined on a case-by-case basis, depending on the depth of drop, the internal structures present, and the degree of deterioration.

7.1.3 Valve, Diversion, and Overflow Structures. Similar to pump and lift stations, these structures have few standard-shaped-elements and will extend in depth to the flow line of the sewer. This results in significant external groundwater pressures when the sewer line is deep and the groundwater level high. Flat floor, wall, and roof surfaces will typically be present, unless special prefabricated units are used. For overflow structures, the weir structure providing the overflow function typically will have both sides of the wall, plus the top of the wall, exposed to corrosion, so they will deteriorate more rapidly than the rest of the structure. Deteriorated flat surfaces that need rebuilding, sealing, or coating require that the repair or rehabilitation materials be bonded or anchored to the host structure (so as to resist external water pressures) or that a separate structure is used inside the sealing layer. Without internal support, poor bonding or anchoring will lead to separation of the sealing layer from the host structure over time, as well as failure of the rehabilitation system.

7.1.4 Layout, Materials, and Records. Because of the individual nature of each ancillary structure and mechanical system, it is important to have accurate records of each structure's layout, its precise location, and the mechanical equipment's operational characteristics. When cities are affected by major disasters, these ancillary facilities may need urgent attention and the usual maintenance and operation crews may not be available. There should be advance planning for providing backup power and the sequence in which pump stations should be brought back on line. GPS coordinates for each facility provide a readily transferable means of finding each facility, even when many surface landmarks are significantly changed.

Ancillary structures on large-diameter lines may present special rehabilitation challenges in terms of the ability to block the normal sewage flow into the structure and bypass it during rehabilitation. The eventual removal and replacement of equipment in ancillary structures also should be given proper consideration during facility design.

When assessing the condition of an ancillary structure, only the internal surface is visible, and the wall's actual, as-constructed thickness may be unknown. In a recent investigation of a major sewer line and various overflow or diversion structures, the internal surface of some sections of tunnel appeared highly corroded. However, coring the wall structure revealed that the depth of concrete affected by corrosion was not large, the compressive strength of the remaining concrete was much higher than anticipated, and the thickness of the wall as constructed was greater than indicated on the original plans. This combination of circumstances changed significant sections of the planned rehabilitation work from being a necessary structural repair to being a rehabilitation to mitigate against future corrosion. More complete as-built records and materials test data, plus an earlier use of coring to determine the actual condition of the host structure, would have made the renewal decision-making process much easier and more effective.

7.2 Monitoring, Inspection, and Condition Assessment

7.2.1 Monitoring Facilities. Monitoring equipment operation has become much simpler and more cost-effective in recent years with the development of low-cost sensors and wireless transmission of data from remote sites. Likewise, remote cameras can now be economically installed to provide visual observation of ancillary structures, equipment, and sites.

Sensors for environmental conditions, such as temperature, pH, and the presence of undesirable gases or fluids, are also more easily placed within or adjacent to ancillary structures than elsewhere in the pipe network.

The physical condition of ancillary structures will normally be inspected by person-access and should be done regularly. When the ancillary structures contain mechanical or monitoring equipment, access for equipment maintenance will typically be more frequent than for structural monitoring; thus, the physical inspection can be carried out with little additional cost.

7.2.2 Inspection Technologies. The widely differing layouts of most ancillary structures preclude much in the way of standardized inspection equipment setup and use. However, most ancillary structures provide for person access to at least a portion of the structure. Confined space-entry procedures must be followed when entering buried chambers and inspection activities should not prevent external personnel from rescuing the inspector in the case of collapse. Inspection technologies may include some or all of the following equipment and techniques to assess the physical condition of the structure:

- Visual inspection should be used for signs of deterioration, such as staining of interior surfaces and evidence of steel corrosion or concrete deterioration.
- Digital photography is a key inspection method. Photos should be marked to clearly identify the structure name and the portion of the structure being photographed. It is important to make sure that there is adequate lighting and to provide a means of scaling the photograph, when necessary. Date, time, and photographer information should also be recorded.
- Hammer tapping may be used to find delaminated sections of the structure. No specific measurements are recorded, but the suspect areas can be outlined and photographed.
- Rebound hammer measurements may be used to determine the structure's hardness/surface condition. A numerical value may be recorded for each measurement.
- Bond tests (e.g., ASTM D4541 and D7274) may be used to test the bond between a lining material and the host structure. Since this is a destructive test, patching of the test site may be needed.
- Ultrasonic pulse thickness testing of surface layers may be used (ASTM E797-05; Kundu, 2003). This equipment measures the time it takes the pulse to travel through the surface layer, be reflected at the interface with the backing material, and then return to the measurement unit (i.e., to travel twice the thickness of the layer). If the unit has been calibrated to samples of known thickness, then the thickness of the in situ layer can be determined. If the thickness of the layer is known to be constant, then variations in the measured travel time will reflect variations in the layer's material properties.
- If movement or tilting of the whole structure or portions of the structure is suspected, electronic tilt gauges may be affixed to precisely monitor such movements. Larger movements can be monitored using surveying techniques.
- Crack gauges can be installed to monitor the opening or shifting of cracks. In their simplest form, crack gauges can consist of reference plates installed on either side of the crack and a depth micrometer to measure the distance from one plate to the other.

7.2.3 Condition Assessment and Recordkeeping. To the authors' knowledge, there is no standard means of assessing the condition of a wastewater system's ancillary structures. However, the observable features that indicate deterioration of the structure and the need for remedial action have many elements in common with the rest of the sewer system and other conventional forms of building structure. Elements that could be included in a condition assessment are:

- Evidence of structural distortion
- Tilting
- Cracking and crack movement
- Out-of-plane distortions (bowing)
- Ovaling
- Corrosion of the external structure itself
- Surface deterioration and discoloration
- Softening of the surface
- Delamination of surface layers
- Spalling
- Corrosion of internal frames and structures
- Loss of protective coatings
- Loss of structural material
- Pitting

- Deterioration of coatings and linings
- Loss of bond strength
- Delamination
- Evidence of pinholes or holidays in the coating
- Evidence of corrosion beneath the coating.

Depending on the type of structure and type of defect, different severity ratings could be applied to each observed defect. Aggregated condition assessment scores could be developed by appropriately weighting the scores for each defect, the numbers of each type of defect, and the impact factor for each type of defect on the overall structural condition and urgency of repair or rehabilitation.

As is true for asset management in the rest of the network, regular inspection and formal and detailed recording of inspection results will result in an understanding of the ancillary structures' rate of deterioration and may indicate some causal factors for the deterioration that can be eliminated or avoided in future construction.

7.3 Methods for Renewal

7.3.1 Repair. Repair of ancillary structures and equipment can take many forms. Repair of the physical structures that house ancillary elements of wastewater collection systems typically will involve the localized repair of a portion of the structure or the sealing of individual leaks into the structure. In most cases, the repair can be accomplished using person entry into the area where the repair is required. External excavation to carry out a structural repair is possible, but likely to be avoided due to the depth of most ancillary structures for sewer systems.

Patching and leak-plugging compounds are available that have high bond strength and can bond to wet surfaces. If active leaks are present, special leak-sealing compounds can be used in high-flow situations. Through-wall grouting can also be used to effect repairs as discussed in Section 7.3.2.

7.3.2 Rehabilitation. Rehabilitation of ancillary structures typically will involve one or a combination of the following three approaches: coatings and adhered linings, cast-in-place repairs, and grouting for leak control. The general approaches for each method are described below. Table 7-1 provides a summary table. Appendix A provides datasheets for applicable products.

7.3.2.1 Coatings and Lining Materials. Coatings and linings are applied from within the structure to protect the structure from further internal corrosion, to provide an interior seal against leaks, and to restore a clean and maintainable internal surface. Coatings may be troweled on or sprayed on, and may be cementitious or polymeric. The same types of materials and application procedures may be used as described in Section 6 on manhole rehabilitation. Figure 7-1 shows an example of a rehabilitated lift station. The principal difference is the presence of large, flat surfaces within ancillary structures. These may preclude designing the coating or lining to resist external water pressure though an arching action of the liner, which is possible in a curved structure. This means that the coating or lining must adhere sufficiently to the host structure to resist the external pressures that will build up behind the lining or coating over time. Most buried ancillary structures are made of concrete, which is porous to a greater or lesser degree. Hence, even though an

Figure 7-1. Spray Epoxy Rehabilitation of a Lift Station (Courtesy RLS Solutions)

internal concrete surface may be dry to the touch, this is only because the rate of evaporation at the surface of the concrete is greater than the transmission of moisture through the concrete. When the surface of the concrete is sealed by the coating or lining, the evaporation is stopped and the moisture gradually builds up in the concrete behind the lining.

Under this situation, the cleaning and preparation of surfaces to be coated or lined is critical to the success of any coating or lining material. It is important to request test results from the coating manufacturer that demonstrate the coating's ability to be applied without pinholes or "holidays." Such problems would compromise the coating corrosion protection. Testing results obtained from the manufacturer should also quantify the bond strength that can be obtained under surface and application conditions approximating those to be met in the field application. Test protocols for these purposes have been developed by the University of Houston (CIGMAT, 2009) for the City of Houston. Several coatings manufacturers have already had their products tested. The EPA's Environmental Technology Verification (ETV) program also provides a variety of test protocols for technologies and materials used in relation to environmental protection and rehabilitation (EPA, 2009c).

The detailed datasheets in Appendix A include several products that can either be spray-applied or troweled onto the surface.

7.3.2.2 Cast-In-Place. Cast-in-place rehabilitation provides a means of creating a new structural layer within the existing host structure. This may be done using conventional formwork and poured concrete; use of preformed panels that are grouted into place; and use of a sprayed-on structural concrete layer that may or may not include reinforcing fibers or a prefixed reinforcing mesh. A significant benefit of this approach is the additional structural component provided and the opportunity to apply a waterproofing layer to the host structure that will be supported by the new structural layer. This removes the need for a secure bond between the waterproofing layer and the host concrete. The principal drawbacks to this approach are that there is often insufficient room in the existing structure to allow the loss of working space resulting from the new structural layer. Also, the structural treatment will be relatively costly compared to a coating-only solution. As for the coating and lining solutions, internal structural elements and equipment supports considerably complicate the installation and integrity of the waterproofing and structural layer.

The detailed datasheets in Appendix A provide information on several products that can either be spray-applied or troweled onto the surface.

7.3.2.3 Grouting. The principles of grouting for sealing mainline pipes, laterals, and manholes were explained in Sections 4, 5, and 6. Appendix A provides datasheets for grouting materials and technologies.

Ancillary structures typically allow person access to the inside of the structure to conduct grouting operations. Within building-type structures, the test-and-seal approach used in pipes is not feasible. Instead, the grouting operation proceeds by drilling a series of holes through the wall of the structure and through cracks, joints, and other leakage areas. Use of the correct pressures and setting times for the grout, and the correct sequence for sealing cracks and joints, creates a barrier to water ingress external to the structure in areas of previous water leakage. A variety of materials are available for use in the grouting process; the most commonly used are cementitious grouts, acrylamides, or urethanes.

7.3.3 Summary of Rehabilitation Technologies for Ancillary Structures. Table 7-1 summarizes the rehabilitation technologies for ancillary structures, along with their main advantages, limitations, and most suitable application conditions.

Table 7-1. Rehabilitation Technologies for Ancillary Structures

Advantages	Limitations	Most Suitable Conditions for Application
Chemical Grouting		
• No excavation required • I/I control • Can fill external voids • Repairs only where needed • Inexpensive	• No structural repair • Sometimes can't be completed (excessive grout quantities)	• Many leaking defects in structurally sound manholes • Groundwater table stable around the manhole throughout the year • Inexpensive and quick repair is desired
Sprayed Cementitious Coatings and Liners		
• No excavation required • Rigid structural materials • Corrosion resistance with applicable materials • Inexpensive materials • Easy application process	• Performance depends on surface preparation • Flat surfaces remove arching action within liner	• Low-moderate corrosion conditions • Some structural capabilities desired
Sprayed Polymer Coatings and Liners		
• No excavation required • High corrosion resistance with proper application • Easy application process	• Expensive materials • Performance depends on surface preparation • Flat surfaces remove arching action within liner	• High corrosion conditions • Suitable application conditions vary widely with type of polymer and application thickness
Cast-in-Place Liners		
• No excavation required • Structural repair possible • Can support a waterproofing layer applied to the structure	• Needs internal lining for corrosion protection • Loss of interior space • Labor-intensive	• Full structural repair needed • Heavily deteriorated structure
Panel Liners		
• No excavation required • High quality control on liner quality	• More labor-intensive than sprayed applications • Depends on bond to existing structure	• High corrosion conditions

7.3.4 Replacement. Full replacement of ancillary structures almost always involves open-cut replacement and an excavation significantly larger than the size of the existing structure in order to remove the existing structure, and either emplace or cast-in-place a new structure. In densely built-up metropolitan regions, the social and indirect costs of fully replacing of a large ancillary structure are likely to be significant relative to the work's direct costs.

8.0 ADDITIONAL TECHNOLOGY CONSIDERATIONS

8.1 Construction Cost

Although cost data were sought from manufacturers and suppliers during the data collection process for preparing the technology datasheets (Appendix A), very little cost data could be collected. However, Figure 8-1 illustrates representative cost data from a collection of bid tenders from across the U.S. on various trenchless installation methods (Simicevic and Sterling, 2003).

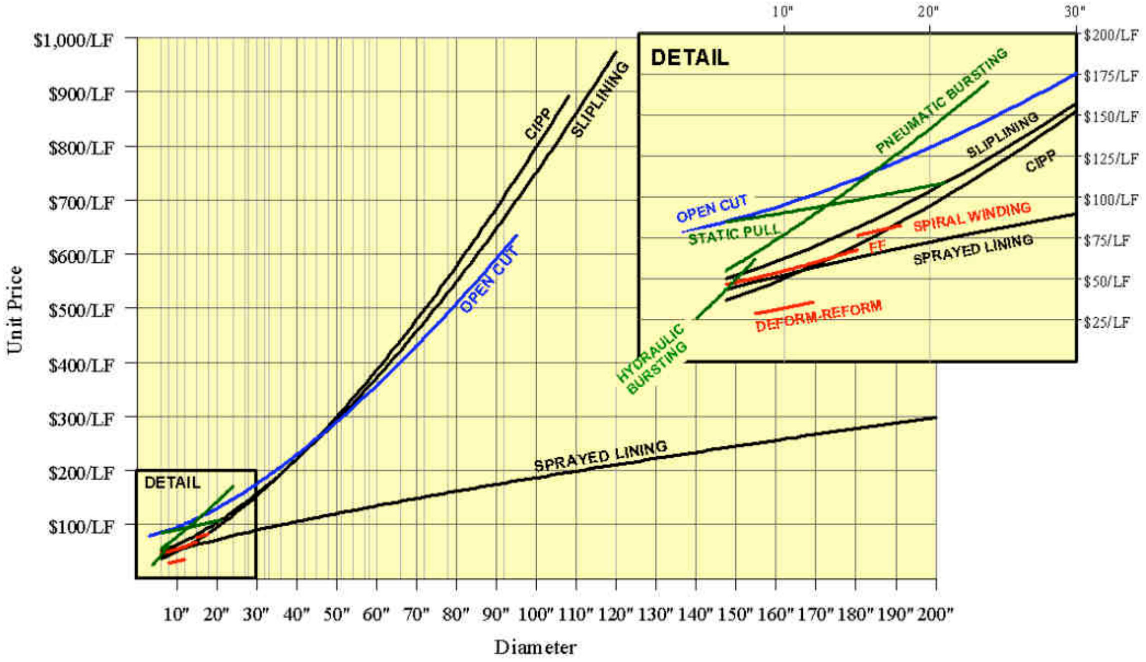

Figure 8-1. Total Installation Cost (in 2003 $) for Trenchless Rehabilitation Methods (Simicevic and Sterling, 2003)

Initial construction cost remains a very important parameter for municipalities, but it is a difficult issue to address in the absence of prior experience with the anticipated rehabilitation technologies in the local region. Costs can vary significantly in different regions of the country, with different site and access conditions, the level of work already under way by the key contractors, and the bidding competition expected within particular technologies or across different technologies that are permitted to bid. Specification and bidding arrangements that allow technologies to compete on a level playing field in terms of overall performance provide the greatest chance of receiving best value.

8.2 Life-Cycle Costs

Most external procurement processes for work within a sewerage system require a public bid with a critical factor being the initial cost to carry out the construction or to complete a rehabilitation process according to the specifications. While the entire operation of a system may be contracted to a private entity based on inclusion of all capital costs, O&M costs, and repair and replacement costs, this is not practical for the pipeline elements of a sewerage system. Once a private entity has taken on the operation of a full system, they have similar difficulties in assessing the relative value of initial cost for a particular technology and its full life-cycle cost.

Civil construction works have used various means of involving the contractor or technology provider in ensuring efficiency of the technology over its planned life cycle. Few of these are appropriate for the pipeline network of a sewerage system.

Some principal examples are:

- **Design-Bid-Build (DBB).** This is the traditional means of procurement for public works. Life-cycle cost issues must be addressed through the specification process in terms of selecting products proven (to the extent possible) to survive to their design life and have a low life-cycle cost.
- **Design-Build (DB).** This procurement method teams the designer with the contractor to complete the design process from an initial scope of work or preliminary design to construction. While the contractor adds valuable know-how to the design process, the long-term data may still not be available to either party to make the correct long-term decisions. The bidding process for the design-build does not extend past acceptance of the completed work and its survival for a warranty period.
- **Design-Build-Operate (DBO).** In this arrangement, the contracted team designs, builds, and operates the facility for a set number of years. For example, the contractor may be allowed to collect a revenue stream from facility operations as in toll road construction. This has the advantage of making the design and construction team responsible for effective facility operations; however, it is difficult to see how such a scheme could be applied to portions of a sewerage network unless the portions have very defined functions and operating characteristics.
- **Design-Build-Operate-Transfer (DBOT).** The added element to this procurement is the requirement that the facility be transferred to the contracting party at the end of the operation period. In this case, the acceptable condition of the facility when transferred back may be difficult to define. Again, this scheme would be difficult to apply to work within a sewerage system.

If the procurement mechanisms for involving the technology provider in the long-term success of the technology are difficult to apply within a sewerage network, what possibilities are available to address life cycle cost issues? Some examples of approaches are given below:

- **Product Acceptance Procedures.** Many municipalities use these procedures to provide a formal acceptance process for new products or technologies before they may be used within the sewerage system. Typically, they include submission of ASTM test results and other qualification testing, verification of the appropriate design procedures to be used, references to previous applications, etc. Long-term performance data in the form of accelerated test results for liner buckling or chemical resistance should be required, but obviously do not guarantee that the product will survive in service for its full design life cycle.
- **Warranty Periods.** Warranty periods are easy to add to specifications, but are often difficult to enforce in practice, and long warranty periods are very problematic for contractors in finding bonding companies willing to take such a long-term performance risk. From discussions with municipalities and contractors, warranties of 1 to 2 years do not present special problems, but warranties of 3 years or more may significantly restrict the companies that can bid on the work. Other issues with warranties are the need to prove that the loss of

performance was caused by the product or its installation, not some other aspect of system performance or maintenance, and the fact that the company providing the warranty may no longer exist when a problem develops.

- **Delayed Acceptance of Work.** In some types of work, defects may not show up immediately after construction, but evidence of problems may appear fairly early in the facility's life. For example, improperly installed flexible pipe may appear perfect in visual inspections following construction, but may deform significantly over its first few months of service due to uneven backfilling conditions. If little deformation is seen in the early months of operation, the facility can be expected to have a long service life. To address this problem, some procurement specifications for flexible pipe have proposed ovality measurements at, say, 1 year after construction. If the construction would not meet the maximum ovality allowed, then the construction would be replaced at the contractor's (or supplier's) expense. The downside of such a provision is that a significant portion of the contractor's reimbursement may be tied up for 12 months pending final acceptance. This increases the cost of carrying out the work and increases difficulty in bonding the work. Similar provisions have been applied in backfilling utility trench work, with the acceptability of backfilling and repaving determined several months after the initial work.

The component costs that affect a facility's full life-cycle cost are well understood in general terms. The difficulties lie in determining the detailed costs and in properly differentiating cost elements among various competing technologies or approaches. The typical life-cycle cost elements are:

- Planning and design costs
- Procurement and construction inspection costs
- Initial construction costs
- Social and indirect costs during construction
- Inspection, maintenance, and operation costs over the facility's service life
- Renewal costs (repair, rehabilitation, and replacement)
- Social and indirect costs from maintenance, operations, repair, rehabilitation, and replacement
- Disposal costs (if appropriate).

Not all of these costs are necessarily paid by the utility operator (e.g., social and indirect costs and disposal costs), and most of the future expenses are very difficult to estimate at the time of construction. In particular, there is a tendency in the life-cycle cost analysis of various construction options to undercount future construction costs that are affected by increases in urban congestion over the expected design life. A readily understood example would be the assessment of pavement thickness for highway construction in an urban area. If the equivalent construction cost at a future date (adjusted for inflation) was used in the cost model, it would result in significant errors favoring a cheaper initial installation. In practice, in the reconstruction of urban highways, the costs of managing the maintenance of increased traffic flows on the highway and the piecemeal approach necessary for such reconstruction greatly increases the costs over a simple inflation allowance from the initial construction.

8.3 Long-Term Performance and Testing

The lack of long-term performance data for rehabilitation technologies is frequently raised as a difficulty in the decision-making process. This applies both to choices between a trenchless technique and an open-cut replacement and to choices among rehabilitation technologies. When a new rehabilitation technology is introduced (or an existing technology substantially altered), there is no direct field experience to establish its longevity. Expectations of longevity are inferred from experience with similar types of installations, from an understanding of structural and material performance parameters, and from accelerated testing on the materials and systems used.

Accelerated testing for liners in the U.S. is currently limited to creep properties of polymers, 10,000-hour buckling tests on sample liners, and accelerated chemical resistance testing (e.g., ASTM D543 and Los Angeles Green Book testing). Accelerated erosion and wear test protocols (e.g., ASTM D4060) are available, and German testing protocols for abrasion also have been used (e.g., the Darmstadt rocker test method).

The difficulties associated with accelerated testing of rehabilitation technologies include:

- Tests to establish long-term material properties (e.g., tensile, compressive, bending strength, long-term creep, etc.) are carried out on samples of the material. With in-situ-created liners, it is very difficult to be sure that the samples prepared for laboratory testing are representative of the installed liner.
- Accelerated laboratory tests are usually carried out under well-defined loading or environmental conditions. It is possible that the behavior of the liner under field conditions is substantially different from behavior in simplified laboratory tests.
- Long-term testing of liner assemblies under more realistic loading scenarios is expensive to carry out and should be used in conjunction with material property tests to better define expectations for long-term behavior.
- If a manufacturer is required to complete 10,000-hour testing before a product can be used in practice, this significantly adds to the cost and time needed to bring a new product to market. Many new technologies developed by small companies do not have the capital backing to survive the initial development, testing, and marketing phases.
- Data from long-term testing (10,000 hours = 1.14 years) can suffer from unanticipated variations in loading or data collection due to equipment malfunction, power failures, and other emergencies.
- When the manufacturer changes the material specifications or the installation protocol, it is necessary to determine to what extent new long-term testing should be initiated. The cost of new long-term testing may deter the manufacturer from making incremental improvements to the technology.

One of the goals of the TO 58 project is to identify appropriate accelerated testing protocols that would help system owners predict the longevity and long-term performance of the products and technologies used, without unnecessarily increasing barriers to the introduction of new technologies.

8.4 Other Design Considerations

8.4.1 Capacity. The capacity available in portions of the sewerage network, in individual lines or in treatment plant capacity, may affect the options considered for pipeline renewal. For instance, the direct cost-effectiveness of rehabilitation to reduce I/I within a system can look very different, depending on whether the system has excess treatment capacity or whether it exceeds its capacity during rainfall events. In the first case, the cost of rehabilitation and I/I reduction may be compared only with the unit cost of treating additional flows within the treatment plant. In the second case, the cost of rehabilitation may be offset against the eliminated need for a new treatment plant. A political influence related to capacity may be the opportunity to add new communities to the existing sewerage system if I/I is reduced in the existing system.

In terms of technology decisions for individual segments of the network, the need to upsize capacity while renewing the element may eliminate relining options. This leaves upsizing using pipe bursting or open-cut replacement as the principal options available.

Capacity and flow conditions can also affect work costs significantly when a bypass is needed to carry out the work. This is especially true in large-diameter sewers. Techniques such as sliplining and other forms of lining that do not require removal of flows become more attractive under these conditions. In addition, the loss of cross section from thicker lining elements can be offset more easily by improved flow conditions in larger-diameter pipes.

8.4.2 Maintenance. Potential maintenance issues with renewal technologies also need to be considered when selecting technologies. Some can be anticipated based on the nature of the product, but many may only become evident after experience with a particular technology. In these cases, effective feedback is important between the maintenance and operations groups and the engineers specifying future renewal work. Once identified and treated as a significant issue by the user community, maintenance issues with products can often be addressed by changes in the product itself.

For example, most full-segment length structural liner materials provide a liner that can withstand normal and maintenance operations within the lined pipe. However, individual repairs, lateral connection liners, short liner sections, etc., all may provide edges within the host pipe that can be caught by mechanical cleaning devices or affected by high-pressure water-jetting. In many cases, the edges of the liner sections are feathered to provide a smooth transition to the host pipe, but these sections may be vulnerable to aggressive maintenance activities. The maintenance crews need to adopt procedures that will not damage these elements and provide feedback if adequate cleaning is not possible without damage.

8.4.3 By-Pass Pumping. By-pass pumping is costly to set up, especially for large flow volumes, and in most cases, must have sufficient redundancy and capacity to handle major storm events and equipment malfunction during the renewal work. Renewal technologies differ in their need for the line or structure to be taken out of service while the repair, rehabilitation, or replacement is carried out. Different components of the sewerage system also differ in their capacity to have flows simply blocked for a sufficient length of time to complete the renewal work.

The impact of using a method that can avoid by-pass pumping can be reflected in the bid cost if the specifications allow both approaches to compete on an equivalent performance level. In residential areas, contractors can be creative in working with residents to reduce or eliminate sewage flows during the critical stages of a project and thus avoid the costs of bypassing. In larger or more critical situations, the utility typically wants more control over the bypass system’s design and operation.

8.4.4 Criticality and Redundancy. The criticality of a particular element of a sewerage network may affect both the choice of technology and the contractor. It will also affect the care the municipality takes to prepare for the renewal work, provide for close inspection, and provide for backup plans, if problems develop during the work.

Segments may be considered critical for a variety of reasons, including:

- Sewage flows are large and unable to be bypassed, and there is no system redundancy that allows flows to be diverted. In such cases, a premium will be placed on renewal technologies that are proven for such applications; will be as long-lived as is practical given the difficulty and cost of the work; and can be sequentially completed during low-flow periods.

- Breaks, failures, or overflows would affect critical environmental resources or critical facilities. Again, in such cases, the emphasis will be on well-proven technologies, rather than novel or emerging technologies, unless the project circumstances preclude the use of such technologies.

8.4.5 **Accessibility.** The contractor's accessibility to the pipe sections to be renewed can significantly impact the cost of the work, the relative desirability of different technologies, and the social and indirect costs associated with the work. It is not possible to outline all potential impacts in this report, but some examples are:

- The frequency and severity of bends in a pipeline between natural access points will affect the choice of technologies that are feasible to carry out the work. The impact of bends on each rehabilitation technology is identified in the technology datasheets. In general, the choice may be between restricting the technology choice to those that accommodate the bends present, or to create new access points at the bend locations that allow a wider range of technologies to compete.
- The road space available to the contractor at each access point, as well as to other nearby staging areas provided, will affect the ease with which the contractor can carry out the work. In the United Kingdom, lane rental concepts have been implemented on a trial basis, whereby the contractor includes in the bid a cost for the number of road lanes occupied and the length of time for which they are occupied. This provides an advantage in the bidding to the contractors who can be the most efficient in terms of their road occupancy. It also benefits the public in terms of reduced traffic impacts. An alternative approach is to provide penalties for street occupancy by the contractor beyond the period specified in the contract (Downey, 2009).
- If the pipeline segments are at or near the limits of a preferred technology, the length of pipeline segments between significant access points will impact both the technologies considered, as well as the contractors who have the experience and capacity to handle technically challenging projects. An analysis should be carried out to determine whether additional access points can be created to reduce the technical risk and to allow a wider range of technologies/contractors to compete on the project.

Permitted hours of operation for the work will affect the contractor's planning for the work execution and cost. Most work on sewer lines is carried out on a segment-by-segment basis (e.g., manhole-to-manhole or individual laterals or manholes). If the equipment and crew size remain the same and are charged to the job on a daily basis, the number of segments that can be completed in a day strongly impacts the work's unit cost. Most rehabilitation technologies have worked to reduce their required time on site and increase the number of segments that can be completed in a day. Examples include preheated water for CIPP curing and reuse of the heated water for additional segments, use of steam and UV curing for CIPP; and rapid-curing polymers for sprayed-liner applications.

9.0 DESIGN AND QA/QC REQUIREMENTS

This section discusses the main design principles for gravity flow sewer system components. This section is not intended to be a design manual or to reproduce the information in the available standards, but rather to indicate the design approaches being used for gravity sewer components and the existing standards and QA/QC requirements that can be readily adopted. Because even gravity flow piping may need to withstand internal pressures (surcharging), some of the standards relating to pressure pipe rehabilitation are also included in this section. It will be noted that not all of the issues in terms of design, QA/QC, and long-term performance of rehabilitation systems are well-covered in existing manuals and standards.

9.1 System Design

Section 8 discussed a variety of technology selection considerations that depend on overall system design and operational issues. Since this section is focused on the specific design of rehabilitation technologies, only those system design issues that have a specific bearing on design or QA/QC standards will be addressed.

9.1.1 Redundancy and Criticality. The redundancy available in a sewer system has two principal impacts on the rehabilitation design process. First, the ability to take a sewer line, manhole, or appurtenance out of service may affect the ability to properly inspect the structure prior to rehabilitation. This is not a significant issue for small- to moderate-diameter sewer mainlines that can be adequately inspected during low flow periods, but it can be a critical issue for force mains (EPA, 2009a) and for large-diameter sewers that have continuous high levels of flow. Second, the importance of a sewer system element in terms of any redundancy available to provide service and its criticality if it should fail to make a difference in the level of reliability sought in the rehabilitation design. For example, a neighborhood sewer mainline is highly unlikely to have a parallel sewer installed; however, a failure or blockage in the sewer line can be addressed with bypass pumping from manhole to manhole with readily available equipment and piping. On the other hand, a large-diameter sewer, also without redundancy, can only be bypassed with a long lead time, great expense, and a high degree of difficulty. Not only should the specifics of the design calculations be adjusted for the changes in geometry, depth, etc., but the expected reliability of the design and its conservatism also should be evaluated.

9.1.2 Performance Expectations. The intent of rehabilitation of a sewerage system is to restore its performance and to extend the system's life. The decision on what level of performance is the goal and what lifetime of service is expected from various system components is typically a system-wide decision. Examples of performance metrics are:

- Allowable I/I in new construction
- Allowable I/I in rehabilitation of existing systems
- Allowable frequency of surcharging/overflows.

The goals chosen within a system may affect the extent of rehabilitation attempted (e.g., including lower and upper laterals with mainline and manhole rehabilitation), the rehabilitation technologies selected, the detailed design of those technologies, the level of inspection, and the QA/QC applied to the work.

9.2 Renewal Design

This section will concentrate on the design issues involved in renewing sewer mainlines. Specific issues regarding special design considerations relative to sewer laterals, manholes, or appurtenances are summarized in Sections 9.4.5 to 9.4.7 and in the respective Sections 5, 6, and 7.

9.2.1 Inspection and Condition Assessment. The detailed design of renewal technologies is heavily dependent on an effective inspection and condition assessment program. For example, a tool to guide the development of such a program is described in a WERF report (WERF, 2000). The available inspection technologies and their use in developing condition assessment and asset management data for sewerage systems have been addressed in a recent EPA report (EPA, 2009b). This evaluation and discussion are not repeated in this report.

9.2.2 Failure Modes for Sewer Mainlines. In designing for an engineering work that will perform satisfactorily for its intended lifetime, it is necessary to consider a wide range of potential failure modes for that work and then to plan, design, specify, and execute the work so that failure is unlikely. Some failure modes (e.g., seismic events) may be regional in severity, and some that did not have a high priority decades ago receive more attention today (e.g., sewer overflows due to excessive I/I or the deliberate destruction of wastewater system components by terrorist activities). Table 9-1 provides a brief and generic summary of the types of failures that can and do occur during the construction or service life of rehabilitation in sewer mainlines. The design procedures, specifications, and QA/QC procedures have been developed to address most of these failure modes. Some failure modes are addressed directly by design (e.g., the long-term buckling performance of polymeric pipe liners in the Appendix to ASTM F1216). Other failure modes are addressed implicitly in some forms of rehabilitation, but may be an issue in other rehabilitation technologies (e.g., longitudinal shifting of the liner), while some are not really addressed at all by current practices. In many cases, inherent conservatism in the design procedures for the failure modes considered often protects against failure due to less well-defined issues. This provides a caveat to the tightening of designs to provide more economical rehabilitations. In such cases, it is important to make sure that reducing safety margins for one failure mode does not allow a previously non-critical failure mode to become important.

9.2.3 Degrees of Deterioration. The ASTM standards of practice for reconstruction products have categorized the condition of existing pipes into either partially deteriorated or fully deteriorated conditions. These conditions are defined as follows (adapted from ASTM F1216):

- **Partially Deteriorated** – Existing pipe can support the soil and surcharge loads throughout the rehabilitated pipe’s design life. The pipe may have longitudinal cracks and up to 10% distortion of the diameter.
- **Fully Deteriorated** – Existing pipe is not structurally sound and cannot support soil and live loads or is expected to reach this condition over the rehabilitated pipe’s design life. This condition is evident when sections of the pipe are missing, the pipe has lost its original shape, or the pipe has corroded.

9.2.4 Design Loads. Unlike water mains or force mains, most gravity sewer liners provide more than just a corrosion protection coating or liner seal to the inside of the main. This is because there is only rarely an internal pressure on the liner due to surcharged flows, but there is often a significant external pressure on the liner due to groundwater. This coupled with the inability to fully prepare and clean the internal surface of a non-person-entry sewer main, means that adhered coatings have a poor chance of success. Some of the loads that must be considered depend on the state of distress in the existing pipe, and include:

- External Loads
    - Soil cover (trench or embankment)
    - Surface surcharge loads
    - Surface live load from truck, rail, and aircraft loadings (HS-20, E-80, etc.)
    - Groundwater pressure (typical fluctuation of groundwater levels is also useful information).
- Internal Loads
    - Internal pressure due to the occasional surcharging of the gravity line during heavy rains.

Other factors that also enter into the design are corrosion, temperature, fatigue, and erosion/abrasion considerations.

Table 9-1. Potential Failure Modes for Rehabilitation Systems

Construction/Installation Failures	
Potential risks:	• Inability to install the system within the existing pipe (due to sharp offsets or lack of access) • Inability to obtain the anticipated fit within the existing pipe due to irregularities, sharp bends, and offsets in the existing pipe, which leads to an unacceptable loss of cross section • Excessive wrinkles or folds in the liner system • Failure to complete a grouting program • Lack of adequate quality control of field processes • Inability to put liner into service because of gross rehabilitation procedural or material defects.
Discussion:	Any lining system has field conditions for which it is not suitable, and these must be determined during the planning and design process. If the lining system is suitable for the actual field conditions, then installation-related failures typically come from inadequate QA/QC on the materials and construction processes.
Structural Failure	
Potential risks:	• Radial liner deflection to a degree that compromises the pipe’s function • Failure of the liner caused by exceeding permissible strains or stresses in the liner material • Failure of the liner through buckling caused by external water pressure acting between the host pipe and the liner.
Discussion:	The liner may be subject to a variety of stress conditions over its lifetime. The most common conditions are likely to be: • Local or general deformation of the host pipe that will transmit loads to the liner from the surrounding soil or live loads from the ground surface. This may result from changes in ground conditions or from continued deterioration of the host pipe. • Internal water pressure resulting from surcharge conditions in the lined pipe. • External water pressure within the annular space that acts on the liner (resulting from the defects in the host pipe and the presence of a temporary or permanent groundwater level above the host pipe).
Liner Material Degradation Over Time (Leading To One of the Other Failure Modes)	
Potential risks:	• Deterioration of the liner material in the presence of chemical or biological agents likely to be found in the service environment • Deterioration or erosion of the liner due to abrasion from flowing particles within the operating sewer • Physical damage to the liner from maintenance operations within the sewer (e.g., cleaning).

Table 9-1. Potential Failure Modes for Rehabilitation Systems (Continued)

Discussion:	It is important to determine if the liner material is adequate for the expected service life of the relined pipe. If the liner material were to deteriorate in the service environment of the sewer – either through chemical/biological action or through physical damage from abrasion/maintenance – then it could become too weak or too thin to withstand the stresses imposed on it (leading to collapse) or it could be punctured in local areas (leading to renewed infiltration or exfiltration).
Hydraulic Inadequacy	
Potential risks:	The flow characteristics of the lined pipe are not adequate for the pipe's service conditions. This depends on the smoothness of the lined pipe and the loss of cross section through the lining process.
Discussion:	It is inevitable that a liner installed within an existing host pipe (that is not in itself enlarged) will reduce the cross-sectional area of the pipe available for flow. Whether the flow capacity is actually decreased or, in fact, enhanced depends on the liner's thickness, the host pipe's diameter, and the change in roughness coefficient. This may or may not be important for a particular pipe, depending on the expected flows relative to its current capacity. Trenchless pipe replacement allows size-on-size or some degree of upsizing of the existing pipe, thereby eliminating this issue.
Failure To Adequately Address Infiltration (When This is an Objective of the Relining Project)	
Potential risks:	• Leakage through the liner material itself • Leakage through the joints in the liner material • Leakage into or out of the lined pipe at lateral connections • Leakage into or out of the sewer system at manholes or similar pipe terminations • Inadequate performance of grouting-type repairs.
Discussion:	Relining projects may have two or more complementary objectives, such as stabilizing structural deterioration of a sewer pipe or reducing infiltration into the sewer system. When infiltration reduction is a relining goal, it is necessary to understand the potential paths for water to enter the sewer system either through the liner or around the installed liner. Few in situ lining methods for sewers currently provide a liner with no annular space that is fully adhered to the inside of the host pipe. In the absence of this condition, it is possible for groundwater to enter the annular space through failures in the host pipe. This water can then migrate along the annular space and enter the sewer system at places where lateral reconnections are made or at the ends of the liner at manholes. The potential flow into the sewer will be controlled by the characteristics of the annular space.
Longitudinal Liner Movement	
Potential risks:	• Expansion or shrinkage of the liner causing movement with respect to the host pipe and misalignment of lateral connections • Sliding of the liner within the host pipe due to drag forces on the liner.
Discussion:	Lining systems may be installed by dragging a liner within the host pipe, by curing the liner at high temperatures, or by other procedures that may affect the longitudinal strain conditions within the liner. If these thermal or mechanical strains are not released or allowed to dissipate before the lateral reconnections are made, problems due to misalignment of the connections may occur. Likewise, if the lining is not well-fixed within the host pipe, it could become dislodged and moved longitudinally.

9.3 Product/Material Standards

National organizations within the U.S. that undertake development of consensus standards covering materials, products, testing methods and installation methodologies are:

- American Society for Testing and Materials (ASTM): Provides a forum for producers, users, and those having a general interest (e.g., government, academia) to write standards that best meet their needs. Representatives from each interested field are involved in the standards process, but the producer community normally takes a leading role.

- Water Environment Federation (WEF) (including their research arm – the Water Environment Research Foundation [WERF]): Provides guidelines and manuals related to sewerage system design.
- National Sanitation Foundation (NSF) International: Standards related to the evaluation of components and devices used in wastewater treatment systems.
- National Association of Sewer Service Companies (NASSCO): Has developed guideline specifications and manuals of practice based on input from producer companies.

The body of standards can be broken down into product/material standards, design standards, installation standards, or manuals of practice. Some of the standards serve more than one purpose. The purpose of this report is not to provide a detailed review of each pertinent standard, but rather to highlight some of the more important standards, and especially those that are relatively new within the past 5 years and that may have application to sewer main renewal.

9.3.1 ASTM Product/Material Standards. This section summarizes product/material standards by pipe type, including those defined for PVC, PE, CIPP, and FRP/GRP materials.

9.3.1.1 PVC Materials. The ASTM standards listed in Table 9-2 cover PVC materials used for renewal.

Table 9-2. ASTM Material Standards for PVC Pipe

Specification No.	Title	Application
ASTM F1504	Standard Specification for Folded Poly (Vinyl Chloride) (PVC) Pipe for Existing Sewer and Conduit Rehabilitation	4 to 15 inches folded PVC for non-pressure sewers
ASTM F1871	Standard Specification for Folded/Formed Poly (Vinyl Chloride) Pipe Type A for Existing Sewer and Conduit Rehabilitation	4 to 18 inches folded PVC for non-pressure sewers
ASTM D2241	Standard Specification for Poly (Vinyl Chloride) (PVC) Pressure-Rated Pipe (SDR Series)	Pressure-rated PVC pipe

ASTM F1504. This product standard is nearly identical to ASTM F1871, except that the minimum flexural modulus is 280,000 psi (19,310 bar) (PS-1, cell 13223-B). With the higher flexural modulus, pipe stiffness values are also higher for the same dimension ratio (DR). Pipe stiffness (a measure of the flexural stiffness of the pipe ring in resisting vertical load) ranges from 10 psi (0.7 bar) for DR 50 (PS-1) to 41 psi (2.8 bar) for DR 35 (PS-3). Diameters covered range from 4 to 15 inches (100 to 375 mm), with a starting DR range of 35 to 50. The final DR will depend on the amount of expansion (or contraction) induced in the PVC liner as it conforms to the host pipe. Typical QC test requirements include diameter and thickness dimensional checks, pipe flattening, impact resistance, pipe stiffness, flexural properties and acetone immersion, and heat reversion for extrusion quality.

ASTM F1871. Diameters covered range from 4 to 18 inches, with a DR range of 26 to 41. Pipe stiffness (which is dependent on the flexural modulus and DR ratio) ranges from a high of 41 psi (2.8 bar) for DR 26 to 11 psi for DR 41. The “A” in Type A is an arbitrary designation of PVC compounds with a minimum modulus of tension of 155,000 psi (10,690 bar) and a maximum of 280,000 psi (19,310 bar). The minimum tensile strength is 3,600 psi (248 bar) and flexural modulus is 145,000 psi (10,000 bar).

ASTM D2241. Covers PVC pipe made in standard thermoplastic pipe DRs and pressure-rated for water. PVC pipes meeting this specification would be suitable for inline replacement of an existing sewer force main by the sliplining method or for the design of sliplining pipes for gravity sewers that may be subject to surcharging (internal pressure).

9.3.1.2 ***Polyethylene Materials.*** The ASTM standards shown in Table 9-3 cover PE materials used for renewal.

Table 9-3. ASTM Material Standards for PE Pipes

Specification No.	Title	Application
ASTM F1533	Standard Specification for Deformed Polyethylene (PE) Liner	3 to 8 inches deformed PE liner for non-pressure
ASTM D2239	Standard Specification for Polyethylene (PE) Plastic Pipe (SIDR-PR) Based on Controlled Inside Diameter	Pressure-rated PE pipe based on ID
ASTM D3035	Standard Specification for Polyethylene (PE) Plastic Pipe (DR-PR) Based on Controlled Outside Diameter	Pressure-rated PE pipe based on OD

ASTM F1533. The renewal process involves installing a deformed PE liner into an existing pipeline and then reforming the liner with heat and pressure to fit tightly to the original pipeline's bore. PE pipe used for a liner under this specification shall be PE 2406 or PE 3408 (ASTM D3350), with a Plastic Pipe Institute (PPI)-recommended hydrostatic design basis (HDB) of 1,250 or 1,600 psi (86 or 110 bar), respectively. Nominal pipe diameters range from 3 to 18 inches (75 to 450 mm), with a DR range of 17 to 32.5. Other non-standard sizes are also covered, providing the materials meet the minimum requirements in this standard. Typical QC test requirements include outside-diameter and wall-thickness checks, tensile strength, tensile elongation, and flexural modulus. Environmental stress crack resistance (ESCR) is a qualification test, with level 3 of ASTM D3350 as a minimum.

ASTM D2239 or ASTM D3035. Pipe meeting these standards would be suitable for inline replacement of a sewer force main by the sliplining method, providing the reduction in flow capacity can be accommodated. The standard could also be used to confirm the ability of a gravity sewer line to resist surcharge pressures.

9.3.1.3 ***CIPP Materials.*** The ASTM standard in Table 9-4 covers CIPP materials used for renewal.

Table 9-4. ASTM Material Standard for CIPP

Specification No.	Title	Application
ASTM D5813	Standard Specification for Cured-In-Place Thermosetting Resin Sewer Pipe	4 to 132 inches CIPP used in gravity systems

ASTM D5813. This standard describes three classes and two grades of CIPP liners. The type of liners ranges from those designed to only provide chemical resistance and prevent exfiltration (Class I) to those designed for use in either a partially deteriorated (Class II) or a fully deteriorated pipe (Class III). The grades are distinguished by whether the tube is impregnated with polyester resin (Grade 1) or an epoxy resin (Grade 2). ASTM D5813 also has two chemical resistance requirements. One requirement stipulates that samples shall be capable of exposure for 1 year to six different chemical solutions (1% nitric acid, 5% sulfuric acid, 100% ASTM Fuel C, 100% vegetable oil, 0.1% detergent, and 0.1% soap) and still retain 80% of their flexural modulus. The other requirement is similar to the one imposed on glass-reinforced thermosetting plastic pipes (ASTM D3262 or ASTM D3754) and is commonly referred to as strain corrosion. For this requirement, samples must be capable of being deflected to meet certain strain requirements (see Table 2 of D 5813) over specific time periods of up to 10,000 hours, while exposed to 1.0 N sulfuric acid (i.e., 5%).

9.3.1.4 Glass-Reinforced Plastic. The ASTM standard in Table 9-5 covers FRP/GRP materials used for renewal. ASTM D3754 combines the pressure requirements of ASTM D3517 Fiberglass Pressure Pipe with the chemical resistance (strain corrosion) requirements of ASTM D3262 Fiberglass Sewer Pipe.

Table 9-5. ASTM Material Standard for FRP/GRP

Specification No.	Title	Application
ASTM D3754	Standard Specification for Fiberglass Sewer and Industrial Pressure Pipe	8 to144 inches GRP pressure pipe for force mains or surcharged pipes, pressures up to 250 psi (17.2 bar)

9.3.2 Design Standards. This section reviews design standards for PVC, PE, and CIPP systems. Tables 9-6, 9-7, and 9-8, respectively, list the ASTM design standards relevant for PVC, HDPE, and CIPP lining materials.

Table 9-6. ASTM Design Standards for PVC Materials

Specification No.	Title	Application
ASTM F1867	Standard Practice for Installation of Folded/Formed Poly (Vinyl Chloride) (PVC) Pipe Type A for Existing Sewer and Conduit Rehabilitation	Design appendix same as F1216.
ASTM F1947	Standard Practice for Installation of Folded Poly (Vinyl Chloride) (PVC) Pipe into Existing Sewers and Conduits	Design appendix same as F1216.

ASTM F1867/F1947. These standards contain non-mandatory design appendices for using formed PVC in either a partially deteriorated or fully deteriorated pipe. The design method is the same as in ASTM F1216 for CIPP products. In the case of a partially deteriorated pipe, where the existing pipe is expected to carry any soil or live load, the formed pipe is designed to resist buckling from external hydrostatic pressure due to groundwater or internal vacuum. In the case of fully deteriorated pipe, the formed PVC is designed to resist buckling from soil, live load, and any external hydrostatic pressure.

Table 9-7. ASTM Design Standard for Polyethylene Materials

Specification No.	Title	Application
ASTM F1606	Standard Practice for Rehabilitation of Existing Sewers and Conduits with Deformed Polyethylene (PE) Liner	Includes a design appendix for non-pressure applications.

ASTM F1606. This standard also contains a non-mandatory design appendix. The liner is designed to resist buckling from hydrostatic groundwater pressure in the case of a partially deteriorated host pipe or from hydraulic, soil, and live load in the case of a fully deteriorated host pipe. Unlike the standard practices for deformed PVC pipe, the design formula for the partially deteriorated condition does not include an "enhancement factor" (K) to reflect the host pipe's confinement contribution to the liner's buckling resistance. However, there is a note that introduces the enhancement factor to the modified Timoshenko formula.

Table 9-8. ASTM Design Standards for CIPP Materials

Specification No.	Title	Application
ASTM F1216	Standard Practice for Rehabilitation of Existing Pipelines and Conduits by the Inversion and Curing of a Resin-Impregnated Tube	Design Appendix X1 most frequently used for renewal products. Covers pressure.
ASTM F1743	Standard Practice for Rehabilitation of Existing Pipelines and Conduits by Pulled-in-Place Installation of Cured-in-Place Thermosetting Resin Pipe (CIPP)	Refers to F1216, Appendix X1 for design
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 (CIPP)	Refers to F1216, Appendix X1 for design

ASTM F1216. This is the most commonly referenced standard practice for CIPP products. In particular, the non-mandatory design appendix (X1) has set the precedent for all other sewer reconstruction products. In addition to having buckling design requirements for a gravity application that depends on whether the host pipe is partially or fully deteriorated, ASTM F1216 also includes design requirements for pressure applications. The basis of sewer rehabilitation design in the appendix of ASTM F1216 is currently being reviewed in an effort led by Dr. Ian Moore of Queens University.

ASTM F1743/F2019. These standards refer to the design appendix in ASTM F1216.

Partially Deteriorated Case. In the case of a partially deteriorated pipe, two basic equations are used in the design. The hydrostatic buckling resistance of the liner is calculated by the following formula:

$$P = \frac{2KE_L}{1-\mu^2} \times \frac{1}{(DR-1)^3} \times \frac{C}{N}$$

Where:

P = groundwater load, psi
K = enhancement factor of the soil and existing pipe adjacent to the new pipe (a minimum value of 7 is recommended for design)
E_L = long-term (time corrected) flexural modulus of elasticity for the liner, psi
μ = Poisson's ratio (0.3 assumed)
DR = dimension ratio (D/t)
C = ovality reduction factor
N = factor of safety (2.0 is suggested).

The above equation is patterned after the classic Timoshenko elastic buckling formula for an infinitely long cylinder subjected to uniform external hydrostatic pressure. Modifications include the addition of the “enhancement factor” K and the ovality reduction factor. The enhancement factor is based mainly on hydrostatic buckling experiments published by Aggarwal and Cooper (1984), where buckling enhancement from the existing host pipe could range from 5 to 20 times greater than the free-standing liner. The ovality factor compensates for ovoid pipes and conservatively reduces the liner’s resistance (refer to ASTM F1216 for the equation for C).

Most of the controversy over the application of the above formula stems from one’s interpretation of the time-corrected value for the modulus of elasticity, E_L. The note to X1.1 in ASTM F1216 states that the choice of value depends on the estimated duration of the application of the load (P) in relation to the structure’s design life (and should be obtained from the manufacturer’s literature). If the total duration of the load is estimated to be 50 years, either continuously or over the sum of intermittent periods, then the appropriate choice for E_L will be that given for 50 years of continuous loading. However, no method of test for determining the long-term modulus, E_L, is referenced in ASTM F1216 or any of the product standards. Therefore, the method of determination could vary considerably, depending on the method employed by the manufacturer. A flexural creep test under constant load would be one way of arriving at a value, but the value here will also depend on the load. The International Organization for Standardization (ISO) standards for GRP pipe contain requirements for the manufacturers to carry out long-term flexural creep or relaxation tests, and then to report the results for design purposes. The creep and relaxation tests specified have been set up to yield similar results independent of the method chosen. It would seem logical that the CIPP industry should consider adopting a similar methodology for their liner materials given that they too are composites made from the same resins (polyesters, vinylesters, and epoxies). Since this long-term property is a key in the design of all gravity CIPP and deformed/reformed thermoplastic pipes, a great deal of development effort is exerted by renewal liner manufacturers to enhance this value. The addition of glass fiber is one example of such enhancement.

A similar note is included for the selection of σ_L as E_L, namely choosing a value that is consistent with the load duration. Assuming that a 50-year design life is expected from the liner, then a value for the long-term flexural strength of the liner material under constant load for 50 years is needed. As in the case of E_L, no test method is stipulated. This is another example where the CIPP liner industry could adopt a test method similar to that described in the GRP pipe handbook. The ISO standard for GRP pipe includes a test method for determining the long-term ring-bending strength of a composite ring subjected to constant loading in an aqueous environment.

The above equations have been primarily developed for use with CIPP products, but the deformed/reformed thermoplastic products have also adopted them. However, even as new structural spray-on lining systems enter the U.S. market, there are few, if any, design guidelines for spray-on coatings. The TTC has been carrying out some tests on spray coatings for the rehabilitation of pressurized pipelines. At the time this report was written, the TTC was in the process of expanding the testing to other spray-on coatings (polyurea) with the intention to develop a generalized equation that incorporates key mechanical properties of the coating materials.

Fully Deteriorated Case. In the fully deteriorated case, the liner is designed to resist all external loads, including groundwater, soil, negative internal pressure (vacuum), and live loads, without buckling. The equation offered in ASTM F1216 has been borrowed from the American Water Works Association (AWWA) design manual for Fiberglass Pressure Pipe, M45. The equation takes into consideration the soil support offered to the original host pipe and the liner:

$$q_t = \frac{C}{N\left[32R_w B' E'_s \left(\frac{E_L I}{D^3}\right)\right]}$$

Where:

q_t = total external pressure on pipe (including negative internal pressure), psi
R_w = water buoyancy factor (0.67 min. – see F1216 for equation)
B' = coefficient of elastic support (see F1216 for equation)
I = moment of inertia = $t^3/12$, in^4/in
C = ovality reduction factor
N = factor of safety
E'_s = modulus of soil reaction, psi
E_L = long-term modulus of elasticity, psi

Values for the modulus of soil reaction may be found in ASTM D3839.

9.3.3 Installation Standards. The following section reviews the ASTM installation standards for PVC, PE, and CIPP materials. Tables 9-9, 9-10 and 9-11 provide the ASTM installation standards for PVC, PE and CIPP materials, respectively used in pipe rehabilitation.

Table 9-9. ASTM Installation Standards for PVC Materials

Specification No.	Title	Application
ASTM F1867	Standard Practice for Installation of Folded/Formed Poly (Vinyl Chloride) (PVC) Pipe Type A for Existing Sewer and Conduit Rehabilitation	Winching of folded PVC Type A with heating and expansion by pressure
ASTM F1947	Standard Practice for Installation of Folded Poly (Vinyl Chloride) (PVC) Pipe into Existing Sewers and Conduits	Similar to F1867. Diameters 4 to 15 inches covered

ASTM F1867. This standard covers the procedures for installing a pipe meeting ASTM F1871. Flow stoppage or bypass pumping is required for the insertion. All protrusions greater than 12.5% of the inside diameter should be removed. Changes in pipe sizes can be accommodated, providing the liner thickness is designed for the expansion. The liner can be pulled through bends up to 30°. The liner pipe (may be pre-heated to 180°F) is winched through the existing pipe. Pulling force should be limited to 50% of yield at 212°F. Using heat (steam) and pressure (typically 3 to 5 psi [0.2 to 0.3 bar]), the liner is expanded beyond extrusion memory to the contact wall of existing pipe. Dimples are formed at service connections. After expansion, the pipe liner is cooled to 100°F before relieving the pressure. In addition to CCTV inspection and leak tightness testing, field samples are prepared by expanding the folded PVC inside a mold pipe of the same diameter as the existing pipe and a minimum of one diameter in length. Dimensional checks (diameter, wall thickness) and flexural and tensile properties are measured on the field sample.

ASTM F1947. This standard covers the procedures for installing a folded PVC pipe meeting ASTM F1504. This standard is similar to ASTM F1867. An optional elastomeric containment tube may be used to protect the folded pipe during installation and to act as a waterproof barrier against infiltration and for containment of the steam. Expansion pressures are in the range of 8 to 10 psi (0.6 to 0.7 bar). Pipe diameters covered are 4 to 15 inches (100 to 375 mm). The inspection and acceptance requirements differ from ASTM F1867, in that no tensile properties of the formed pipe are checked, only the flexural modulus. The minimum flexural modulus is 280,000 psi (19,310 bar) (cell classification 13223 per ASTM D1784).

Table 9-10. ASTM Installation Standard for Polyethylene Materials

Specification No.	Title	Application
ASTM F1606	Standard Practice for Rehabilitation of Existing Sewers and Conduits with Deformed Polyethylene (PE) Liner	Covers installation of deformed PE liner meeting ASTM F1533

ASTM F1606. After cleaning and inspecting of the existing pipe, the deformed PE pipe is pulled directly through the insertion point to the termination point. The pulling force should not exceed the axial strain limits of the deformed pipe, which is accomplished by limiting the pulling force to a tensile stress of 1,500 psi (103 bar), or 50% of the yield. The steam temperature for reforming is to be between 235°F and 260°F, with pressure starting at 14.5 psi gage (psig) (19.2 psi or 2 bar) and rising to 26 psig (40.7 psi or 2.8 bar). The reformed pipe is cooled to 100°F, with the internal pressure increased to 33 psig (47.7 psi or 3.3 bar), while the liner is cooled to ambient temperature. Acceptance testing includes dimensional checks of the outside diameter and installed wall thickness, along with flexural and tensile properties of a reformed field sample prepared at the insertion or termination point. CCTV inspection is also recommended.

Table 9-11. ASTM Installation Standards for CIPP Materials

Specification No.	Title	Application
ASTM F1216	Standard Practice for Rehabilitation of Existing Pipelines and Conduits by the Inversion and Curing of a Resin-Impregnated Tube Rehabilitation	Covers 4 to 96 inches CIPP inversion insertion and hot water or steam cure.
ASTM F1743	Standard Practice for Rehabilitation of Existing Pipelines and Conduits by Pulled-in-Place Installation of Cured-in-Place Thermosetting Resin Pipe (CIPP)	Covers 4 to 96 inches CIPP pulled-in-place insertion, inflation with calibration hose, and hot water or steam cure.
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 (CIPP)	Covers 4 to 48 inches CIPP pulled in place insertion, air inflation, and steam, or UV light cure.

ASTM F1216. This reconstruction process can be used in gravity and pressure applications. The cured CIPP product is expected to have the minimum structural properties shown in Table 9-12. As part of the inspection and acceptance process, ASTM F1216 requires that two samples be prepared for testing: (1) one taken from an intermediate manhole or at a termination point that has been inverted through a like diameter pipe with a suitable heat sink and (2) the other fabricated from material from the tube and the resin/catalyst system and cured in a clamped mold. Physical property testing includes short-term flexural and tensile properties. For pressure applications, a hydrostatic pressure test is suggested for twice the working pressure or working pressure plus 50 psi, whichever is less. The allowable leakage rate over the 1-hour test is 20 gal/inch diameter/mile/day.

Table 9-12. Minimum Structural Properties of CIPP Products by ASTM F1216

Property	Test Method	Minimum Value, psi
Flexural strength	D790	4,500
Flexural modulus	D790	250,000
Tensile strength (pressure pipe only)	D638	3,000

ASTM F1743. This process may be used in a variety of gravity and pressure applications. CIPP products conforming to ASTM D5813 would be installed following this standard practice. An outer impermeable plastic coating may optionally be perforated to allow resin to be forced through and out against the existing pipe wall during the calibration with pressure. Table 9-13 presents the minimum initial physical properties of the CIPP product. This practice also contains a chemical resistance requirement. On a qualification basis, the cured resin/fabric tube matrix must retain 80% of its flexural modulus after 1 year of exposure at 73.4°F to five different reagents. The exposure is not under a strained condition. Recommended inspection practices include obtaining at least three, and preferably five, samples of the cured CIPP taken at either intermediate manholes or termination points, or fabricated from material placed and cured in a clamped mold. In addition to testing for the flexural properties, tensile testing is also required for pressure applications. If the CIPP is fiber-reinforced with oriented or discontinuous fibers, then tensile testing in both the axial and circumferential direction is recommended. Pressure pipes should be subjected to a hydrostatic pressure test of twice the working pressure, or working pressure plus 50 psi (3.4 bar), whichever is less. If required by the purchaser, a delamination test in accordance to D903 is also to be made.

Table 9-13. Minimum Structural Properties of CIPP Products by ASTM F1743

Property	Test Method	Minimum Value, psi
Flexural strength	D790	4,500
Flexural modulus	D790	250,000
Tensile strength (pressure pipe only)	D638	3,000

ASTM F2019. The reconstruction process can be either for gravity flow or pressure applications. CIPP liners meeting ASTM D5813 would be installed under this practice. Isophthalic polyester, vinylester, or epoxy thermosetting resins may be used. After CCTV inspection and cleaning, a sliding plastic foil is installed, covering the lower third of the circumference to reduce friction and damage to the CIPP liner. After insertion, the calibration hose is inflated and the liner cured. The calibration hose is removed after cure. As in all of the CIPP standard practices for acceptance, samples of the CIPP liner are cut from a section at an intermediate manhole, at a termination point of like diameter section, or from material taken from the fabric tube along with the resin/catalyst system. The samples are cured in a clamped mold. Since the glass fiber material can be bi-axial, samples are marked to designate the axial and circumferential directions. Testing includes short-term flexural and tensile properties. Table 9-14 shows the minimum acceptable properties under this standard.

Table 9-14. Minimum Structural Properties of CIPP Products by ASTM F2019

Property	Test Method	Minimum Value, psi
Flexural strength	D790	6,500
Flexural modulus	D790	725,000
Tensile strength	D638 or D3039	9,000

In addition, wall thickness measurements are made (with no point measurement to be less than 85% of the average design-specified thickness), and a CCTV internal inspection is conducted. Since F2019 covers pressure applications, a pressure and leak tightness hydrostatic pressure test is included, with a recommended test pressure of twice the working pressure or working pressure plus 50 psi (3.4 bar), whichever is less. Allowable leakage is 20 gal/inch diameter/mile/day.

9.4 QA/QC Requirements

QA is a procedure or set of procedures intended to ensure that a manufactured product or performed service meets the quality or performance requirements desired by the owner or project designer or requirements for system safety. Where QA can be fully determined by testing after work is complete without creating other time or contractual problems for the owner, such testing can be done after production or construction. Otherwise, documentation and/or testing of materials and processes before and during construction are required. Such QA may be more or less stringent, depending on the application. In critical applications, it may reach back several layers into the qualifications of companies and individuals conducting related work, as well as document the sources and test data on materials used in the system. On the other hand, QC is a procedure or set of procedures intended to ensure that a manufactured product or performed service meets specific requirements set out by the owner in terms of specifications for a product or project. QC may be conducted by the owner, the contractor, or both, and is intended to prevent a substandard product or construction as defined by the specification. Contractors may conduct their own in-house QC, using similar or different procedures to those specified by the owner. The objective is to avoid rejected work.

The following QA/QC activities could occur for an example using pipe jacking with on-site casting of concrete pipe:

- **Owner QC:** Requires adherence to minimum specifications on materials with periodic testing. For example, may require 28-day strength as the control for acceptable compression strength of the concrete. However, by the time this test is available, the contractor may have jacked the relevant pipe sections into the ground and sub-par strengths would require some very difficult decisions.
- **Contractor QC:** May control component materials and quantities to provide an enhanced mix design intended to prevent rejected work. May monitor its own samples rapidly after manufacture of each pipe section to avoid the possibility of non-compliance or to adjust materials or procedures quickly to meet the specifications.
- **Owner QA:** Documenting sources and quality of materials, checking test equipment and procedures, checking design calculations and qualifications of designers/operators, and collecting and archiving construction and test data, so that causes of problems that develop later can be investigated, etc.

For mainline sewers, laterals, manholes, and appurtenances, the opportunities to provide cost-effective QA/QC for rehabilitation technologies may be significantly restricted as follows: (1) by the lack of information on the condition of the pipe or structure to be rehabilitated (and the surrounding ground conditions), (2) by the inaccessible nature of some of the field processes involved in the rehabilitation (e.g., grouting processes or CIPP inversion and curing), and (3) by the cost of QA/QC procedures relative to the cost, value, or risk associated with the rehabilitation work itself.

There are differences in the impact of rehabilitation failures according to the technology used, the depth and diameter of the pipe, and the criticality of the sewer element. These issues can affect the timing and types of QA/QC testing.

Some of the product standards require the manufacturers to undertake qualification or “type” testing, which is intended to demonstrate the long-term performance of the liner under the intended use conditions. However, the amount of this testing is very limited. Post-installation CCTV is the most common QC requirement for all liners, followed by the retrieval of samples for physical property verification. More details on these requirements can be found in the following sections on short-term and long-term QA/QC requirements in factory and field settings.

9.4.1 Grouting Performance. Typical QA/QC parameters and their impact on sewer renewal of gravity sewer mains can be summarized as:

- **QA Parameters:** Pipe leakage rates pre- and post-rehabilitation; quantities and type of grout injected at each location; longevity of rehabilitation as measured by periodic leakage evaluation.
- **QC Parameters:** Documentation of grout materials and mixes; test pressures for each section pre- and post-grouting; CCTV inspection of grouted pipe (owner and contractor may use the same QC measures).
- **Cost of QA/QC Activities:** Most data are collected as part of a controlled grouting operation. Onsite inspection is important during the procedures. Periodic follow-up can be a part of regular inspection activities.
- **Impact of Non-Compliance with Specifications:** Regrouting may be required, or it may be determined that the section is not suitable for grouting. In either case, there are no special additional costs incurred, unless the grout migrates to an unwanted location and causes plugging of other services.

9.4.2 CIPP and Close-Fit Lining of Pipes. Typical QA/QC parameters and their impacts on sewer renewal of gravity sewer mains can be summarized as:

- **QA Parameters:** CCTV inspection of line prior to rehabilitation to determine suitability and preparation for rehabilitation; CCTV inspection after completion; assurance that QC specifications are followed; physical testing of as-installed liner (if not part of QC requirements) (not frequently specified at present); “type” testing for long-term performance estimation based on laboratory testing.
- **QC Parameters:** Material controls; control of temperatures and pressures during installation (e.g., fold-and-form); control of liner curing before and during installation, plus monitoring of liner temperature to document exotherm and pressure to control liner thinning (e.g., CIPP); post-installation CCTV; retrieval of material samples in special sections adjacent to installed sections.

- **Cost of QA/QC Activities:** Material records and testing are standard relative to other construction activities; onsite inspection during installation is important and affects QA/QC costs.
- **Impact of Non-Compliance with Specifications:** If a liner can be identified as substandard or improperly installed prior to curing or expansion to its close-fit condition, replacement costs are limited to reinstallation of a new liner. If the liner is unacceptable after installation due to excessive folds, uncured or porous sections or other serious defects, then significant difficulties and costs may be encountered in removing the previously installed liner and may result in the need to dig up and replace the segment. Costs of failures rise significantly with diameter and for dig-ups with depth and/or accessibility impacts. Differences among rehabilitation technologies in terms of their ability to be cut up and removed and their field failure history should be considered in the design of contractor QC activities and the monitoring of these activities by the owner.

The following sections provide more details on the requirements for QA/QC testing for relining systems.

9.4.3 Short Term – Factory and Field Requirements

9.4.3.1 Folded PVC Short-Term QA/QC Requirements. The short-term QC requirements in the factory for folded PVC pipes include pipe flattening, pipe impact strength, pipe stiffness, extrusion quality (acetone immersion, heat reversion), and flexural properties. Dimensional checks on the pipe diameter and wall thickness are also included. The pipe flattening and impact requirements are designed to primarily ensure that the pipe can be folded and reformed during the installation without damage, while the stiffness and flexural properties relate to the design. There are no QC requirements on measuring tensile strength, while the Type A material is to be made from virgin PVC with a minimum tensile strength of 3,600 psi. A low-pressure leakage test with a limiting exfiltration level of 50 U.S. gal/inch diameter/mile/day is recommended. Samples of the rounded pipe are also retrieved at the insertion point, with diameter, thickness, and flexural properties measured. For the Type A material, ASTM F1867 also includes testing for tensile properties (3,600 psi [248.3 bar] minimum).

9.4.3.2 PE Short-Term QA/QC Requirements. Most rehabilitation undertaken with PE pipe has been either with pipe bursting or sliplining. Pipes used in these applications normally meet either AWWA C901 or C906, or the ASTM specification for OD-controlled pipe, ASTM D3035. Typical factory QC requirements in each case include visual inspections for workmanship (no cracks, holes, foreign inclusions, etc.); diameter and wall thickness checks; density measurements (per ASTM D1248); sustained pressure tests (subjecting the wall to a hoop stress equal to the hydrostatic design stress [HDS]); burst pressure tests (1.6 times the HDS for PE 3408); environmental stress cracking tests; elevated temperature sustained pressure tests; and apparent ring tensile strength tests.

In the case of sliplining, the original pipeline is visually inspected in the field by CCTV to locate problem areas, including offset joints, crushed walls, obstructions, and the location of service connections. ASTM F585 covers gravity applications and includes a low-pressure exfiltration test for acceptance. The AWWA M45 PE Pipe – Design and Installation manual provides some guidelines on the use of PE pipe for pipe bursting and sliplining, but does not contain any specific field QC test requirements except recommending a hydrostatic pressure test for acceptance in pressure-pipe applications.

Deformed PE. In the factory, deformed PE liners are dimensionally checked, and are evaluated for ESCR, tensile strength, tensile elongation, and flexural modulus. These tests are part of the normal qualification and QC requirements. ASTM F1606 is for gravity applications and QC requirements, including a CCTV inspection of the liner after insertion and reversion; an exfiltration or low-pressure air test for leakage; and samples taken at the insertion or termination point for further analysis. This includes diameter and wall thickness checks, plus measurement of flexural modulus and tensile strength.

9.4.3.3 CIPP Short-Term QA/QC Requirements. ASTM D5813 Standard Specification for Cured-in-Place Thermosetting Resin Sewer Pipe requires the fabric tube to have a minimum tensile strength of 750 psi. This pertains more to handling and insertion needs than actual in situ performance. Once the CIPP liner is installed, the recommended QC practice in all of the ASTM standards is for samples to be cut from a representative section of the CIPP liner and then tested for short-term flexural strength and modulus and short-term tensile strength. Two methods (ASTM D3039 and ASTM D638) are offered for determining the tensile strength. The minimum value is 9,000 psi (621 bar), as specified in ASTM F2019, which is the only standard practice for pressure applications.

Wall thickness measurements are also made on the retrieved samples. There is no requirement for measuring the wall thickness of the in situ liner. Theoretically, this is now possible with the use of a laser profiler. The inside surface of the original pipe would first be surveyed with the profiler and then the liner's inside surface after cure. Assuming the liner hasn't shrunk away from the inner surface of the original pipe, the liner's thickness could then be determined from these two survey measurements. Ultrasonic tools are also being developed that not only can be used to measure the thickness of the in situ liner, but also its flexural modulus of elasticity where the thickness is known. This could be especially important to an owner who may want to check on the condition of an old liner to determine if any deterioration (loss of thickness or modulus) has taken place.

The last field QC requirement is a visual inspection, usually by CCTV, to check workmanship. No dry spots, lifts, or delaminations that would affect the liner's long-term performance are permitted. Excessive wrinkles are also not permitted, especially those that impede flow or cleaning equipment.

9.4.4 Long Term – Qualification Requirements

9.4.4.1 PVC Long-Term QA/QC Requirements. PVC pipe meeting AWWA C900 or C905, or ASTM D2241 Standard Specification for Poly (Vinyl Chloride) (PVC) Pressure-Rated Pipe (SDR Series) is subjected to long-term pressure regression testing to establish an HDB for the pipe. Pipes are tested per ASTM D1598 and the results analyzed in accordance with ASTM D2837. An HDS, which is the maximum tensile stress the material is capable of withstanding continuously with a high degree of certainty that failure of the pipe will not occur, is determined. Fusible PVC and Duraliner are the only two PVC products made from standard AWWA C900 or C905 stock, so these are qualified.

Folded PVC. There are no long-term qualification requirements in the folded PVC liner standards. Only one manufacturer of a folded PVC product, Ultraliner, stipulates that this product could be used for a low-pressure sewer force main renewal. In the future, a requirement should be established similar to that in AWWA C900 or AWWA C905, where reformed pipes are subjected to long-term pressure regression tests. This would allow design of a reformed PVC liner to act as a fully structural pipe for 50 years. At the present time, that information is not available.

9.4.4.2 PE Long-Term QA/QC Requirements. PE pipe meeting AWWA C901 or C906, or ASTM D3035 is similar to PVC in that these products are also subjected to long-term pressure regression testing. These tests establish a basis for the long-term pressure rating of the products. There are no other long-term tests for standard PE pipe.

Deformed PE. PE used for deformed liners under ASTM F1533 is to be made from materials that have a PPI HDB of either 1,600 psi (110.3 bar) for PE 3408 or 1,250 psi (86.2 bar) for PE 2406. However, there is no requirement for the reformed PE liner to demonstrate that it has a similar HDB rating.

9.4.4.3 ***CIPP Long-Term QA/QC Requirements***. ASTM D5813 includes a long-term qualification test for chemical resistance, which has two requirements. The first is that the CIPP specimens retain 80% of their flexural modulus of elasticity after 1 year of exposure to six chemical solutions. Table 9-15 lists the solutions and their concentrations.

The other chemical resistance requirement is the strain corrosion test requirement of ASTM D3681, developed for fiberglass pipes used in gravity sewers. Eighteen samples are deflected to achieve four different tensile bending strains on the inside surface of the liner. With exposure to H_2SO_4, they must last (without failure) the specified time period associated with each strain level. This qualification test is intended to ensure that the liner can withstand up to 5% long-term vertical deflection when exposed to 5% H_2SO_4 and will last 50 years.

Table 9-15. ASTM D5813 Chemical Solution Specifications

Chemical Solution	Concentration, %
Nitric acid	1
Sulfuric acid	5
ASTM Fuel C	100
Vegetable oil	100
Detergent	0.1
Soap	0.1

9.4.5 **Laterals.** Section 6 describes special considerations for laterals. The only standard pertaining specifically to laterals is ASTM F2454 for the grouting of laterals. Otherwise, design and application to laterals are typically treated or implied within other standards.

9.4.6 **Manholes.** Special considerations for the design of manholes include:

- The structural thickness requirements of manhole linings vary with the depth below ground level and/or groundwater level. If the thickness of linings is set for the maximum load condition, then the manhole rehabilitation may be more costly than necessary.
- Manhole diameters are much larger than most sewer pipes; hence, the thicknesses of liners needed to resist buckling against external groundwater pressures become significant for the more expensive polymer materials.

Most calculations for a structural lining do not account for bonding with the manhole structure, although for a sealant-only coating, the bond is critical in terms of the coating's ability to resist seepage pressures. Design procedures are typically based either on the Appendix to ASTM F1216 or to design equations in the UK Water Research Centre (WRc) manual (WRc, 2001). If the manhole has deformed significantly, has local loss of thickness (> 0.5 inch or 12 mm) or if sections of the manhole structure are missing, then bending moments in the liner should be considered.

For products that depend on a bond to the existing manhole substrate, QA/QC is especially critical to ensure that project objectives are met. There are hundreds of manhole specialty products and thousands of coating formulas available from various manufacturers. These products have different surface preparation requirements and compatibility with other materials present in the manhole. A thorough inspection of existing conditions will identify the types of coatings/liners that should be considered acceptable for those conditions; and the specification and inspection process must then ensure that the product is applied correctly and under the right conditions.

9.4.7 Ancillary Structures. For the non-flow areas of pump and lift stations, normal structural rehabilitation issues will apply. The structures are often below ground and may suffer from some groundwater leakage into the structure and or from condensation during humid weather. Under damp and humid conditions, steel supports and frames may become corroded, and equipment may gradually deteriorate. Rehabilitation typically involves eliminating the groundwater leakage and providing new, easily maintained surfaces within the structure. Combinations of grouting, sealing, and coating of interior walls are the typical approaches for such rehabilitation. Since the shape of the structures is often rectangular, it is not possible for liners to resist external groundwater pressure by arching action in curved sections; hence, most coating applications require the ability to bond to the existing structure. The internal supports for equipment further complicate the ability to seal such structures fully; they may be bolted to internal walls and penetrations for venting to pass through the structure’s walls and any waterproofing or sealing layers. Wet-well areas of lift and pump stations are subject to erosion and corrosion concerns, depending on the structural materials used and the level of hydrogen sulfide produced by turbulence in the wastewater flow.

Overflow structures will likely have flat surfaces along some or all exterior walls and interior walls, or along weirs for the overflow operation. Original operation of the overflow structures also likely included gratings or mesh structures to retain solid materials within the main wastewater stream. These fixtures may provide exposure of steel within concrete structures at the attachment points and, therefore, an opportunity for accelerated deterioration of the concrete at these locations.

10.0 OPERATION AND MAINTENANCE

10.1 Ensuring Compliance with Environmental Regulations

O&M activities on a wastewater collection system are typically designed to keep the sewers and allied structures and equipment in an acceptable working condition and to minimize the total life-cycle costs of operation, maintenance, rehabilitation, and replacement. However, activities are often constrained by the lack of funding that can accommodate only a portion of the desired maintenance activities. A key driver in recent decades in operating parameters and maintenance scheduling has been to keep the system in compliance with environmental regulations as far as possible. In portions of the system with low impacts from failures and simple emergency replacement procedures, the lowest cost approach to maintenance might be to allow system components to fail and then replace them on an emergency basis. However, regulatory penalties, public pressure, and high-risk locations all increase the "cost" of operating on a reactive basis. Deliberate disregard of environmental regulations can result in prosecution, so compliance with environmental regulations is an important driver in O&M activities.

10.2 Inspection

Inspection is both an important part of regular O&M activities and a repeated activity in terms of identifying segments that will need rehabilitation or replacement in the foreseeable future. Inspection resulting only in maintenance activities may include identifying debris or foreign objects that are blocking flow, and excessive fat, oil or grease build-ups. However, regular inspection will typically identify pipe conditions that can only be solved by significant actions involving repair, rehabilitation, or replacement. The technologies available for pipe inspection and the resulting data on pipe condition have improved immensely in the past two decades. Several reports describe the conventional and emerging technologies in the marketplace, how the visual images and other associated data are used to assess the condition of a pipe segment, and how condition assessment data are used to prioritize pipe segments both for renewal actions and for the frequency of future inspections (e.g., EPA, 2009b). The overall goal is to use the inspection data, over time, to understand the deterioration rates in various elements, materials, and segments of the system. This will allow operations, maintenance, and renewal activities to be adjusted to smooth budgetary requirements and operate the entire system on the lowest life-cycle-cost basis. It will also allow the impact of available budget to be clearly tied to the future operational condition of the wastewater system.

10.2.1 Cleaning. Gravity sewers are designed with gradients that create self-cleansing fluid velocities, but many factors can cause obstructions within the pipe network. These factors include foreign debris entering the system, local loss of gradient due to pipe settlement, build-up of fats, oils, and grease, blockage due to pipe collapse, and infiltration of soil into pipes through open cracks and joints. Depending on the expected or encountered pipe conditions, cleaning can be carried out as a separate maintenance activity or can be combined with CCTV inspection. CCTV requires reasonably clean lines for effective inspection, but can also be used to identify the reasons for problems encountered in cleaning a particular section. One benefit of a regular inspection program that is not tied to pipe condition is the identification of operational issues in the pipe network before they cause backups or overflows.

Cleaning methods fall into two categories: those that dislodge the solids so that they are carried away with the wastewater flow, and those that remove the solids from the pipeline. Mechanical scrapers or flails have historically been used in mainlines to dislodge debris and remove roots and build-ups within the pipe, but have largely been replaced by high-pressure water-jetting. To remove the dislodged solids, bucket dredgers or vacuum collection points can be used. Where a line is in deteriorated condition or has been repaired or rehabilitated, it is important to determine whether the cleaning procedures used by the maintenance crews will hasten the pipe deterioration or damage repairs or pipe liners.

10.2.1.1 High-Pressure Jetting. Jetting has become very common, yet is somewhat limited in its capabilities. It is currently the most popular cleaning method for gravity sewers and is widely used throughout the world. Jetting machines range from compact van-pack units for cleaning small-diameter drains, through trailer-mounted jetters of various power ratings, to full tanker-jetters, which may also combine vacuum removal and, on the largest units, a water-recycling facility.

Although high-pressure jetting can achieve excellent results if used wisely, it also has the potential to make a bad situation worse and to create problems where none existed. Jetting a cracked or fractured pipe may cause the fragments to become loose and fall into the pipe, creating a collapse and a blockage. Persisting with high pressures in an attempt to remove a blockage can wash away the pipe surround, resulting in further destabilization and perhaps even subsidence at the surface. Leaving a high-pressure jet in one position for more than a few seconds may puncture the pipe or damage the wall of some types of pipe, even if the pressure is below the recommended maximum.

There is some risk in jetting at high pressure in plastic pipes, notably uPVC. Generally, the wall thickness of a solid-wall uPVC pipe is such that high-pressure jetting is unlikely to cause serious damage, although excessive pressures should be avoided. The main concern is with structured wall polymeric pipes, where most of the strength is provided by external ribs or corrugations, and the inner wall can be quite thin – sometimes less than 0.08 inch (2 mm). Structured wall pipes were introduced to reduce the required quantity of pipe wall material (and hence the weight and cost) for medium to large diameters, while providing adequate stiffness to resist external loads.

The main drawback of high-pressure jetting without associated debris removal is that more often than not, the debris in the sewer is flushed downstream, rather than being effectively washed away. Jetters may be excellent for clearing localized blockages, but are less well-suited to dealing with large volumes of silt or similar material over long lengths of sewer.

10.2.1.2 Drain Rodding and Root Cutters. Simple drain rods are an obvious low-tech alternative to water jetting for small-diameter pipes such as laterals. For laterals, old-fashioned drain rods are still the most common tool for blockage clearance and can be very effective. The limitation is that there is little control nor is there any feedback as to whether the blockage is adequately cleared. Another drawback is that the rods may simply be pushing the problem somewhere else. Nevertheless, this is an effective method for removing small blockages in small-diameter sewers.

Rotary root cutters are a common tool for clearing root obstructions from sewer laterals; many providers offer such services to homeowners. One drawback of using such rotary cutters without associated camera inspection is the danger of cutting through plastic gas or water services that have been inadvertently drilled through sewer laterals or mainline sewers using horizontal directional drilling. Cutting through such gas services creates a very dangerous condition; the resulting explosions have killed a number of individuals across the country over the past decade.

10.2.1.3 Debris Removal. Pipe cleaning and blockage clearance should involve more than just passing the problem downstream, which jetting and rodding may do. Jetters are better than rods in this respect, since they break up accumulations of debris into finer material that is more likely to be carried in the flow and dispersed.

Where there are greater volumes of debris, which would almost certainly settle out further downstream, a common solution is to use a combination jetter/vacuum machine, which simultaneously flushes the sewer and sucks out the resulting sludge. Some of the larger, more sophisticated units incorporate water filtering and recycling systems, together with compression of the solids, so they take up less space and are easier to dispose of in a drier state.

10.2.1.4 Flushing. Flushing involves simply pouring a large volume of water into a sewer as quickly as possible, in the hope that the sudden increase in flow will wash away any accumulations of debris. It is an attempt to replicate the effect of a summer storm on a combined sewer. Today, such a procedure would be carried out using a large-capacity tanker-jetter, possibly with recycling and filtering facilities. Flushing is seldom used today, since it has been largely superseded by jetting. Jetting uses less water and is a more controllable and reliable technique.

10.2.2 Monitoring Flows. Flow monitoring is an important tool in managing of a wastewater collection system. Changes in flow characteristics at different points within a system can indicate the presence of obstructions or the deterioration of a portion of the pipe network in terms of allowing additional I/I. Flow monitoring of particular basins where rehabilitation is being carried out also is an important tool in gauging the success of I/I removal. This is typically done by installing temporary flow-monitoring stations so that the flows reflect only the area being rehabilitated. If lateral and/or manhole rehabilitation is also being carried out, then the flow monitoring can be conducted before and after each stage of the rehabilitation. Getting a reasonable representation of changes in I/I through rehabilitation requires monitoring periods that include a similar range of rainfall events. Comparison may be done through analysis of hydrographs before and after rehabilitation or by developing regression lines comparing flow versus rainfall before and after each stage of the rehabilitation. Figures 5-5 and 5-6 provided examples of regression analyses to evaluate sewer lateral rehabilitation effectiveness from Nashville. If the expense or practicality of flow monitoring eliminates this as an option, other indicators of changes in flows can be used. Parameters that have been used include run time of pumps in lift stations, as well as the number of truck trips to relieve surcharging during rainfall events.

10.2.3 Monitoring Overflows. Since sewage overflows represent a serious event in a wastewater system operation and are regulated by EPA, the detection and documentation of overflows is necessary for responsible system operation. Sewer network basins showing high numbers of overflows can be targeted for early rehabilitation activities, providing the potential for a disproportionate reduction in overflows when only portions of a sewer network are rehabilitated. Figure 10-1 shows the experience of the City of Dallas during the 1990s in reducing overflows through this strategy.

10.2.4 Maintenance and Enforcement Practices. Maintaining good records of system performance and of maintenance and repair activities allows identification of operational problems, illegal uses of the sanitary sewer, and potential deterioration of portions of the system. For example, continual maintenance issues in removing grease buildups in a particular line can lead to the identification of a missing or inoperative grease trap serving a restaurant. Also, the continual removal of sediment during cleaning activities from a portion of the network may indicate the loss of soil into the sewer through open cracks and joints. If no action is taken, this condition can eventually lead to pipe collapse and possible sinkholes extending to the ground surface. Flow monitoring, evidence of surcharging, overflow records, and physical inspection can identify the potential for significant inflow sources to be connected to the sewer network.

When illegal conditions or activities are identified, steps can be taken to request that the property owners in question deal with the problem(s) identified. Enforcement procedures, incentives, or a combination of both may be used to gain compliance, as indicated in the discussion of private property issues for laterals in Section 5. While not directly involving system rehabilitation, removal of inflow sources can be a very cost-effective step in addressing I/I problems with a wastewater collection system.

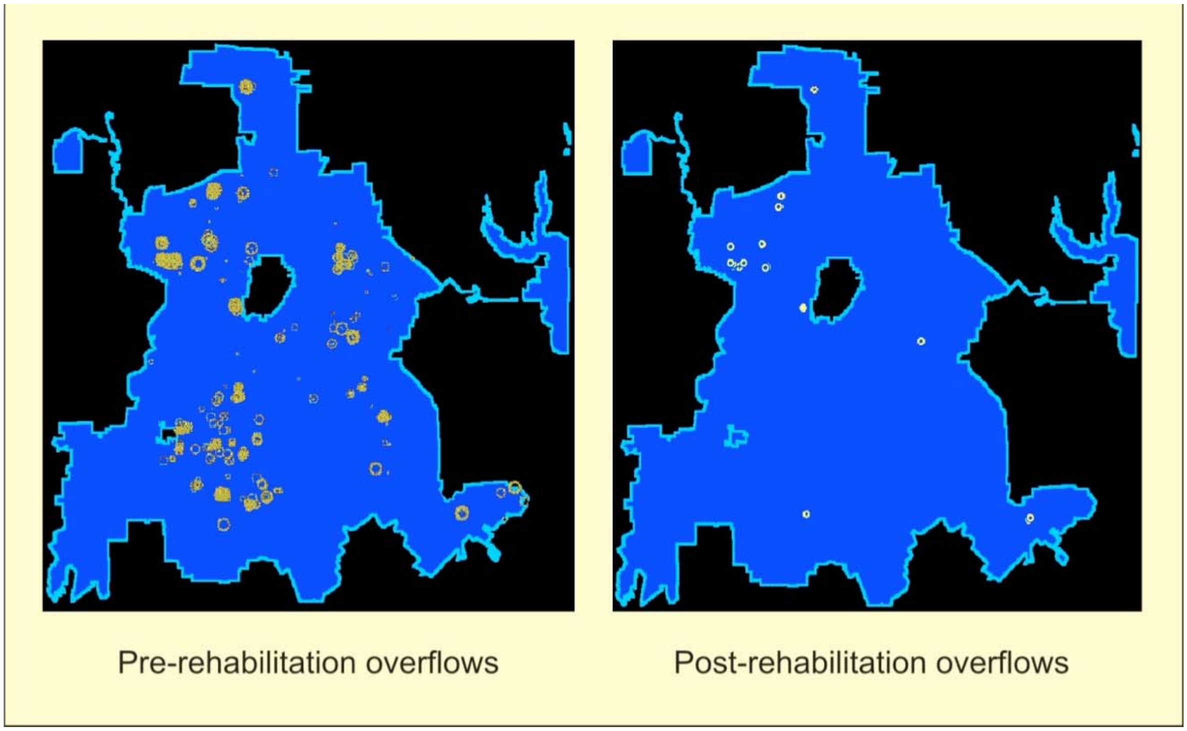

Figure 10-1. Reduction in Overflows Due to Rehabilitation Work in Dallas in the 1990s

10.2.5 Emergency Repair. Sudden failures within a wastewater system can occur, even within well-managed and maintained systems. Emergency repair procedures, crews, and materials need to be available when an emergency develops. However, running an entire system on the basis that it can be run until it fails and then repaired is not an acceptable practice. Such practice is likely to cause preventable overflows from the system and to be a less cost-effective option than proper system maintenance and timely renewal. The direct costs of emergency repairs are often much more than scheduled repairs; major disruption and ancillary repair costs may be incurred when a system component fails in a busy area and damages neighboring utilities and structures and the street pavement above. In low-building-density areas away from sensitive environmental areas, the consequences of failure are reduced and these sections could be given a lower priority for preventive renewal when funds are insufficient.

Since the system elements dealt with in this report do not include force mains under pressure, dealing with previously rehabilitated sections in terms of emergency repair is not a significant issue for the emergency crews. Flexible coupling systems can be used to connect the host pipe sections, and it is not essential (in the short term at least) to address the loss of the internal liner in the repaired section.

10.2.6 Private Property Issues. A large portion of the overall wastewater collection system for a municipality underlays private property. Sewer laterals connect the structure served by the sewer to the mainline, which is typically located in the public right-of-way. The overall length of sewer laterals in a sewer system often approaches or even exceeds the length of the mainline sewer. Ownership and responsibility for maintenance and rehabilitation of sewer laterals varies widely among municipalities, even within a region. Figure 3-1 showed the proportion of ownership conditions among utilities surveyed in 2004 (Simicevic and Sterling, 2005). In more than half of the utilities surveyed, the owner is responsible for the entire lateral to the mainline in the street (even though the lateral extends beyond the owner's property line). In the remaining cases, the property owner owns the lateral either to the property line or to a clean-out near the property line where these are regularly used within the system. Most property owners do not maintain their sewer connection unless an operational problem occurs and the QC on sewer lateral installations is often poor. For these reasons, many of the lateral connections may be in bad condition and contributing significant I/I to the collection system.

When a wastewater utility embarks on a program to reduce I/I in its system, it typically begins with the poorest condition segments of its mainline system. This is the logical place to start, but when the condition of laterals is ignored, the results in terms of I/I reduction from the mainline rehabilitation may be disappointing. In high groundwater areas, a leaking main acts to draw down the groundwater level. Once the main is sealed by rehabilitation, the groundwater level tends to rise, but this may increase the level of flow into leaky laterals, thereby circumventing a significant portion of the benefit from the mainline rehabilitation. Thus, the omission of laterals from an I/I reduction program may result in an incomplete solution to the problem.

Even when municipalities have concluded that their sewer laterals present a problem that should be addressed systematically, there is still often a reluctance to move ahead. Issues relating to work on private property are described in detail in the WERF report on lateral rehabilitation (Simicevic and Sterling, 2005). Key issues relating to legal liability and public funding mechanisms were summarized in Sections 5.1.3 and 5.1.4.

11.0 FINDINGS AND RECOMMENDATIONS

11.1 Gaps between Needs and Available Technologies

The immense task involved in renewing and upgrading the nation’s sewerage systems means that there are many unfilled needs. The primary need is for adequate funding to enable municipalities to respond adequately to their aging collection systems and, in some cases, to overcome decades of past neglect. Adequate funding also permits agencies to overcome the second principal need, which is to have the necessary engineering, technical, and field staff to handle system design, operation, renewal, and maintenance. However, even with adequate financial and staff resources, there are still gaps between what is desired in terms of technologies and what is currently available in the marketplace. These are discussed below in terms of gaps in rehabilitation technologies and gaps in data and asset management practices.

11.1.1 Rehabilitation Technology Gaps. Trenchless rehabilitation technologies are available for the renewal of all but the most difficult challenges in a sewerage system. Such challenges may include fully collapsed sections, sections with many bends, and sections with flows that cannot be bypassed. In many cases, more than one rehabilitation technology could be used, allowing effective competition among available technologies. The technology gaps occur mostly in matching design procedures to the actual loadings that the technology will experience in the field and in controlling the field processes to provide high QA/QC of the finished product across a wide range of projects and contractors. Low bids and reduced costs for rehabilitation technologies are welcomed, but not at the expense of a poorly performing product. It is difficult to single out specific areas where improvement is critical, but the list below provides a number of technology advances that would promote cost-effectiveness, increase performance of the rehabilitated product, and provide higher levels of quality assurance for the owner:

- Shorter field installation times that increase the number of installation segments that each crew can complete in a day
- QA/QC procedures that document the delivery of a high-quality liner and record the as-built properties of the liner to track life-cycle performance
- Rapid and cost-effective means to seal the annular gap between the liner and the host pipe at lateral reopening and manhole terminations (when Top Hat™ style or connection lateral liners are not being used)
- Technologies providing lower cost with the same or enhanced performance.

11.1.2 Data and Capability Gaps. Many sections of this report have discussed the paucity of data on the actual deterioration rates of both host pipes and liner systems. In the case of liner systems, this indicates that most rehabilitation systems are performing effectively to date, but a better understanding of expected life cycle and deterioration rates is important to properly use asset management systems. Some key gaps are:

- Improved nondestructive inspection and condition assessment tools, including:
  - Assessment of thickness and material properties for pipe walls and liners
  - Identification of annular gaps between the liner and the host pipe
  - Identification of void areas outside the walls of the host pipe

- Integration of condition assessment with the quantitative design of the rehabilitation system

- Availability of data-sharing among municipalities to allow improved prediction of deterioration rates and life-cycle costs
- Ability to tie the specifics of improved longevity created by rehabilitation to the asset management indicators used in asset accounting (for instance, many cities implementing Government Accounting Standards Board (GASB) 34 use only very crude measures of length of lines rehabilitated to adjust asset values; this negates some of the economic rewards of doing high-quality renewals).

11.1.3 Benefits, Costs, and Challenges in Closing Gaps. There are costs as well as benefits in closing the capability gaps outlined above. Some of the needed steps will be taken by private enterprise at their own cost to improve the technologies offered to owners and thereby increase their business share. Other steps are either difficult for private entities to manage, or not necessarily in their own economic interest. These include sharing data on the performance of competing systems or development of a new technology that may supplant or add to a provider's existing technology. The key steps for municipalities as owners of sewerage systems and for government agencies in a support and/or regulatory role are:

- Create a level playing field where technologies compete on the basis of long-term performance as well as initial cost.
    - Benefit: Selection of the most cost-effective technologies over their life cycle
    - Cost: Developing the understanding and statistical database necessary to compare technology performance
    - Challenges: Developing an effective means of tracking the performance of rehabilitation technologies over their lifetime.
- Create or participate in national resource databases that amalgamate the experience of municipalities with rehabilitation technologies across a wide range of climatic, site, and use conditions.
    - Benefit: Increased confidence that the large expenditures of funds on system rehabilitation will result in higher performance and/or lower operational and maintenance costs in the future
    - Cost: Creating the databases, translating data into common formats, and encouraging municipalities to participate
    - Challenges: Extracting meaningful results from disparate datasets.

11.2 Key Parameters for Evaluation in Demonstration Projects

The findings of the interim SOT report prepared at the beginning of this project, the input from the international technology forum, and the review of the SOT presented in this report identified a number of key parameters for inclusion in demonstration projects focused on the rehabilitation of sewer mainlines, laterals, and ancillary structures. These are discussed in the following sections.

11.2.1 Provide Demonstrations of Suitable Technology Performance Metrics for the Technologies Selected. Demonstrating only a handful of novel and emerging technologies is going to have a limited impact on the national effort to rehabilitate aging sewer systems. The demonstrations need to have a broader impact (e.g., on design and QA/QC practices), rather than just showing that a technology can be installed successfully.

Metrics that can be used to document rehabilitation system application and performance include:

- Selection criteria that pointed to selection of the demonstrated technology
- Identification of the anticipated failure modes for the technology
- Formal consideration of the anticipated modes and documentation of design procedures
- Documentation of the rehabilitation technologies' ability to handle non-ideal rehabilitation conditions
- Recording the cost parameters for the technology application
- Recording installation time and social disruption
- Development of a QA/QC plan and documentation of its outcome
- Evaluation of manufacturer-stated performance versus actual performance
- Prior experience and accelerated testing to provide evidence of durability
- Compression, tensile, and bending strength, as appropriate, and elastic modulus
- Changes in physical properties expected with time (creep and other forms of accelerated testing)
- Expected visual appearance and geometric uniformity after installation
- Flow properties and friction factors
- Documentation of I/I reduction achieved.

A key purpose of the demonstration projects is therefore not only to demonstrate a successful application of the technology, but also to collect the range of material, product, and application data that will allow documentation of a successful application and provide an appropriate expectation of adequate long-term performance over the planned rehabilitation life cycle.

11.2.2 Long-Term Performance Assessments of Rehabilitation Projects. As a result of the interim report findings (EPA, 2009a) and the input received at the technology forum, an effort has been initiated to develop protocols for quantitative retrospective assessments of previously installed rehabilitation projects that would provide a detailed investigation and estimation of deterioration versus as-designed and installed condition. Long-term data regarding the performance of various rehabilitation systems is badly needed. The availability of such data will enable decision-makers to make fully informed cost-benefit decisions. The demonstration projects to be carried out under TO 58 provide an opportunity to demonstrate the kind of as-built dataset that should be created for rehabilitation projects to enable comparative evaluation of the liner's deterioration during subsequent investigations. Separate demonstrations of the protocols for the retrospective evaluations will be undertaken with the objective of providing protocols that offer meaningful results at a cost and level of effort acceptable to the agencies involved.

11.2.3 Accelerated Testing Opportunities. Another opportunity included in the demonstration projects is to identify appropriate accelerated testing protocols that would help system owners predict the longevity and long-term performance of the products and technologies used. Accelerated testing for liners in the U.S. is currently limited to creep properties of polymers, 10,000-hour buckling tests on sample liners, and accelerated chemical resistance testing. Accelerated erosion and wear test protocols under ASTM and international standards also are available. Representative and effective accelerated testing protocols against other failure modes would further help municipalities select effective long-term solutions. Possible candidates for inclusion (depending on the specific technologies selected) could include new approaches to qualifying rehabilitation products as to their long-term performance. These should provide testing standards that can be used across different technologies and materials so that comparable performances can be assured.

11.3 Selection Criteria for Field Demonstrations

Several criteria have been identified for possible inclusion in the current EPA Demonstration Program:

- Novel and emerging technologies that are commercially ready
- Adaptability to and widespread benefit for small- to medium-sized utilities
- Ease of installation
- Truly novel and more than incremental improvement over conventional methods
- Environmentally friendly.

These are mostly subjective criteria, but are being used to help select a small number of demonstration projects from the large number of candidate technologies available.

11.4 System Rehabilitation Program Guidance

Many utilities are now relatively comfortable with at least some of the trenchless rehabilitation methods available and have some level of inspection, condition assessment, and asset management approaches in place. However, there is still a large gap between the advances in theory and software tools for asset management and their implementation across a wide range of utilities. Gaps remain in terms of:

- Comparing the benefits and drawbacks among competitive rehabilitation systems
- Developing formal QA/QC plans for each rehabilitation technology that would provide consistent quality of rehabilitation projects across a wide range of vendors and contractors
- Collecting the necessary data that would allow more effective use of asset management tools (e.g., real data on the expected longevity of rehabilitation systems)
- Justifying the cost and manpower necessary to improve inspection and condition assessment
- Collecting and storing baseline data at the time of installation of rehabilitation systems, including data on items such as soil type, depth, effluent characteristics, frost impacts, etc., that may affect deterioration rates
- Periodic sampling of previously rehabilitated lines to provide quantitative evaluations of condition with respect to time
- Sharing data among utilities to provide a more comprehensive database of deterioration rates than any one utility is likely to be able to compile (initial steps have already been taken to establish such a database (Sinha, et al., 2009; Vemulapally and Sinha, 2009).

11.5 Maintenance Program Guidance

Municipalities must identify any forms of repair or rehabilitation that may cause problems with future maintenance activities. This means including maintenance personnel in the review of new technologies and creating a viable feedback loop from maintenance and operations to the design and construction divisions. Most full segment-length rehabilitation solutions for gravity sewers do not create special maintenance issues. Such issues are more pronounced for rehabilitation of pressure lines, such as force mains and water distribution systems.

It is also important for municipalities to track whether any maintenance practices contribute to accelerated deterioration of the pipe network (for example, aggressive cleaning of heavily cracked pipe segments may further degrade the pipe condition and wash away soil outside the pipe envelope, leading to more distortion).

Less easy to accomplish, but also with potential benefits would be to identify whether there are maintenance practices that improve the longevity of an original pipe or a rehabilitated section. Examples that have been used include the application of cuprous oxide or silver oxide to mitigate against hydrogen sulfide corrosion of concrete.

11.6 Guidance Based on Lessons Learned

At present, there are only limited mechanisms for nationwide information-sharing based on lessons learned. Journal papers typically do not simply report experiences with the application of various technologies. Conference papers and magazine articles contain a good proportion of case study reports, but negative results are often either not reported or are described in such a way that it is difficult to gain specific lessons from the difficulties or failures. Creating a database of lessons learned requires significant QC procedures to ensure that products or providers are not unfairly identified as responsible for difficulties without any avenue for alternate perspectives to be presented. The database also needs to shield agencies that supply information from identification. If this is not done, there is a strong disincentive for agencies to supply data that may provide negative publicity.

Despite the difficulties, there are significant benefits to a more organized sharing of rehabilitation results. These include:

- A better understanding of the percentage of rehabilitation projects that experience installation problems or premature failures (anecdotally, this is understood to be quite low, but hard data on this question would be very comforting to specifiers if the numbers were low and would drive improvements by providers if the relative results for their technology were poor)
- Identification of causal factors for installation or performance problems.

Other avenues for sharing lessons learned include peer-to-peer discussions, such as those included in the municipal forum programs organized by the Trenchless Technology Center (TTC, 2009).

Another example of successful data sharing involving failures is the Damage Information Reporting Tool (DIRT) managed by the Common Ground Alliance (CGA, 2009). This Web-based reporting tool allows organizations and companies to enter damage reports that essentially report the facts surrounding the damage and do not assign blame. Participation in the damage reporting continues to grow each year, and the statistics generated are proving very useful in understanding damage trends and identifying possible correlations between cause and effect.

11.7 Risk-Based Decision-Making Processes

Long-term goals for decision-making in rehabilitating wastewater systems are to understand the most effective rehabilitation procedures in the support of the lowest life-cycle cost operation of the wastewater system. This includes understanding all of the various components of life-cycle cost identified in Section 8.2. It also includes understanding the sensitivity of system performance to each of the potential decisions (i.e., the risks associated with doing nothing, underfunding renewal activities, choosing the wrong technology, or providing inadequate inspection and QA/QC procedures).

Such relationships and decisions can be quite well understood in repetitive manufacturing settings where it is relatively easy to collect detailed statistics on materials, equipment maintenance, and manufacturing operations. These data have allowed refinement of manufacturing processes to significantly reduce unacceptable products (e.g., the “Six Sigma” standard). It is not anticipated that such data collection efforts are either realistic in field operations or cost-effective for complex field activities that result in relatively low-value creations. However, it is believed that much better use could be made of data already available during rehabilitation processes and collected during subsequent inspections.

The path forward appears to be for municipalities to be more diligent in collecting and analyzing data that are useful in understanding the impact of rehabilitation efforts on long-term system performance; for a greater sharing of such data, both nationally and internationally, to demonstrate the ability to reduce system operating costs through effective asset management; and to find the right level of expenditure on management and decision-making, as opposed to rehabilitation work in the field.

11.8 Demonstration/Verification of Sewer System Rehabilitation

Nearly 100 different rehabilitation technologies have been identified in this report, and 79 technology datasheets have been included. Other technologies applicable to force main applications and water distribution networks are described in companion reports (EPA, 2010a; EPA, 2010b). Some of these technologies have been used internationally for nearly 40 years and in the U.S. for around 30 years; other technologies are either just being developed or just introduced into the U.S. after substantial experience overseas. On the user side, an annual survey of municipalities indicates that as much as 70% of rehabilitation work is being carried out using trenchless methods (Carpenter, 2009), yet the development of trenchless rehabilitation practices and the commercial market are not fully matured. Municipalities still lack the data to fully understand the relative performance of different rehabilitation technologies and how to specify rehabilitation so that different technologies can compete to the same performance-based requirements. In this context, demonstration projects must do more than simply demonstrate an additional application of technologies that already have some application experience either in the U.S. or internationally.

The EPA demonstration program provides the opportunity to demonstrate models for the acceptance of new products, the creation of QA/QC protocols, and the creation of models that will capture the as-installed condition of rehabilitation technologies, thus providing the basis for tracking their life-cycle cost and performance. Combined with the demonstration of practical protocols for the retrospective evaluation of previously installed rehabilitation technologies, this program will help to create a fuller understanding of the role of trenchless rehabilitation in managing and operating of wastewater systems.

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APPENDIX A

TECHNOLOGY DATASHEETS

The following datasheets represent a useful collection of technology and product descriptions related to the rehabilitation of gravity sewers, laterals, manholes, and ancillary structures to sewer systems. Datasheets that were prepared as part of the companion water rehabilitation and force main rehabilitation reports have also been included in this set where the product/technology has a clear applicability and/or a stated market in the gravity sewer sector. Not all applicable products have been included in the datasheets provided, since there may be many similar commercial offerings of a similar technology. In general, datasheets from major or long-standing providers have been sought to represent each class of product.

The datasheet information was prepared initially by the research team from existing knowledge, product brochures, and company Websites. The datasheets were then forwarded to the technology provider for additional information or clarification. This process has resulted in some variation in the quantity and quality of information available for each product. However, the authors hope that this will be a useful compilation of information on the range of technologies available. Contact information has been provided for the reader to access additional information, as needed.

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Datasheet A-1. AM-LinerII® Fold-and-Form PVC Liner

Technology/Method	**Fold and Form PVC/ Thermoformed**
I. Technology Background	
Status	Conventional
Date of Introduction	1992
Utilization Rates	Over 100 miles for gravity sewer, no force mains
Vendor Name(s)	**AM-Liner II®** American Pipe & Plastics, Inc. PO Box 577 Binghamton, NY 13902 Phone: (607) 775-4340 Email: ampipe@ampipe.com Website: www.amliner.com
Practitioner(s)	Not available.
Description of Main Features	AM-Liner II is manufactured from PVC specially formulated for pipeline rehabilitation. The AM-Liner II is thermoformed, pulled into the host pipe, and thermoformed creating a seamless, jointless, solid-wall PVC pipe, that tightly conforms to the interior contours of the original host pipe.
Main Benefits Claimed	• Installation can be done in under 4 hours – minimizes bypass pumping and traffic control • Liner is manufactured in a controlled environment, not in the field • Installed only by trained licensed contractors • PVC is resistant to all chemicals normally found in a sewer • Smooth interior – low friction factor
Main Limitations Cited	• No experience with pressure applications • May not be cost-competitive with CIPP in diameters over 12”
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other: Culverts
II. Technology Parameters	
Service Application	Gravity wastewater and stormwater
Service Connections	Laterals reinstated robotically. No pressure connections.
Structural Rating Claimed	Fully structural for gravity sewer. Not actively marketed for force mains.
Materials of Composition	PVC compound conforming to ASTM D 1784 Cell Classification 12111. The installed liner has the following minimum physical properties: Property — Test Method — Value Tensile strength, psi — ASTM D638 — 3,600 Tensile modulus, psi — ASTM D638 — 155,000 Flexural strength, psi — ASTM D790 — 4,100 Flexural modulus, psi — ASTM D790 — 145,000 A 25% reduction used for long-term modulus.
Diameter Range, inches	6 to 12 inches
Thickness Range, inches	0.0185 inches (SDR 32.5) to 0.462 inches (SDR 26)
Pressure Capacity, psi	Not available
Temperature Range, °F	Not available
Renewal Length, feet	1,000 feet
Other Notes	Not available

III. Technology Design, Installation, and QA/QC Information	
Product Standards	ASTM F1871, Standard Specification of Folded/Formed Poly (Vinyl Chloride) Pipe Type A for Existing Sewer and Conduit Rehabilitation
Design Standards	ASTM F1867, Appendix X1 (same as F1216)
Design Life Range	Not available
Installation Standards	ASTM F1867, Standard Practice for Installation of Folded/Formed Poly (Vinyl Chloride) (PVC) Pipe Type A for Existing Sewer and Conduit Rehabilitation
Installation Methodology	High-pressure water jet and CCTV line before installing liner. Heat the coil of folded flat AM-Liner II in the trailer until it is flexible enough to uncoil and pull through the shaping device and into the host pipe. Shaping device located at entrance to host pipe, or alternatively on back of heating trailer. High-pressure water hose from cleaning truck is connected to the water spray nozzle assembly on the shaping device. The liner is pulled from the reel, the end (3 feet) folded over, and holes drilled for attachment of the pulling cable. The liner is then winched through the shaping device, after flow of water to the spray nozzles is started. The liner is pulled until it arrives at the downstream pit (manhole) and is brought to street level. The liner is cut at street level at both ends, leaving several ft of extra liner for stress relief. Steam is applied to the liner from the upstream free end. The pressure in the liner is controlled with the release of steam at the downstream end. A temperature of 200^{o}F is maintained for the predetermined length of time. The cooling process is begun by switching from steam to compressed air. The pressure is maintained for 30 minutes after the liner has cooled to 80^{o}F. The pressure is released and the ends trimmed. The liner is CCTV-inspected and service connections reinstated robotically.
QA/QC	Field samples collected per ASTM F1867, Section 7.3. Leakage test after cool down, and before reinstatement of connections.
IV. Operation and Maintenance Requirements	
O&M Needs	Not available
Repair Requirements for Rehabilitated Sections	Not available
V. Costs	
Key Cost Factors	Not available
Case Study Costs	May not be cost-competitive with CIPP above 12”.
VI. Data Sources	
References	AM-Liner Data Sheet, AM-Liner II General Specification (Aug. 16, 2005), AM-Liner Installation Procedure (10/05)

Datasheet A-2. Angerlehner MCS-Inliner GRP Lining

Technology/Method	**MCS-Inliner/GRP relining**
I. Technology Background	
Status	Mature in Europe; novel in U.S.
Date of Introduction	In 1999, "MCS-Inliner®" was internationally registered and patented. Has entered the Indian market.
Utilization Rates	Thousands have been installed.
Vendor Name(s)	**Angerlehner Hoch- und Tiefbaugesellschaft mbH** Pucking, Austria Phone: 43 7 229-798-8881 Email: c.dobretsberger@angerlehner.at Website: www.angerlehner.at
Practitioner(s)	Not available
Description of Main Features	A specially designed reaming machine developed from tunneling technology is used to cut away a specified thickness of the pipe wall of the host sewer pipe and install a glass-fiber-reinforced plastic (GRP) pipe lining, thus maintaining or increasing the cross-sectional area of the existing sewer. The new lining is prefabricated and slid into the sewer in sections and finally grouted in place.
Main Benefits Claimed	• Ability to maintain or increase cross-sectional area while re-lining • Adaptability to a wide range of cross-sectional shapes
Main Limitations Cited	• Not all host pipes or sewers are suitable for the excavation process • Not cost-competitive at shallow depths if open cut is permissible
Applicability (Underline those that apply)	Force Main [✓ Gravity Sewer] Laterals Manholes Appurtenances Water Main Service Lines Other:____________________________
II. Technology Parameters	
Service Application	Large-diameter sewer pipes and tunnels
Service Connections	Not available
Structural Rating Claimed	Fully structural
Materials of Composition	Glass-fiber-reinforced plastic (GRP)
Diameter Range, inches	Person entry
Thickness Range, inches	As needed (lining is prefabricated and grouted in place)
Pressure Capacity, psi	Not available
Temperature Range, °F	Not available
Renewal Length, feet	Limited by ability to slide in new liner sections
Other Notes	Not available
III. Technology Design, Installation, and QA/QC Information	
Product Standards	No U.S. standards
Design Standards	No U.S. standards
Design Life Range	Not available
Installation Standards	No U.S. standards
Installation Methodology	Roadheader-type excavation of the existing sewer wall to a predetermined profile. Lining sections are slid into place and the annular space surrounding the completed lining is grouted in place.
Qualification Testing	In-house testing, 2003: • Material properties: material composition per ASTM D2584, compressive strength per ASTM D 695, flexural strength and modulus per ASTM D790, barcol hardness per ASTM D2583 • Chemical resistance per ASTM C581
QA/QC	Not available
IV. Operation and Maintenance Requirements	
O&M Needs	Not available
Repair Requirements for Rehabilitated Sections	Not available

Technology/Method	**MCS-Inliner/GRP relining**
V. Costs	
Key Cost Factors	• Insertion of road header excavation equipment • Removal of existing sewer wall material
Case Study Costs	Not available
VI. Data Sources	
References	www.angerlehner.at http://www.aquamedia.at/templates/index.cfm/id/2105

Datasheet A-3. Avanti Chemical Grouting Materials

Technology/Method	**Avanti grouts/Chemical grouts**
I. Technology Background	
Status	Mature
Date of Introduction	Chemical grouts started being used in the U.S. in the 1950s for soil stabilization. Around 1960, they were used to stop water infiltration into sewer systems.
Utilization Rates	Estimated millions of ft repaired worldwide/millions of gallons
Vendor Name(s)	**Avanti International, Inc.** Webster, TX Phone: (800) 877-2570 Email: sales@avantigrout.com Website: www.avantigrout.com
Practitioner(s)	City of Plant City, FL; City of Pompano Beach, FL; City of Tampa, FL; City of O'Fallon, MO; City of Sunrise, FL; Lower Southampton Township, PA; City of Ashland, OH; Southwest Suburban Sewer District, WA; Pierce County Utilities Department, WA; City of Anniston, AL; City of Dickson, TN; Lower Allen Township Authority, New Cumberland, PA; City of Fairfield, OH; Miami-Dade Water & Sewer; City of Orlando, FL; County of Hawaii - Dept. Environmental Management; City of Denver, CO
Description of Main Features	Chemically activated gels cure ("gel") when properly mixed with activators and catalysts. **Acrylamide grout** (AV-100) and Acrylic grout (AV-118) are extremely low-viscosity resins (1-2 cP, just like water) with controllable gel times from 5 seconds to several hours. In addition to creating an impermeable water barrier, acrylamide grouts provide for soil stabilization and longevity. The Department of Energy tested the AV-100 and determined it to have a 115-year half-life. **Polyurethane grouts** • Hydrophilic gels (AV-254 and AV-350) are also used to stop water infiltration around underground structures via a technique called curtain-grouting in which the manhole (or other underground structure) is encapsulated by an impermeable gel/soil matrix after resin has been injected into the surrounding soil. • Hydrophilic foams (AV-202. AV-333, AV-310, AV-315, AV-330) are used in cracks in moving concrete because of their flexibility. They expand about 4 to 6 times their original volume and seek water via tiny capillaries in the leaking concrete. Hydrophilic foams lock the water out by creating a compressive, mechanical, and adhesive bond to the concrete. • Hydrophobic foams (AV-248, AV-278, AV-280, and AV-290) are typically used to fill large voids in soils and in places where wet/dry cycles are anticipated. The majority of hydrophobic foams cure to a rigid or semi-rigid state; however, unique hydrophobic foams may be used in moving cracks if they cure flexibly. **Ultrafine cementitious** grouts can be composed to permeate almost any granular soils, including fine sands, and are used to stabilize weak soils. There are two types: a standard grade (sieve analysis of 90% less than 8 microns and an average size of 4 microns) and a premium grade (sieve analysis of 90% less than 5 microns and an average size of 2.5 microns). Both products have set time from a few minutes to several days. The shelf life is unlimited as long as the grout is kept dry.

Technology/Method	**Avanti grouts/Chemical grouts**
Main Benefits Claimed	Acrylamide & Acrylic Grouts: • The thinnest product on the market • Controllable gel times • Product longevity – 115-year half-life • Stabilizing weak soils • Sealing seepage in mines, dams, tunnels, sewers, laterals, manholes • Extremely low permeability grout curtaining • Hazardous waste containment • 1/1 ratio pumping • May add root inhibitors, gel strengtheners, dyes • True solution grout = no suspended solids Polyurethane Gels: • Stabilizing weak soils • Sealing manholes, underground structures, and occasionally in laterals and mainline sewers • Low-permeability grout curtaining 8/1 water/resin ratio Hydrophilic Foam Grouts: • Uses and seeks the water that is present at the leak • Expand 400 to 600% • Cures flexibly • Adhere to concrete • Dense closed-cell foam Hydrophobic Foam Grouts: • Needs very little water to react • Expand 1500 to 2000% • Some are flexible; some are rigid • Dense closed-cell foam Ultrafine Cementitious Grouts: • Stabilizing weak soils • Sealing seepage in mines, dams, and tunnels • Low-permeability grout curtaining • Hazardous waste containment • Oil well squeeze-cementing
Main Limitations Cited	Acrylamide & Acrylic Grouts: • May not be used aboveground • May not be used with potable water applications • Requires stainless steel pump/parts Polyurethane Gels: • Pumped 8:1 • May not be used aboveground • Limited control of cure time Hydrophilic Foam Grouts: • Should be used in a moist environment • No catalyst required Hydrophobic Foam Grouts: • Rigid cure • Catalyst required Ultrafine Cementitious Grouts: • Not true solution grout; contains suspended solids • Limited by porosity of earth strata and size of cement particles • Limited control of cure time
Applicability (Underline those that apply)	Force Main [✓ Gravity Sewer] [✓ Laterals] [✓ Manholes] [✓ Appurtenances] Water Main [✓ Service Lines] Other:___________________________

Technology/Method	**Avanti grouts/Chemical grouts**
II. Technology Parameters	
Service Application	Mainline Sewer Joint sealing, Lateral sealing, Manhole sealing
Service Connections	AV-100/AV-118
Structural Rating Claimed	Non-structural repair
Materials of Composition	Acrylamide grouts Acrylic grouts Polyurethane gels Hydrophilic foam grouts: urethane Hydrophobic foam grouts: urethane Ultrafine cementitious grouts: a finely ground mixture of Portland cement, pumice, and dispersant.
Diameter Range, inches	Not available
Thickness Range, inches	Not available
Pressure Capacity, psi	Cured state approx. 120 psi
Temp Range, °F	Do not recommend grouting below freezing temperatures
Renewal Length, feet	Not available
Other Notes	AV-100/AV-118 designed and engineered to stop I/I
III. Technology Design, Installation, and QA/QC Information	
Product Standards	Not available
Design Standards	Not available
Design Life Range	Longevity study Department of Energy (115-year half-life AV-100)
Installation Standards	ASTM F 2304 Standard Practice for Rehabilitation of Sewers Using Chemical Grouting (Installation of the AV-100/AV-118)
Installation Methodology	AV-100 & AV-118 test-and-seal procedure, curtain grouting, encapsulation Urethanes: V-PAT crack injection, expanded gasket placement (EGP) technique
Qualification Testing	Not available
QA/QC	Not available
IV. Operation and Maintenance Requirements	
O&M Needs	No further action required
Repair Requirements for Rehabilitated Sections	Not available
V. Costs	
Key Cost Factors	Cost-effective way to stop water infiltration
Case Study Costs	http://www.avantigrout.com/files/literature/Would_You_Spend.pdf
VI. Data Sources	
References	www.AvantiGrout.com

Datasheet A-4. Avanti Ultrafine Cementitious Grouts

Technology/Method	**Ultrafine cementitious grouts**
I. Technology Background	
Status	Mature
Date of Introduction	Not available
Utilization Rates	Widespread
Vendor Name(s)	**Avanti International, Inc.** Webster, TX Phone: (800) 877-2570 Email: sales@avantigrout.com Website: www.avantigrout.com
Practitioner(s)	Not available
Description of Main Features	Ultrafine cementitious grouts are composed of a finely ground mixture of Portland cement, pumice, and dispersant. The Ultrafine grout has an average particle size of only a few microns, in contrast to typical particle sizes of 60 to 70 microns in conventional cements.
Main Benefits Claimed	Product applications for Ultrafine Cementitious Grouts include: • Stabilizing weak soils • Sealing seepage in mines, dams, and tunnels • Low-permeability grout curtaining
Main Limitations Cited	• Ability to penetrate cracks and voids for sealing • Excessive grout loss in large voids or connected fissures
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other:__________________________
II. Technology Parameters	
Service Application	Principally manholes
Service Connections	Not applicable
Structural Rating Claimed	Not applicable
Materials of Composition	Portland cement, pumice, and dispersant. Premium and standard grades of cement grout formulated with superplasticizer for a system with zero bleed and very high compressive strengths. Particle sizes are 90% <5 microns averaging 2.5 microns and 90% <8 microns averaging 4 microns.
Diameter Range, inches	Equipment and application process varies with diameter
Thickness Range, inches	Not applicable
Pressure Capacity, psi	Not applicable
Temperature Range, ^{o}F	Limitations during installation only
Renewal Length, feet	Not available
Other Notes	Not available
III. Technology Design, Installation, and QA/QC Information	
Product Standards	Depends on application
Design Standards	Depends on application
Design Life Range	Depends on application
Installation Standards	Depends on application
Installation Methodology	Depends on application
Qualification Testing	Depends on application
QA/QC	Depends on application
IV. Operation and Maintenance Requirements	
O&M Needs	No special needs
Repair Requirements for Rehabilitated Sections	Not applicable
V. Costs	
Key Cost Factors	Accessibility for grouting equipment/personnel; Grout usage
Case Study Costs	Not available
VI. Data Sources	
References	www.avantigrout.com

Datasheet A-5. Berolina Liner CIPP Pull-in-Place

Technology/Method	CIPP/Pull-in-Place/UV Cured
I. Technology Background	
Status	Emerging
Date of Introduction	1997; first usage in Europe, outside Europe since 2001
Utilization Rates	2008: 660,000 feet (200,000 m)
Vendor Name(s)	**Berolina Liner** BKP Berolina Polyester GmbH (a division of Greiffenberger AG) Am. Zeppelinpark, 27 D-13591 Berlin Germany Phone: +49 30 3647 1400 Email: info@bkp.berolina.de Website: www.bkp-berolina.de
Practitioner(s)	Berliner Wasserbetriebe, 10864 Berlin, Germany Mr. Bernhard Czikkus, bernhard.czikkus@bwb.de or Mr. Andreas Rademacher, andreas.rademacher@bwb.de Phone: +49 30 864 44160 PipeFlo Contr. Corp., Mr. Bruce Noble, bruce@pipeflo.ca; 180 Chatham Street, Hamilton, Ontario L8P 2B6, Canada; phone: +19055727767 Arkil Inpipe GmbH, Mr. Werner Manske, Werner.manske@arkil.de; Lohweg 46E, 30559 Hannover, Germany; phone: +495119599536 Tuboseal c.c.; Mr. Jean-Louis Frey, jlf@tuboseal.co.za; P.O. Box 2513; Somerset West, 2 Cape Town, 7129 South Africa; phone: +27824528129
Description of Main Features	The Berolina-Liner is composed of glass-fiber and/or polyester webs impregnated with polyester or vinylester resin. The layers are overlapped and staggered, giving the tube variable stretching capability. The liner is UV-cured. The glass-fiber layer provides sufficient axial strength for pulling the liner into place. BKP produces the Berolina-Liner with a protective inner film and a UV-resistant outer film. The inner film is removed after installation. The outer film also prevents resin from migrating into laterals. The liner is delivered pre-wet-out and ready for installation. The liner can be stored for up to 6 months without cooling.
Main Benefits Claimed	• UV-cured resulting in less CO_2 emission and reliable curing results – neither influenced by groundwater, temperature, and storage time. • For same stiffness, thickness less than polyester felt product. • Inflation by compressed air (7.5 psig) allows CCTV inspection of liner prior to UV cure. • Suitable for circular and oval profiles. • Designed with ring stiffness classes SN1250-10000 (MPa), which is similar to GRP pipe for direct burial. • Can bridge over profile or cross-section changes. • Highest rating in IKT water impermeability tests.
Main Limitations Cited	• BKP production is located in Berlin, Germany. • Not certified for use with potable water. • No long-term pressure regression or tensile testing to substantiate a full structural (Class IV) design.* • No strain corrosion testing as per ASTM D5813 (6.4.2)* • Tests have been done and certified according to European and Japanese standards. ASTM test will follow.
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other: Culverts
II. Technology Parameters	

Technology/Method	**CIPP/Pull-in-Place/UV Cured**
Service Application	Gravity and low-pressure wastewater, stormwater
Service Connections	Laterals are optically located (CCTV) after curing and reinstated with robotic cutters. No provisions for pressure connections.
Structural Rating Claimed	No claim made in literature, but with stiffness class SN10000 through 20" (500MM), liner suitable for fully deteriorated gravity host pipe.
Materials of Composition	The Berolina-Liner is made of up to 5 layers of glass-fiber and/or polyester web that is impregnated with a UV-light-curing polyester resin. BKP uses only ISO NPG resin of the type 1140 according to DIN 16946/2. The resin is qualified for Group 3 in accordance with DIN 18820/1. For demanding requirements, a vinylester resin is used. The inner protective film and outer UV-resistant film are flexible, water-impenetrable, and equipped with a styrene barrier. Minimum initial ring flexural modulus claimed is 1.45×10^6 psi, and the approximate initial tensile modulus is 2.03×10^6 psi.
Diameter Range, inches	6-40 inches (other sizes available upon request)
Thickness Range, inches	0.08-0.47 inches (2mm to 12mm), depending on diameter
Pressure Capacity, psi	New Berolina-LP-Liner (low pressure) currently in test phase with pressure capacity up to 45 psi.
Temperature Range, °F	Polyester resin up to 122°F; Vinylester resin up to 158°F
Renewal Length, feet	1,200 feet (400 m)
Other Notes	Licensed CIPP Corp (Hudson, IA) sold nationwide by US provider as of November 2008. Local contractors acceptable
III. Technology Design, Installation, and QA/QC Information	
Product Standards	According to EN 13566-4/DRAFT INTERNATIONAL STANDARD ISO/DIS 11296-4; ASTM not applicable, new ASTM standard in preparation
Design Standards	ATV-M 127-2; ASTM F1216, Appendix X.1
Design Life Range	Minimum 50 years
Installation Standards	New ASTM standard in preparation; WRc-certified installation manual available
Installation Methodology	• The host pipe is first thoroughly cleaned and CCTV-inspected. A protective film sleeve, covering the lower half of the host pipe, is next drawn into the pipe to be rehabilitated by a winch. The Berolina-Liner is then winched into place and both ends are closed off with end cans. The tube is calibrated using compressed air (7.5 psig), which presses the liner against the host pipe's inner wall. • The outer UV-resistant tube prevents migration of the resin and styrene into the soil and groundwater, and also prevents resin from penetrating the laterals. • After expansion of the liner, a special UV light is "fired" and pulled through the liner at a defined speed. A CCTV camera can monitor the liner during the passage of the light train. • With the tube ends sealed, the curing occurs free of any emissions. • After curing, the inner film is removed, leaving a smooth inner surface. • Laterals are easily identified (outward expansion of liner) and reinstated using conventional robotic cutters.

Technology/Method	**CIPP/Pull-in-Place/UV Cured**
QA/QC	BKP controls the quality of the liner with testing of the liner and components at their plant, as well as during and after curing in the field. Qualification testing of the liner has included: • high-pressure water-jet cleaning (Hamburg Model) – 60 passes • 10,000 hrs fatigue (creep) tests • leakage tests (CP308) (water impermeability) • Darmstadt tilted drain experiment (abrasion test) • burning test The more important QA (factory) requirements are: • reactivity tests of resin • impermeability tests (DIN/EN 1610) • wall thickness measurement • measurement of initial ring stiffness • 3-point bending test (flexural modulus and strength) • barcol hardness • residual styrene content During installation, the more important QC requirements are: • installation pressure diagram • curing speed diagram • number of UV-lights used • temperature diagram After installation, the more important QC requirements are: • impermeability test • wall thickness • measurement of the initial ring stiffness • 3-point bending test • measurement of the resin content (loss on ignition) • residual styrene content • CCTV of liner for visual defects
IV. Operation and Maintenance Requirements	
O&M Needs	None
Repair Requirements for Rehabilitated Sections	Use standard methods for GRP-polyester pipes/products
V. Costs	
Key Cost Factors	Totally trenchless method; no pits needed up to installation of 36” (depending on manhole cover size). Costs mainly driven by wall thickness (according to static needs) and diameter of pipe. Bypass pumping time and cost are limited due to fast installation procedure. Mobilization and site setup reduced because of small footprint; liner is shipped to site ready for use; customized equipment, opening of lateral completely possible directly after installation.
Case Study Costs	No project costs available from BKP.
VI. Data Sources	
References	Website www.bkp-berolina.de; BKP-Berolina brochure (no date); IKT Liner Report (2007)

Datasheet A-6. Blue Shield (PIM Corp) Polyurethane Coating

Technology/Method	**PmB/Blue Shield High Performance Coating**
I. Technology Background	
Status	Mature
Date of Introduction	Not available
Utilization Rates	Not available
Vendor Name(s)	**PIM Corporation** Piscataway, NJ Phone: (732) 469-6224 Email: jtorielli@pimcorp.com Website: www.pimcorp.com
Practitioner(s)	Not available
Description of Main Features	PmB/Blue Shield (Baytec) is a high-grade, twin-component, spray-applied polyurethane elastomer, installed to a minimum tolerance 80 mils thickness
Main Benefits Claimed	• Longevity • Corrosion protection • Preventing chemical contamination of permeable and degradable construction materials
Main Limitations Cited	• Access for spray application • Surface preparation to ensure adequate bonding
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other:___________________________
II. Technology Parameters	
Service Application	Manholes
Service Connections	Not applicable
Structural Rating Claimed	Not applicable
Materials of Composition	Polyurethane
Diameter Range, inches	Not applicable
Thickness Range, inches	Minimum 80 mils
Pressure Capacity, psi	Not applicable
Temperature Range, °F	Applied membrane is elastomeric up to 300% and retains physical properties from -43.6°F to +230°F. PmB/Blue Shield (Baytec) is totally reactive; it is unaffected by prevailing temperatures and by damage from rainfall during installation.
Renewal Length, feet	Not applicable
Other Notes	Not available
III. Technology Design, Installation, and QA/QC Information	
Product Standards	Not available
Design Standards	Not available
Design Life Range	Service life expectancy at this time is in excess of 20 years
Installation Standards	Not available
Installation Methodology	• Rapid installation at 240 square yards per hour per spray plant.
Qualification Testing	Not available
QA/QC	• Site product testing is able to confirm bond quality and installed integrity.
IV. Operation and Maintenance Requirements	
O&M Needs	Avoid mechanical damage of coating
Repair Requirements for Rehabilitated Sections	Manholes only
V. Costs	
Key Cost Factors	• Surface preparation • Material and labor costs
Case Study Costs	• Not available
VI. Data Sources	
References	www.pimcorp.com

Datasheet A-7. Blue-Tek™ (Reline America) CIPP UV Light Cure

Technology/Method	**CIPP/UV Light Cure**
I. Technology Background	
Status	Emerging
Date of Introduction	Developed by Brandenburger in Germany. Introduced by Reline America into US in 2007.
Utilization Rates	5 million feet installed in 24 countries.
Vendor Name(s)	**Blue-Tek™** Reline America, Inc. 116 Battleground Ave. Saltville, VA 24370 Phone: (866) 998-0808 Email: mburkhard@relineamerica.com Website: www.relineamerica.com
Practitioner(s)	Amarillo, TX
Description of Main Features	Glass-fiber-reinforced CIPP liner that is UV-cured. The liner strength stems from a seamless, spirally wound glass-fiber tube. Polyester, vinylester, or ortho resins can be used. All wet-out is performed in the factory. The seamless liner has both an interior and exterior film, with the exterior film blocking UV light.
Main Benefits Claimed	• Glass-fiber-reinforced wall thickness for higher strength and stiffness • Thinner wall than ordinary felt-reinforced liners • Good flow characteristics • Fast curing times for both small and large diameters (250 to 750 ft per hour) • Passed the APS Standard Porosity Test with score of 100% • Quality-Tracker™ System for tracking entire curing process (7 steps) with a data logger and retrieval system. • Reduced styrene emission during curing
Main Limitations Cited	• Not NSF 61 listed – not suitable for potable water • No long-term pressure regression tests for establishing HDB for pressure pipe design – Class III for pressure applications only • 48” diameter is upper limit • Limited licensee contractor base in US at the moment
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other:
II. Technology Parameters	
Service Application	Wastewater, stormwater, and raw water
Service Connections	Remote reinstatement of lateral connections similar to other CIPP products. Lateral Hat™ for connection to sewer laterals.
Structural Rating Claimed	Class III or IV, Semi or Fully Structural
Materials of Composition	Advantex® EC-R glass fiber from Owens Corning and polyester, vinylester, or ortho resin, depending on application.
Diameter Range, inches	6 to 48 inches, circular, oval, egg-shaped and square pipes (60 inches in future)
Thickness Range, inches	Min 0.14 inches (3.5mm)
Pressure Capacity, psi	Short-term flexural modulus - 1.1 × 10^6 psi (up to 2.16 x 10^6 possible) Long-term flexural modulus – 660,000 psi (1.6 reduction factor) Short-term tensile strength – 20,000 to 26,000 psi
Temperature Range, ^{o}F	Not available
Renewal Length, feet	1,000 feet
Other Notes	Not NSF 61 listed yet. May be in the future.

<table>
<tr><th colspan="2">III. Technology Design, Installation, and QA/QC Information</th></tr>
<tr><td>Product Standards</td><td>ASTM F 2019-03</td></tr>
<tr><td>Design Standards</td><td>Not available</td></tr>
<tr><td>Design Life Range</td><td>50 years</td></tr>
<tr><td>Installation Standards</td><td>Not available</td></tr>
<tr><td>Installation Methodology</td><td>The liner is shipped in special containers and UV-protected foil, and can be stored for up to 6 months without refrigeration. Sewage flow needs to be either plugged or bypassed. After sewer is cleaned and CCTV-inspected, the Blue-Tek liner is winched into the existing pipe, inflated with air (6 to 8 psi), and then cured using a UV light train that is pulled through the pipe. Special care is needed to ensure that the exterior film is not damaged during installation. After curing, the inner film is removed and discarded and the liner post CCTV inspected.</td></tr>
<tr><td>QA/QC</td><td>• Verification of UV lamp intensity and number (wattage)
• CCTV inspection of entire line before curing
• Record of liner’s inner air pressure during curing
• Documentation of curing speed (ft/min)
• Resin reaction temperatures (infrared sensors)
• CCTV documentation of curing process
• Physical property tests on specimens from the liner, including water-tightness porosity test</td></tr>
<tr><th colspan="2">IV. Operation and Maintenance Requirements</th></tr>
<tr><td>O&M Needs</td><td>Not available</td></tr>
<tr><td>Repair Requirements for Rehabilitated Sections</td><td>Not available</td></tr>
<tr><th colspan="2">V. Costs</th></tr>
<tr><td>Key Cost Factors</td><td>Not available</td></tr>
<tr><td>Case Study Costs</td><td>Not available</td></tr>
<tr><th colspan="2">VI. Data Sources</th></tr>
<tr><td>References</td><td>www.relineamerica.com</td></tr>
</table>

Datasheet A-8. Carbon Wrap™ Pipe Reinforcement

Technology/Method	**Pipe Wrapping**
I. Technology Background	
Status	Conventional
Date of Introduction	Invented and introduced in 1989 at Arizona State University; largely used in the Southwestern states.
Utilization Rates	Over 100,000 linear feet have been wrapped by the CarbonWrap family of products across the country
Vendor Name(s)	**CarbonWrap** CarbonWrap™ Solutions LLC 3843 N. Oracle Rd. Tucson, Arizona 85705 USA Phone: (866) 380-1269 E-mail: info@carbonwrapsolutions.com Web: http://www.carbonwrapsolutions.com
Practitioner(s)	Not available
Description of Main Features	• One of the most effective and economical applications of CarbonWrap™ is strengthening buried pipes. • Concrete and steel pipes can be strengthened to take pressures even greater than that of their original design value.
Main Benefits Claimed	• Requires no excavation. Increases pipe strength to even higher than its original pressure rating. • Access is made only through manholes. • Creates a very smooth surface and improves pipe flow significantly • Requires no heavy equipment for installation • Low cost compared to equivalent alternatives and results in speedy construction
Main Limitations Cited	Temperature – above 200°F
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other:___________________________
II. Technology Parameters	
Service Application	Repair
Service Connections	This repair technique is only good for the pipe barrel.
Structural Rating Claimed	Structural material
Materials of Composition	Epoxy and carbon
Diameter Range, inches	Works for 3 feet and larger diameter pipe
Thickness Range, inches	One-eighth of an inch thick
Pressure Capacity, psi	Typically approximately 10 times the pipe-pressure capacity
Temperature Range, °F	Application in humid and high temperature is not recommended.
Renewal Length, feet	No limitation-1,000/2,000 feet or shorter lengths
Other Notes	Not available
III. Technology Design, Installation, and QA/QC Information	
Product Standards	NSF 61 compliant
Design Standards	ACI 440
Design Life Range	Minimum 25 years
Installation Standards	As per manufacturer guidelines
Installation Methodology	In the case of 3-feet and larger-diameter pipes, simple access is made through the manholes and all operations are conducted internally. If the pipe can be accessed from the outside, the wrapping can be performed on the outside face of the pipe, resulting in the same benefits. It is generally applied in the following format: Epoxy-fiber-epoxy-fiber.
QA/QC	Not available

Technology/Method	**Pipe Wrapping**
	IV. Operation and Maintenance Requirements
O&M Needs	Regular cleaning is required. Maintenance strategies should include condition assessment measures.
Repair Requirements for Rehabilitated Sections	Not available
	V. Costs
Key Cost Factors	The composite material is generally the key governing cost in the contracts. It may vary from job, to job depending on site accessibility and pipe condition.
Case Study Costs	Material cost at 10 to 15 $/sq. feet
	VI. Data Sources
References	http://www.carbonwrapsolutions.com/PDFinfo/Brochure.pdf Phone correspondence with Dr. Hamid Saadatmanesh. Email correspondence with Faro Mehr.

Datasheet A-9. Channeline SL Segmental Lining Panels

Technology/Method	**Channeline SL/Segmental lining with GRP (FRP) panels**
I. Technology Background	
Status	Conventional
Date of Introduction	1984 in UK and Europe; in US since 1998 Used worldwide: UK, Ireland, Russia, Europe, USA, Argentina, India, Middle East, Hong Kong, South Africa, etc.
Utilization Rates	Estimated 500,000 linear feet of pipes have been rehabilitated with this product (in US or worldwide)
Vendor Name(s)	**Channeline International Ltd.** Head Office: Dubai, UAE North America: Niagara-On-the-Lake, Canada Phone: (289) 668-0351 Email: channelineintl@cogeco.ca Website: www.channelineinternational.com
Practitioner(s)	• District of Chicago, IL, Mr. Paintail, (312) 751-4020 (16,000 feet of 8 feet and 7 feet Elliptical 2001) • City of Los Angeles, CA (LADPW), Keith Hanks, (213) 485-1694 (470 feet of flattened Elliptical pipe, 4 feet x 2 feet 6 inches, rehabilitated in 2002) • City of Cleveland, OH, Brian Page, (216) 881-6600 (2,000 linear feet of oval pipe, 67 inches x 51 inches, rehabilitated in 2007)
Description of Main Features	GRP (FRP) panels or "full perimeter" sections are individually set in place and bonded together, and the annular space is subsequently filled with grout.
Main Benefits Claimed	• High chemical resistance (sewer gases, most industrial effluents) • High-impact and abrasion-resistance • Panels of any required liner type strength and stiffness can be produced using the sandwich construction method. • Self-cleaning property under normal flow conditions • Small alignment changes and offsets can be accommodated (socket- and-spigot jointing method tongue & groove L/joint) • Flow isolation is not required (can be installed with live flow)
Main Limitations Cited	• Large diameters only 36 inches and larger
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other:____________________________
II. Technology Parameters	
Service Application	Wastewater, stormwater, raw water, industrial, power
Service Connections	Laterals can be connected with wire mesh and mortar. Where necessary, for severely degraded lateral connections, repair mortars and GRP inserts can be prefabricated, installed, and subsequently bonded to the main sewer liner to provide a smooth, durable solution.
Structural Rating Claimed	Non-structural corrosion barrier, semi-structural (composite design) or fully structural (stand-alone design)
Materials of Composition	GRP panels have a sandwich construction: • The inner sandwich structure has a 1.5-mm resin-impregnated coating (isophthalic or vinyl ester resin is used) that acts as a corrosion barrier, and an inner sandwich skin made of several layers of resin-impregnated multi-axial engineered fabric (CSM, Chlorosulphonated polyethylene, which is an unsaturated polyester resin, is used) • A central core is made of silica and resin that are mixed and evenly applied to the exact thickness. • An outer sandwich skin is made of several additional layers of multi-axial fabric and CSM resin. The installed liner has the following physical properties:

<table>
<tr><th>Technology/Method</th><th>Channeline SL/Segmental lining with GRP (FRP) panels</th></tr>
<tr><td></td><td><table>
<tr><th>Property</th><th>Test Method</th><th>Value</th></tr>
<tr><td>Flexural modulus, psi</td><td>ASTM D790</td><td>1,450,000</td></tr>
<tr><td>Flexural strength, psi</td><td>N/A</td><td>17,400 (min)</td></tr>
<tr><td>Comp. strength, psi</td><td>ASTM D695</td><td>10,150 (min)</td></tr>
<tr><td>Tensile strength, psi</td><td>ASTM D638</td><td>15,230 (min), wall ≤ 14mm</td></tr>
<tr><td>Tensile elongation, %</td><td>ASTM D638</td><td>8% - 9%</td></tr>
<tr><td>Apparent hoop</td><td>ASTM D2290</td><td>289,980 (min)</td></tr>
<tr><td>Tensile strength, psi</td><td>N/A</td><td>N/A</td></tr>
<tr><td>Identation hardness</td><td>ASTM D2583</td><td>40^{0}</td></tr>
<tr><td>Ring stiffness, psi</td><td>ASTM D2412</td><td>14 (min) at 5% deflection</td></tr>
</table></td></tr>
<tr><td>Diameter Range, inches</td><td>Man-entry diameters, with no theoretical limit to the size and shape</td></tr>
<tr><td>Thickness Range, inches</td><td>Depends on design type (composite, stand-alone or corrosion barrier)</td></tr>
<tr><td>Pressure Capacity, psi</td><td>10 psi</td></tr>
<tr><td>Temperature Range, ^{o}F</td><td>150°F</td></tr>
<tr><td>Renewal Length, feet</td><td>Essentially unlimited, but efficiency drops as the distance from an access point increases. Approx. 1,500 feet for practical reasons.</td></tr>
<tr><td>Other Notes</td><td>Not available</td></tr>
<tr><td colspan="2">III. Technology Design, Installation, and QA/QC Information</td></tr>
<tr><td>Product Standards</td><td>• ASTM D3262 - 06 Standard Specification for "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Sewer Pipe
• BS 5480:1990 Specification for glass-reinforced plastics (GRP) pipes, joints, and fittings for use for water supply or sewerage
• WIS 4-32-01 Guidance Note</td></tr>
<tr><td>Design Standards</td><td>• WRc SRM (Water Research Centre’s Sewer Rehabilitation Manual)
• WRc Type I (composite) design; WRc Type II (stand-alone) design; WRc Type-III (corrosion barrier) design
• BS 8010-2.5 - Code of practice for pipelines - Pipelines on land: design, construction, and installation – Glass-reinforced thermosetting plastics
• ISO/TR 10465-2 - Underground installation of flexible glass-reinforced thermosetting resin (GRP) pipes - Part 2: Comparison of static calculation methods</td></tr>
<tr><td>Design Life Range</td><td>50 years</td></tr>
<tr><td>Installation Standards</td><td>• BS 8010-2.5 - Code of practice for pipelines - Pipelines on land: design, construction, and installation – Glass-reinforced thermosetting plastics
• ISO/TR 10465-1 - Underground installation of flexible glass-reinforced thermosetting resin (GRP) pipes; part 1: installation procedures</td></tr>
<tr><td>Installation Methodology</td><td>• Access pits are dug at suitable locations along the length of the pipeline and the crown of the pipeline is removed to allow insertion of sections.
• Multi-segmented panels are bonded onsite to “full perimeter” liner segments using epoxy bonding compound.
• The segments are lowered into the pipeline opening using a suitably rated crane until they rest in the invert of the pipeline at the pit location.
• A special hydraulic trolley is used to transport each liner segment along the length of the host pipe to the required location. Once in position, the liner segment is centralized and chocked using hardwood wedges.
• Each liner segment is connected to the previously installed one by means of the socket and spigot joint. Once butted together, the joints are injected with a flexible mastic epoxy adhesive/filler.
• The annular space between the liner and the host pipe is filled with a low-viscosity, free-flowing, rapid-setting, and high-strength grout.</td></tr>
</table>

Technology/Method	**Channeline SL/Segmental lining with GRP (FRP) panels**
Qualification Testing	All tests performed with third-party witnessing: • Ring stiffness tests (DIP Chaneline Lab, Dubai, 2008) • Compression test (S.A.Redco, R&D Center, Belgium, 2002) • Flexural modulus tests (DIP Chaneline Lab, Dubai, 2008) • Flexural creep tests (COPRO ASBL, Belgium, 2003/04) • Aging tests, exposure to sulfuric acid (COPRO ASBL, Belgium, 2004) • Leak tests, internal and external (DIP Chaneline Lab, Dubai, 2008)
QA/QC	Daily and batch testing of each material production run is carried out by the QC department to verify conformity with design dimensions (wall thickness, ID, OD, height, and width), bending and flexural modulus, tensile tests, socket and spigot fit, Barcol hardness, and visual appearance. ISO 9001:2000/EN ISO 9001:2000/BS EN ISO 9001/2000/ANSI/ASQC
IV. Operation and Maintenance Requirements	
O&M Needs	None
Repair Requirements for Rehabilitated Sections	None
V. Costs	
Key Cost Factors	• Mobilization • Preparation work required (pipe cleaning, pit excavating) • Cost of material
Case Study Costs	• In Chicago, IL: $900/feet (with 16,000 feet, diameters 7 feet and 8 feet, installed in 2001) • In Cleveland, OH: $1,250/feet (with 2,000 feet, oval 65 inches, installed in 2007)
VI. Data Sources	
References	• http://www.channelineinternational.com/ • Personal communication

Datasheet A-10. Consplit (PIM Corp) Pipe Splitting

Technology/Method	**Consplit (PIM Corp)/Pipe Splitting**
I. Technology Background	
Status	Conventional
Date of Introduction	1994
Utilization Rates	4 miles as of 1996; current length not available
Vendor Name(s)	**ConSPLIT** **PIM Corporation** Piscataway, NJ, Phone: (732) 469-6224 Website: www.pimcorp.com
Practitioner(s)	Owner: Long Island Lighting Co. (Lilco) Location: Long Island, New York Replaced 620’ of 4” with Plastic Pipe Pipeline & Gas Journal, March 1996, Volume 223, Issue 3 City of New York has used the technology to replace tens of thousands of feet of steel and ductile iron pipelines.
Description of Main Features	Splits steel, ductile iron, and plastic pipelines in gas, water, electric, communications, and industrial applications.
Main Benefits Claimed	• Costs 50% less than excavation • Virtually eliminates risk to other utilities • Eliminates open trenches • Splits steel barrel compression couplings • Installation rate of 5 to 6 feet per minute • Up-size or size-for-size replacements
Main Limitations Cited	• Requires bypass pumping, entry and exit pits, and excavations at each lateral location.
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other:___________________________
II. Technology Parameters	
Service Application	Gas, water, electric, communications; industrial applications.
Service Connections	Pits are dug at each service location; each service is disconnected before splitting, then reconnected after the new pipe has been pulled through.
Structural Rating Claimed	Depends on the selection of the new pipe to be installed.
Materials of Composition	Depends on the selection of the new pipe to be installed.
Diameter Range, inches	2-8 inches
Thickness Range, inches	Depends on the selection of the new pipe to be installed.
Pressure Capacity, psi	Depends on the selection of the new pipe to be installed.
Temperature Range, ^{o}F	Depends on the selection of the new pipe to be installed.
Renewal Length, feet	400 feet is typical.
Other Notes	Not available
III. Technology Design, Installation, and QA/QC Information	
Product Standards	Depends on the selection of the new pipe to be installed.
Design Standards	Depends on the selection of the new pipe to be installed.
Design Life Range	Depends on the selection of the new pipe to be installed.
Installation Standards	Guideline Specification for the Replacement of Mainline Sewer Pipes by Pipe Bursting. (IPBA, NASSCO), Guidelines for Pipe Bursting (TTC).
Installation Methodology	The patented ConSplit tool is launched into an existing pipe at an entry pit and pulled through the pipeline to an exit pit. The old pipe is split open and expanded out into the soil, allowing a polyethylene pipe to be pulled into the enlarged hole immediately behind the ConSplit tool. As the ConSplit tool moves through the old pipe, two cutting wheels press a deep cut into the interior pipe wall. The eccentric body of the ConSplit expander concentrates stress at the cut. This tears the pipe along the cut and opens it smoothly without high pulling forces. A sail

Technology/Method	**Consplit (PIM Corp)/Pipe Splitting**
	blade located between the cutting wheels and eccentric body cuts through repair clamps. When especially strong fittings, such as steel barrel compression couplings, are encountered, a pneumatic hammer inside the ConSplit tool supplies the added force needed to drive the blade through the coupling. When the splitting operation is complete, the new polyethylene pipe has been simultaneously installed.
Qualification Testing	Not available
QA/QC	A post-installation CCTV inspection is conducted to ensure the new pipe is free of defects.
IV. Operation and Maintenance Requirements	
O&M Needs	O&M consistent with that of a newly installed pipe.
Repair Requirements for Rehabilitated Sections	Not available
V. Costs	
Key Cost Factors	Requires entry and exit pits as well as pits at the location of each lateral for reconnection. Bypass pumping is required to divert the flow during installation. Material costs are dependent on the selection of the new pipe to be installed.
Case Study Costs	$90 - $110/linear feet (Survey of Bid Prices, TTC)
VI. Data Sources	
References	PIM Website, Underground Construction Article (2002); Guidelines for Pipe Bursting (TTC).

Datasheet A-11. Danby Panel Lok PVC Liner

Technology/Method	**Danby Panel Lok/Rigid PVC panels**
I. Technology Background	
Status	Conventional
Date of Introduction	Not available
Utilization Rates	Not available
Vendor Name(s)	**Danby of North America, Inc.** Cary, NC Phone: (919) 467-7799 Email: danby@mindspring.com Website: www.danbyrehab.com
Practitioner(s)	Not available
Description of Main Features	Danby Panel Lok, which is used in a variety of man-entry applications, is a series of ribbed plastic panels which are placed inside a pipe and locked together on the edges to form a continuous liner. The PVC panels incorporate male and corresponding female double-locking edges.
Main Benefits Claimed	Minimum loss of diameter, improved hydraulic capacity, an effective barrier to hydrogen sulfide corrosion, and greater flexibility in structural repair
Main Limitations Cited	Not available
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other:___________________________
II. Technology Parameters	
Service Application	Wastewater, stormwater, raw water, industrial, power
Service Connections	Opened and sealed by hand
Structural Rating Claimed	Not available
Materials of Composition	PVC, cementitious grout
Diameter Range, inches	Any man-entry (36 inches and larger)
Thickness Range, inches	0.5 to 1 inch in panel thickness
Pressure Capacity, psi	Not available
Temperature Range, °F	Not available
Renewal Length, feet	No special limit
Other Notes	Not available
III. Technology Design, Installation, and QA/QC Information	
Product Standards	Not available
Design Standards	Project-specific
Design Life Range	Not available
Installation Standards	ASTM F1698
Installation Methodology	The panels and joiner strip are light and easily handled and can be passed through a narrow opening or manhole; therefore, there is no need for excavation. Installation is quick and simple. The edges form a circumferential joint which is simply snapped together by a smaller joiner strip. The joiner strip utilizes a flexible polymer co-extrusion to make the joint gas- and water-tight. Both the panels and joiner strips are manufactured from rigid PVC. Panel Lok is extruded in 12 inches (300 mm) widths with an overall profile height of either 0.5 or 1.0 inch. After installation, the annular space between the panels and the host pipe is grouted with a cementitious grout.
Qualification Testing	ASTM F1735
QA/QC	Not available
IV. Operation and Maintenance Requirements	
O&M Needs	Not available
Repair Requirements for Rehabilitated Sections	Not available
V. Costs	
Key Cost Factors	Not available
Case Study Costs	Not available
VI. Data Sources	
References	www.danbyrehab.com

Datasheet A-12. Danby Panel Lok GIPL

Technology/Method	**Danby Panel Lok/Grout-in-Place PVC liner (GIPL)**
I. Technology Background	
Status	Conventional
Date of Introduction	Developed in Australia in 1984; in USA since 1988. Danby material suppliers in USA, UK, Japan, Australia and Dubai.
Utilization Rates	Approximately 1 million feet of liner installed in the US.
Vendor Name(s)	Danby LLC Houston, TX Phone: (281) 598-0326 Website: www.danbyrehab.com
Practitioner(s)	• Houston, TX, PW Dept, Approx. 25,000 LF of large-diameter (60-84 inches) sewer rehab since formal approval in 1996. • City of Los Angeles, Keith Hanks, (213) 485-1694 /Keith.Hanks@lacity.org, Approx. 10,000 LF of large-diameter (36-84 inches) sewer rehab since formal approval in 1991. • Illinois DOT, Mr. James Miller, (309) 671-3451, (120 inches CMP pipe rehabilitated with 114 inches ID liner, spirally wound and grouted, 400 LF, 2001) • Oregon DOT, John Woodroof, P.E., (509) 986-3366 (72 & 84 inches CMP culverts rehabilitated, spirally wound, and grouted, 215 LF, 2002)
Description of Main Features	The liner is made from rigid PVC either spirally wound strip or from panels installed as arches. The strip has "T"-shaped ribs on one side, which provide a mechanical anchor for the PVC liner as the annular gap is filled with suitable grout; smooth surface on the other (flow surface) side. The panels are 12 inches wide and can be made in lengths specific to the job requirements (the length is practically limited by the ability of trucks to deliver them onsite, e.g., up to 50 feet). The PVC is coiled (150' to 300') for spiral-wound applications. The annular space between the PVC liner and the host pipe is filled with high-strength grout. The grout is the primary structural element (GIPL).
Main Benefits Claimed	• Minimum loss of diameter • Improved hydraulic capacity • An effective barrier to hydrogen sulfide corrosion • Greater flexibility in structural repair
Main Limitations Cited	Person-entry sizes only
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other: Pump Stations, Box culverts
II. Technology Parameters	
Service Application	Wastewater, stormwater, raw water, industrial, power
Service Connections	Re-established as lining is installed
Structural Rating Claimed	Yes
Materials of Composition	PVC, cementitious grout
Diameter Range, inches	Any man-entry (36 inches and larger)
Thickness Range, inches	0.5 to 1 inch in panel thickness
Pressure Capacity, psi	Depends on diameter and condition of host pipe
Temperature Range, ^{o}F	< 140° F
Renewal Length, feet	Unlimited
Other Notes	Include specific notes here such as water quality, I/I control, other
III. Technology Design, Installation, and QA/QC Information	
Product Standards	• ASTM D1784 • ASTM F1735
Design Standards	ASTM F1698
Design Life Range	50 years plus
Installation Standards	ASTM F1698
Installation Methodology	**Preparation.** Hydroblasting is recommended to remove buildup of grease and

Technology/Method	**Danby Panel Lok/Grout-in-Place PVC liner (GIPL)**
	other foreign matter from walls and all loose tiles and aggregate. Prior to lining, steel welded wire mesh can be placed inside the pipe (in concrete pipes). Rebar beam bolsters can be installed (in corrugated metal pipes) to serve as annulus spacers and grout anchors to host pipe. **(a) Spiral winding.** The PVC strip for winding is delivered onsite in coils. The strip is taken into the pipe's interior by simply pulling it from the inside of the bound coil. One end of the liner is formed, usually at the upstream starting point, by creating a circular hoop of desired diameter. The edge joints of adjacent windings are joined together by a second "joiner" strip that is inserted with an air hammer. The joiner strip has a co-extruded rubber gasket that forms a compression seal, making the joint watertight. **(b) Lining with PVC Panels.** Ribbed plastic panels are used for lining, which can be made to match any shape of the host culvert pipe. The panels are placed inside a pipe and locked together on the edges (snapped) to form a continuous liner. **Grouting.** The annular space is subsequently filled with grout.
Qualification Testing	• Utah State University, Logan, UT • *Strength of Buried Broken Rigid Pipes with Danby Liners* by Reynolds K. Watkins • Structural strength: D-Load Tests (County Sanitation District of Los Angeles, CA, 1994)
QA/QC	See ASTM F1698 & F1735.
IV. Operation and Maintenance Requirements	
O&M Needs	Treat as any other PVC pipe
Repair Requirements for Rehabilitated Sections	Can be cut and patched as needed
V. Costs	
Key Cost Factors	Mobilization cost dominates short-length rehab (<1,000 LF), flow diversion/bypass cost may dominate large-diameter rehab.
Case Study Costs	Actual job bid cost range from $8 to $13/ID-in/ft
VI. Data Sources	
References	www.danbyrehab.com

Datasheet A-13. DeNeef Chemical Grouting Materials

Technology/Method	**DeNeef grouts/Chemical grouts**
I. Technology Background	
Status	Mature
Date of Introduction	1973
Utilization Rates	Estimated millions of ft repaired worldwide
Vendor Name(s)	**De Neef Construction Chemicals** Houston, TX Phone: (713) 896-0123 Email: eparadis@deneef.com Website: www.deneef.com
Practitioner(s)	Hundreds of cities, including Seattle, WA; Gainesville, FL; Yakima, WA; also many cities in Europe (as acrylamides are not allowed in the E.U.) (e.g., Antwerp, Belgium; Frankfurt, Germany)
Description of Main Features	Chemically activated grouts cure ("gel") when properly mixed with activators and catalysts. **Acrylate chemical grout** (AC-400) is a sealant designed for controlling infiltration in sewer joints, for water control during tunneling operations, and for curtain grouting. The grout contains no acrylamide monomer. **Hydrophilic polyurethane gel** (HYDRO ACTIVE Multigel NF) is designed to react with water and form a water-impermeable gel mass. The grout is a pale yellow, nonflammable liquid, which begins to foam or gel when it comes into contact with water; depending on the temperature and amount of water present, it quickly cures to a flexible, impermeable foam or gel mass unaffected by mildly corrosive environments. Cure times can be modified using accelerator. NSF/ANSI 61 potable-water-approved.
Main Benefits Claimed	Acrylate Grout: • Contains only 1/100 the toxic exposure of acrylamide grout and 1/50 the toxic exposure of NMA • Operates in existing chemical grout equipment currently used to place acrylamide grout with no modification requirements • Provides low-viscosity grout (1 to 3 cps) that penetrates the sewer joint and the soil around the joint. • Exhibits very low permeability (5x10^{-9} cm/sec) for long-term infiltration control • Available in liquid form (40% solids) and presents no dust toxicity hazard. • Not flammable or explosive • Because of the low toxicity level of AC-400 grout, no certification program is required to use this grouting system • No haz-mat shipping required Polyurethane Grouts: • 18 Standard Resins • 7 products with ANSI/NSF 61 potable-water approval • High chemical resistance • Stops high-volume water flows
Main Limitations Cited	Acrylate Grouts: • May not be used aboveground without proper additives • Generally not applicable for potable water application • Requires stainless-steel pump/parts Hydrophilic Polyurethane Grouts: • Water temperature determines set time • Hydrophilic grouts may shrink if exposed to wet/dry cycling.

Technology/Method	**DeNeef grouts/Chemical grouts**
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other: Storm pipe systems
II. Technology Parameters	
Service Application	Mainline sewer joint sealing, lateral sealing, manhole sealing
Service Connections	Not available
Structural Rating Claimed	Non-structural repair
Materials of Composition	• Acrylate grouts • Hydrophilic polyurethane gels
Diameter Range, inches	Not available
Thickness Range, inches	Not available
Pressure Capacity, psi	Not available
Temp Range, ^{o}F	Precondition materials; follow cold weather instructions
Renewal Length, feet	Not available
Other Notes	Not available
III. Technology Design, Installation, and QA/QC Information	
Product Standards	Not available
Design Standards	Not available
Design Life Range	Longevity study by Swedish National Testing Institute: 110 years
Installation Standards	As per manufacturers' specifications, info@deneef.com
Installation Methodology	Test-and-seal pipeline procedures, point grouting via probe injection, pressure injection, curtain-grouting of manhole and lift stations
Qualification Testing	Not available
QA/QC	Not available
IV. Operation and Maintenance Requirements	
O&M Needs	No further action required
Repair Requirements for Rehabilitated Sections	Not available
V. Costs	
Key Cost Factors	• Acrylates - No haz-mat shipping • Polyurethane - low equipment cost
Case Study Costs	Not available
VI. Data Sources	
References	www.deneef.com; www.deneef.net

Datasheet A-14. Duraliner (Underground Solutions) Expandable PVC Pipe

Technology/Method	**Duraliner™ expandable PVC pipe/Continuous Sliplining**
I. Technology Background	
Status	Conventional
Date of Introduction	Not available
Utilization Rates	Not available
Vendor Name(s)	**Underground Solutions, Inc.** 229 Howes Run Road Sarver, PA 16055 Phone: (724) 353-3000 Email: info@undergroundsolutions.com Website: www.undergroundsolutions.com
Practitioner(s)	Not available
Description of Main Features	Duraliner™ is a patented, fully structural pipe rehabilitation system. The piping system can handle a wide range of system operating pressures and restore or improve the flow capacity of the host pipe. Duraliner™ PVC provides a design life of 100+ years. The end result is a brand new pipe within the existing pipe.
Main Benefits Claimed	• Meets system operating pressure requirements. • Fully structural "stand-alone" system. • Is resistant to water-disinfectant-induced oxidation and resistant to hydrocarbon permeation.
Main Limitations Cited	Not available
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other: Fire protection systems, Industrial water lines
II. Technology Parameters	
Service Application	Rehabilitation and replacement
Service Connections	• Duraliner™ is tapped with standard fittings and procedures. • Duraliner™ easily connects with standard fittings and valves. • Most common applications have Duraliner™ expanded to ductile iron (DI) outside diameters (OD), making standard PVC-gasketed fittings compatible. Connect to MJ. • Duraliner™ may be tapped with the same tapping saddles used on conventional PVC. • When tapping Duraliner™, one should refer to the Uni-Bell PVC Pipe Association's guidance for tapping PVC.
Structural Rating Claimed	Fully structural for both gravity- and pressure-pipe applications
Materials of Composition	PVC
Diameter Range, inches	4 to 16 inches
Thickness Range, inches	Not available
Pressure Capacity, psi	150 psi+
Temperature Range, °F	Not available
Renewal Length, feet	Not available
Other Notes	The improved coefficient of friction offsets the reduction in internal area to maintain or improve flow.

III. Technology Design, Installation, and QA/QC Information	
Product Standards	NSF-61-certified Products meet all of the same current performance standards and health/safety issues as AWWA C900 and C905 PVC pipe.
Design Standards	It conforms to cell classification 12454 as defined in ASTM D1784; meets ANSI/AWWA C900 or ANSI/AWWA C905
Design Life Range	100-year design life
Installation Standards	Not available
Installation Methodology	1. Minimal excavations are performed. 2. Duraliner™ is fused to length for the project. 3. Duraliner™ is expanded tightly against the interior walls of the host pipe. 4. Exposed ends of the Duraliner™ are expanded to standard fitting sizes. 5. The new Duraliner is cut to length and reconnected to system. 6. Fused Duraliner™ is inserted into cleaned, inspected host pipe.
QA/QC	Not available
IV. Operation and Maintenance Requirements	
O&M Needs	As Duraliner™ is expanded; molecular reorientation increases its hydrostatic design basis. This works toward offsetting the DR increase from expansion in the pressure rating.
Repair Requirements for Rehabilitated Sections	No special requirements.
V. Costs	
Key Cost Factors	Not available
Case Study Costs	Not available
VI. Data Sources	
References	www.undergroundsolutions.com

Datasheet A-15. Easy Liner Lateral Lining System

<table>
<tr><th>Technology/Method</th><th>House Liner™, Junction Liner™/Lateral CIPP</th></tr>
<tr><td colspan="2">I. Technology Background</td></tr>
<tr><td>Status</td><td>Innovative</td></tr>
<tr><td>Date of Introduction</td><td>House Liner™ was developed in Great Britain, 1989. Available in U.S. since 2000. Used in U.S., Europe, and Australia.

Junction Liner™ was developed in Great Britain, 2002. Available in U.S. since 2004. Used in UK, Europe, and U.S.</td></tr>
<tr><td>Utilization Rates</td><td>Estimated 10,000 feet laterals relined with House Liner in U.S. and 8.5 million feet laterals worldwide.

Estimated 2,000 feet laterals relined with Junction Liner in U.S. and 100,000 feet laterals worldwide.</td></tr>
<tr><td>Vendor Name(s)</td><td>Easy Liner, Inc.
Thomasville, PA
Phone: (888) 639-7717
Email: andyc@easy-liner.com
Website: http://easy-liner.com</td></tr>
<tr><td>Practitioner(s)</td><td>Not available</td></tr>
<tr><td>Description of Main Features</td><td>House Liner™ is a standard CIPP product for lateral relining installed through a cleanout or a small pit. The liner is air-inverted and ambient-temperature-cured. The final product stops infiltration, eliminates root intrusion, is chemically resistant, provides full structural repair (can bridge missing pipe sections) and carries a 50-year manufacturer's warranty.

Junction Liner™ is remotely installed, needing access only from the mainline.</td></tr>
<tr><td>Main Benefits Claimed</td><td>Requires single access point so laterals can be relined without entering private property or can be done from the mainline
Can reline through 4" to 6" transitions, through multiple bends (several 22°, 45°, 90° bends)
Quick installation (1 to 2 hrs cure, 3 hrs per lateral)</td></tr>
<tr><td>Main Limitations Cited</td><td>Connection with mainline not sealed
Not applicable in laterals with severe mineral buildup, severe offset joints, or sags in the pipe
Flow isolation required (flow bypass required in some cases)</td></tr>
<tr><td>Applicability
(Underline those that apply)</td><td>Force Main Gravity Sewer [✓ Laterals] Manholes Appurtenances
Water Main Service Lines Other:____________________________</td></tr>
<tr><td colspan="2">II. Technology Parameters</td></tr>
<tr><td>Service Application</td><td>Gravity or force lines</td></tr>
<tr><td>Service Connections</td><td>Not applicable</td></tr>
<tr><td>Structural Rating Claimed</td><td>Fully structural</td></tr>
<tr><td>Materials of Composition</td><td>Tube material is polyester (knitted or needle punched). Resin is polyester or epoxy. Protective coating is PU or PVC (after installation facing the inside of pipe).

The installed liner has the following physical properties :<table><tr><th>Property</th><th>Test Method</th><th>Value</th></tr><tr><td>Flexural modulus</td><td>ASTM D790</td><td>250,000 psi</td></tr><tr><td>Flexural strength</td><td>ASTM D790</td><td>4,500 psi</td></tr></table></td></tr>
<tr><td>Diameter Range, inches</td><td>Lateral ID 2-6 inch; Mainline pipe diameter 8 - 15 inches</td></tr>
<tr><td>Thickness Range, inches</td><td>Nominal liner thickness 3.0 to 5.0 mm</td></tr>
<tr><td>Pressure Capacity, psi</td><td>Not applicable</td></tr>
<tr><td>Temperature Range, °F</td><td>160°F</td></tr>
<tr><td>Renewal Length, feet</td><td>300 feet in single run</td></tr>
</table>

Technology/Method	**House Liner™, Junction Liner™/Lateral CIPP**
Other Notes	Not available
III. Technology Design, Installation, and QA/QC Information	
Product Standards	ASTM F1216
Design Standards	ASTM 1216-03
Design Life Range	50-year manufacturer's warranty
Installation Standards	Not available
Installation Methodology	Inversion through a cleanout Junction liner relining method: Special vessel tube is used.
Qualification Testing	Not available
QA/QC	Post-installation CCTV inspection is performed to verify the proper cure of the material and the integrity of seamless pipe.
IV. Operation and Maintenance Requirements	
O&M Needs	None
Repair Requirements for Rehabilitated Sections	The pipe is cleaned (all roots and debris removed); heavy leaks are sealed using chemical grouting, and the pipe is inspected with a pan/tilt camera prior to lining.
V. Costs	
Key Cost Factors	• Density of laterals on the mainline between two manholes (i.e., the frequency of setting up the lateral equipment) • Preparation work required (removal of roots and soft deposits in the lateral pipe, cleaning) • Cost of material
Case Study Costs	• $1,500 to $3,000 per lateral (manufacturer's quote)
VI. Data Sources	
References	• WERF, 2006. Methods for Cost-Effective Rehabilitation of Private Lateral Sewers, 02CTS5, Water Environment Research Foundation, Alexandria, VA, 436p. • http://easy-liner.com

Datasheet A-16. EX Pipe (Miller Pipeline) Fold-and-Form PVC Liner

Technology/Method	**Ex Pipe Fold & Form PVC/Thermoformed**
I. Technology Background	
Status	Conventional
Date of Introduction	1999
Utilization Rates	200 miles in the past 10 years.
Vendor Name(s)	**EX Pipe** **Miller Pipeline** P.O. Box 34141 Indianapolis, IN 46234 Phone: (800) 428-3742 Email: info@millerpipeline.com
Practitioner(s)	City of Plano – Over 200,000 LF installed Steve Spencer P.O. Box 860358 Plano, Texas 75086 (972) 769-4140 Anne Arundel Co, MD – Over 130,000 LF installed Lew Addison 504 Baltimore Annapolis Blvd. Severna Park, MD 21146 (410) 647-2727 Collier County, FL – Over 100,000 LF installed Steve Nagy 6027 Shirley St. Naples, FL 34109 (239) 591-0186
Description of Main Features	EX Pipe is a high-strength, un-plasticized PVC manufactured in a factory environment, meeting ASTM F1504. The EX Pipe material is softened with heat and continuously inserted into the host pipe via manholes or other access points. After insertion, the pipe is then expanded approximately 10% to fit tightly within the host pipe.
Main Benefits Claimed	• Resistant to chemicals and abrasion • Stops water infiltration and exfiltration, root intrusion, and soil loss • Smooth pipe finish improves flow characteristics • Cost to install EX Pipe is much less than conventional trenching techniques • No styrene odors • Low coefficient of thermal expansion means service cutouts will not move • Can be installed in lines with 90^{o} bends and small-diameter changes • Minimal reduction in cross section
Main Limitations Cited	• Only available in diameters 6 to 15 inches • Installation by Miller Pipeline only • No long-term pressure or tensile testing to substantiate a hydrostatic design basis for pressure use
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other:
II. Technology Parameters	
Service Application	Not available.
Service Connections	Sewer laterals reinstated with robotic cutter and CCTV. No information on use of EX Pipe for low-pressure applications.
Structural Rating Claimed	Not available.
Materials of Composition	EX Pipe is made from a base PVC, conforming to ASTM D1784, cell classification 12334B. The following are physical properties of EX Pipe: Property Test Method Value

Technology/Method	**Ex Pipe Fold & Form PVC/Thermoformed**
	Flexural Modulus, psi ASTM D790 340,000 Flexural Strength, psi ASTM D790 9,000 Tensile strength, psi ASTM D638 6,000 Coeff. of thermal expansion, in/in/°F 3.0 x 10^{-5} Long-term reduction of flexural modulus for creep – 50%.
Diameter Range, inches	6 to 15 inches
Thickness Range, inches	0.20-0.43 inches
Pressure Capacity, psi	Not available
Temperature Range, °F	140°F
Renewal Length, feet	6 inches to 600’; 8 inches to 580’; 10 inches to 425’; 12 inches to 425’; 15 inches to 350’
Other Notes	No NSF 61 listing, so not approved for potable water.
III. Technology Design, Installation, and QA/QC Information	
Product Standards	ASTM F1504
Design Standards	ASTM F1947, Appendix X1 (same as F1216)
Design Life Range	50 years
Installation Standards	ASTM F1947
Installation Methodology	Existing pipe is first cleaned and CCTV performed. Protruding service connections are removed, and partially collapsed sections repaired (open cut). The EX Pipe is heated in the pipe warmer trailer to soften the PVC. Once softened, the EX Pipe is winched through the host pipe. Once in place, steam and pressure are applied to expand the PVC tightly against the host pipe. Steam is then replaced with air, while maintaining a constant pressure and the PVC is cooled to 100°F. After cooling, the PVC is trimmed at each pipe end. If for gravity sewer, house service connections are reopened using robotic cutting devices combined with a CCTV.
QA/QC	CCTV of the line is performed after installation. A section of pipe (“coupon”) is removed from each run of pipe for independent testing. Testing should include flexural and tensile properties, as a minimum.
IV. Operation and Maintenance Requirements	
O&M Needs	Same as PVC pipe
Repair Requirements for Rehabilitated Sections	Same as PVC pipe
V. Costs	
Key Cost Factors	• Avg. length of line per setup • Number of laterals to be reconnected • On 12 to 15 inches bypass, pumping can become a cost factor • Heavy cleaning or protruding tap removal • Limited easement access • Point repairs of collapsed or partially collapsed pipe
Case Study Costs	$20 to $45 LF, depending on size and quantities
VI. Data Sources	
References	www.millerpipeline.com

Datasheet A-17. Flowtite® Preformed FRP Manhole Unit

Technology/Method	**Flowtite Fiberglass Rehabilitation Manholes /Glass-Fiber Reinforced Polyester (FRP) Rehabilitation Manholes**
I. Technology Background	
Status	Mature
Date of Introduction	Since 1974 in U.S.
Utilization Rates	Thousands have been installed in US.
Vendor Name(s)	Containment Solutions Inc Conroe, TX Phone: (512) 527-0719 Email: dscamardo@csiproducts.com Website: www.containmentsolutions.com
Practitioner(s)	• New York State Correctional Facilities, NY, Jay Leary, *Ramsco*, (518) 273-6300 (in Oneida Correctional Facility, Rome, NY, 145 rehab manholes, 42 inches -diameter installed in 2005; in Attica Correctional Facility, Buffalo, NY, 90 rehab manholes, 42 inches -diameter, installed in 2003) • City of Corpus Christi, TX, Foster Crowell, (361) 857-1800 (50 rehab manholes, 42 inches -diameter, installed in 2005; additional 12 rehab manholes, 42 inches -diameter, installed in 2008) • Kankakee San. Sewer Dist, IL, Vince Thompson, (815) 933-0447 (38 rehab manholes, 42 inches -diameter, installed in 2004)
Description of Main Features	A one-piece monolithic manhole unit that is made to be installed within an existing deteriorated concrete, brick, or precast manhole. The unit is constructed of unsaturated polyester resin, glass-fiber reinforcements, and chemically enhanced silica to improve corrosion resistance, strength, and overall performance. The installation can often be accomplished without sewage bypassing or diversion.
Main Benefits Claimed	• Lightweight, strong, and durable • Watertight construction (no sidewall joints, seams, or sections to let groundwater in or wastewater out) • Corrosion-resistant • Not subject to "float-out" due to buoyancy • Installation in live conditions • Fast installation (on average, requires 3 to 8 hrs) • Low cost compared to other manhole rehabilitation options
Main Limitations Cited	• Reduction in manhole inside diameter occurs • Not suitable for oddly shaped manholes
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other:____________________________
II. Technology Parameters	
Service Application	Manholes
Service Connections	Not applicable
Structural Rating Claimed	Fully structural. Engineered to withstand a 16,000-lb vertical dynamic load (AASHTO H-20)
Materials of Composition	The manhole is made of laminate that comprises multiple layers of glass matting (reinforcing material) and resin. Glass matting is commercial grade "E"-type glass. Resin is unsaturated isophthalic polyester.
Diameter Range, inches	42 to 90 inches, in 6 inches increments (inside diameter of manhole units) The top is reduced to a circular manway not smaller than 22.5 inches ID
Thickness Range, inches	As necessary determined by depth.
Pressure Capacity, psi	Not applicable
Temperature Range, °F	Not available
Renewal Length, feet	3 feet to 40 feet, in 6 inches increments (height of manhole units)
Other Notes	Not available

Technology/Method	**Flowtite Fiberglass Rehabilitation Manholes /Glass-Fiber Reinforced Polyester (FRP) Rehabilitation Manholes**
III. Technology Design, Installation, and QA/QC Information	
Product Standards	ASTM D3753: Standard Specification for Glass-Fiber Reinforced Polyester Manholes
Design Standards	Not available
Design Life Range	50 years
Installation Standards	Not available
Installation Methodology	An area around the top of the existing manhole is excavated sufficiently wide and deep for removal of old castings (ring and cover) and reducer (cone) section. The bottom of the rehabilitation manhole is cut to fit existing manhole invert as closely as possible (good fit is essential to support H-20 wheel loads). Cutouts are made in the rehabilitation manhole wall to accommodate existing inlets, drops, and cleanouts using an electric or gasoline saw fitted with a masonry-type blade or with a special jigsaw. A 4 inches × 4 inches timber is inserted crosswise inside the new manhole to the underside of the collar and attached to a backhoe with a rope or chain. The new manhole is inserted into the existing manhole, and the annular space between two manholes is grouted. Portland cement and sand grout mixture is used and poured in layers of not more than 12 inches. Backfill (stabilized sand or crushed stone) is placed evenly around any exposed portions of the manhole in 12 inches maximum lifts and compacted to 95% standard proctor density before the next layer is installed. A chimney is constructed on flat shoulder of manhole using precast concrete rings to bring the new manhole unit to grade.
Qualification Testing	The product has been tested by a third party to verify that it meets ASTM 3753. The testing party was Clark Engineers.
QA/QC	Each manhole unit is inspected (for dimensional requirements, hardness, and workmanship) before it is released for shipping.
IV. Operation and Maintenance Requirements	
O&M Needs	Virtually no maintenance recommended after the repair.
Repair Requirements for Rehabilitated Sections	Bench and invert may need to be rehabilitated, as necessary.
V. Costs	
Key Cost Factors	• Material costs • Labor
Case Study Costs	• In NY: Approx. $3,200 per manhole, assuming unit cost of $400/VF and average manhole depth of 8 feet (in two correctional facilities) • Manufacturer's quote: Material costs only approx. $125/VF
VI. Data Sources	
References	http://www.containmentsolutions.com/about/index.html

Datasheet A-18. Fusible C-900/905 (Underground Solutions) PVC Pipe

Technology/Method	**Fusible C-900/905 Pipe/Sliplining/HDD/Pipe Bursting/Direct Bury**
I. Technology Background	
Status	Emerging
Date of Introduction	Introduced November 2003. First commercial installation January 2004.
Utilization Rates	Over 1 million linear ft installed since 2004
Vendor Name(s)	**Fusible C-900®/Fusible C-905®/FPVC™** **Underground Solutions, Inc. (UGSI)** 13135 Danielson Street- Suite 201 Poway, CA 92064 Phone: (858) 679-9551 Email: info@undergroundsolutions.com Website: www.undergroundsolutions.com
Practitioner(s)	Over 700 projects with municipal and industrial users in 40 out of 50 states, Canada, and Mexico. Primarily used for pressurized potable water, reclaim, and wastewater lines
Description of Main Features	Fusible PVC™ pipe is extruded from a specific formulation of PVC resin which allows the joints to be butt-fused together using UGSI's fusion process. Industry standard butt-fusion equipment is used with some minor modifications. The resin/compound meets the PVC formulation in PPI Technical Report #2. With the proprietary formulation, the fused-joint strength is about (90%) as strong as the pipe wall. The fusible pipe is made in DIPS and IPS OD series, as well as schedule and sewer sizes. The Fusible C-900®, Fusible C-905®, and FPVC™ pipes are NSF 61-certified for potable water.
Main Benefits Claimed	• AWWA C900 and C905 PVC pipe • Corrosion-resistant, abrasion-resistant, high "C" factor at 150 • Fully restrained joint - Fusible PVC™ joints allow long lengths of pipe to be used for HDD, pipe bursting, and sliplining applications. • NSF 61-certified for potable water • Use standard fittings and service saddles • Higher strength enables longer pulls and larger inside diameters
Main Limitations Cited	• Fusion time for joint is 1.5 to 2 minutes per diameter inch • PVC fusion technicians need to be trained and qualified by UGSI. Qualification only lasts 1 year. • PVC is impacted by cyclic (fatigue) pressure loadings, which are typically experienced in a force main application. • As a stiff, strong thermoplastic, PVC has specific guidelines for bending radius
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other: Culverts
II. Technology Parameters	
Service Application	Sliplining, HDD, pipe bursting, direct bury
Service Connections	Reinstate with excavation. Tapping procedure per Uni-bell standards. No direct tapping. Connect to MJ or flanged fittings.
Structural Rating Claimed	Fully structural (Class IV) - carry full internal pressure and external loads independent of the host pipe's remaining strength.
Materials of Composition	Fusible PVC™ is extruded with a unique patent-pending formulation that meets PPI TR-2 range of composition of qualified PVC ingredients. Meets ASTM cell classification 12454.
Diameter Range, inches	4 to 12 inches for Fusible C-900® (potable water) 14 to 36 inches for Fusible C-905® (potable water) 4 to 36 inches for FPVC™ (potable water in other than C900/C905 dimensions and non-potable applications)
Thickness Range, inches	Fusible C-900: DR 14, 18, 25 Fusible C-905: DR 14, 18, 21, 25, 32.5, 41, 51 FPVC: DR 14, 18, 21, 25, 26, 32.5, 41, 51, Sch 40, Sch 80 D3034 and F679 sewer sizes through 36"

Technology/Method	**Fusible C-900/905 Pipe/Sliplining/HDD/Pipe Bursting/Direct Bury**
Pressure Capacity, psi	165 psi to 305 psi under C900; 80 psi to 235 psi under C905
Temperature Range, °F	Limited to 140ºF and below. Above 73ºF, standard internal pressure de-rating factors apply for long-term elevated temperature exposure.
Renewal Length, feet	Standard guidance of 300 to 500 feet for pipe bursting with length of >1,000 feet completed in a single burst. Slipline lengths of 3,500 feet in a single pull have been completed. HDD lengths of over 5,100 feet in a single length.
Other Notes	Not available.
III. Technology Design, Installation, and QA/QC Information	
Product Standards	AWWA C900, AWWA C905, NSF 61-certified (for potable water applications), ASTM D2241, D3034, F679, D1785
Design Standards	AWWA C900, AWWA C905
Design Life Range	100+ years
Installation Standards	ASCE "Pipe Bursting Projects" - ASCE Manual and Report on Engineering Practice #112. AWWA installation standard is in development.
Installation Methodology	For sliplining, host pipe is cleaned and CCTV is performed. Depending on site logistics, the Fusible PVC™ pipes can be strung out and the joints butt-fused above-grade prior to insertion, or butt-fused in the ditch. For pipe bursting, the pipe normally is butt-fused in a single length. Static burst methods only are used. The fused PVC pipe is either winched into the host pipe if sliplining, or pulled in behind the expansion head when bursting. A non-rigid connection from the pipe to the expansion head is used. In all installation methods, the maximum recommended pull force and the minimum recommended bend radius must be followed.
QA/QC	The stock pipe is subjected to all of the normal QC requirements in AWWA C900/C905, including dimensional conformance, flattening, acetone immersion, hydrostatic, and burst tests. UGSI includes impact, heat reversion, and axial tensile testing as well. In addition, third-party labs are used to confirm extrusion results on key tests prior to shipment. The fusion process parameters of pressure and the time are recorded for each joint using a datalogger. Additional parameters such as the heat-plate temperature are also recorded.
IV. Operation and Maintenance Requirements	
O&M Needs	No special O&M.
Repair Requirements for Rehabilitated Sections	Cut out and replace with AWWA PVC of the same OD, using repair clamps and all standard PVC and DI waterworks fittings
V. Costs	
Key Cost Factors	Benefits: Due to the high tensile strength of PVC (compared to softer thermoplastic rehab materials), Fusible PVC™ allows longer lengths of cased and uncased pulls, which can reduce the number and cost of pit excavations required. Reduced wall thickness for a given pressure maximizes inner diameter (ID) for a given outer diameter (OD), either maximizing flow in an OD-constrained environment or minimizing cost of pipe material and installation as well as risk for a given ID and pressure requirement. Additional ease and reduced cost of reconnections using standard waterworks fittings. Limitations: Due to limitations of bending radius, Fusible PVC™ may require longer insertion pits over softer thermoplastics.
Case Study Costs	Fusible PVC™ pipe was used for a 5,120 feet directional drill crossing under the Beaufort River for the Beaufort Jasper Water & Sewer Authority in June of 2007 and was compared in costs to both steel and HDPE pipe. The overall project cost $1.7 million and the customer estimated savings of $400,000 (materials and installation) by selecting Fusible PVC™ pipe over other materials for the drill portion.
VI. Data Sources	
References	www.undergroundsolutions.com

Datasheet A-19. Grundoburst® Static Pipe Bursting

Technology/Method	**Grundoburst®/Pipe bursting, static pull**
I. Technology Background	
Status	Conventional
Date of Introduction	Offered since 1998. Used worldwide.
Utilization Rates	Not available
Vendor Name(s)	**TT Technologies** Aurora, IL Phone: (650) 208-9035 Email: corton@tttechnologies.com Website: www.tttechnologies.com
Practitioner(s)	• Ho-Chunk Nation and the Rainbow Casino, Port Edwards, WI (replaced 24,000 feet of 4" force sewer main with 8" HDPE in 2003) • South Tahoe Public Utility District (STPUD), CA (replaced 350 feet of 10 inches Steel Water Main with 10" Restrained Joint PVC) • Weber, Box Elder Conservation District, Ogden, UT (replaced 1,300 feet of 8 inches steel irrigation main with 8" Restrained Joint PVC)
Description of Main Features	A self-contained, hydraulically operated static pipe bursting system that is used to replace sewer mains made of any fracturable pipe material, as well as ductile iron and steel mains. There are eight models available, ranging in pullback force from 60,000 lb to 650,000 lb.
Main Benefits Claimed	• Substantial lengths of existing pipe can be burst and replaced in one step. • Quicklock rods save time, increase safety, and reduce cutting-head wear.
Main Limitations Cited	• Requires entry and exit pits and excavations at each lateral location • Requires bypass pumping • Difficulty when used in expansive soils, in close proximity to other services, and in host pipes with collapsed sections.
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other:____________________________
II. Technology Parameters	
Service Application	Water, sewer, gas, electric, and telephone.
Service Connections	Service connections need to be excavated before bursting and reconnected to the new pipe after bursting and then backfilled.
Structural Rating Claimed	Depends on the selection of the new pipe to be installed.
Materials of Composition	Depends on the selection of the new pipe to be installed.
Diameter Range, inches	4 to 48 inches
Thickness Range, inches	Depends on the selection of the new pipe to be installed.
Pressure Capacity, psi	Depends on the selection of the new pipe to be installed.
Temperature Range, °F	Depends on the selection of the new pipe to be installed.
Renewal Length, feet	750 feet
Other Notes	Not available
III. Technology Design, Installation, and QA/QC Information	
Product Standards	Depends on the selection of the new pipe to be installed.
Design Standards	Depends on the selection of the new pipe to be installed.
Design Life Range	Depends on the selection of the new pipe to be installed.
Installation Standards	Not available
Installation Methodology	The static-bursting process is basically a three-step process. After establishing launch and exit pits, bursting rods are inserted through the existing pipe from the exit pit to the launch pit. At the launch pit, the bladed rollers (if ductile pipe is being replaced), bursting head, expander, and new HDPE are connected to the bursting rods. Finally, the entire configuration is pulled back through an existing line by a hydraulically powered bursting unit. During the pull, the host pipe is fractured or split. An expander attached to the rollers forces the fragmented pipe into the surrounding soil, while simultaneously pulling in the new pipe.

Technology/Method	**Grundoburst$^{®}$/Pipe bursting, static pull**
Qualification Testing	Depends on the selection of the new pipe to be installed.
QA/QC	A post-installation CCTV inspection is conducted to ensure the new pipe is free of defects.
IV. Operation and Maintenance Requirements	
O&M Needs	O&M consistent with that of a newly installed pipe.
Repair Requirements for Rehabilitated Sections	Consistent with that of a newly installed pipe.
V. Costs	
Key Cost Factors	• Excavation of pits • Bypass pumping • Material costs are dependent on the selection of the new pipe to be installed • Region of the country
Case Study Costs	Not available
VI. Data Sources	
References	www.tttechnologies.com; Guidelines for Pipe Bursting (TTC)

Datasheet A-20. Grundocrack® Pneumatic Pipe Bursting

Technology/Method	**Grundocrack®/Pipe bursting, pneumatic**
I. Technology Background	
Status	Conventional
Date of Introduction	Offered since 1990. Used worldwide.
Utilization Rates	Approx. 2,000,000 + feet of lateral pipes replaced with this method
Vendor Name(s)	**TT Technologies** Aurora, IL Phone: (650) 208-9035 Email: corton@tttechnologies.com Website: www.tttechnologies.com
Practitioner(s)	• City of Hillsborough, CA (replaced over 1,800 ft of 15 inches VCP sanitary sewer main with 28 inches HDPE in 2006). Contact Curt Luck, Project Manager (CSGConsultants), (650) 678-3820 curt@csgengr.com • City of Atlanta, GA (replaced existing 10 inches with 16 inches HDPE in 2007). Contact Ray Hutchinson (MWH) Program Manager for City of Atlanta; raymond.hutchinson@mwhglobal.com • City of South San Francisco, CA (replaced 1,800 feet of 27 inches VCP gravity sewer with 36” HDPE in 2007). Contact Dennis Chuck, Project Manager City of South San Francisco, (650) 829-6663 • Many other practitioners are available.
Description of Main Features	A pneumatic pipe bursting system used to replace sewer mains made of any fracturable pipe material. (See Grundoburst for splitting steel and ductile iron mains.) Twenty-one Grundocrack models, including 6 straight-barrel auto-reverse tools, from 5 inches through 32 inches -diameter, are available.
Main Benefits Claimed	• Burst and replace substantial lengths of existing pipe in one step • Minimal disruption to traffic, buildings, and other utilities • Avoids sizable surface damage and costly restoration required for trenching methods • Fast installation • Easy to set up and operate • Minimal crew size • Installs a new pipe • Ability to increase pipe size • Substantial cost saving vs. traditional open-cut construction methods
Main Limitations Cited	• Requires entry and exit pits and excavations at each lateral location. • Requires bypass pumping • Difficulty in sandy soils with high groundwater level
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other:
II. Technology Parameters	
Service Application	Pipe bursting
Service Connections	Services need to be excavated before bursting and reconnected to the new pipe after bursting and then backfilled.
Structural Rating Claimed	Depends on the selection of the new pipe to be installed.
Materials of Composition	Depends on the selection of the new pipe to be installed.
Diameter Range, inches	4 to 54 inches for mains; ½ to 2 inches for services
Thickness Range, inches	Depends on the selection of the new pipe to be installed.
Pressure Capacity, psi	Depends on the selection of the new pipe to be installed.
Temperature Range, °F	Depends on the selection of the new pipe to be installed.
Renewal Length, feet	750 feet (exception: over 2,000 feet in favorable soil conditions)
Other Notes	Not available
III. Technology Design, Installation, and QA/QC Information	
Product Standards	Depends on the selection of the new pipe to be installed.

Technology/Method	**Grundocrack®/Pipe bursting, pneumatic**
Design Standards	Depends on the selection of the new pipe to be installed.
Design Life Range	Depends on the selection of the new pipe to be installed.
Installation Standards	Depends on the selection of the new pipe to be installed.
Installation Methodology	Pits are excavated and, at the same time, the replacement pipe sections butt-fused together into a continuous pipe. The pipe is attached to the bursting head. The bursting tool is guided through a fracturable host pipe by a constant tension winch. As the tool travels through the pipe, its percussive action effectively breaks apart the old pipe and displaces the fragments into the surrounding soil. Depending on the specific situation, the tool is equipped with an expander that displaces the host-pipe fragments and makes room for the new pipe. As the tool makes its way through the host pipe, it simultaneously pulls in the new pipe, usually HDPE.
Qualification Testing	Depends on the selection of the new pipe to be installed.
QA/QC	Depends on the selection of the new pipe to be installed. Contractors may be asked to submit information regarding prior experience.
IV. Operation and Maintenance Requirements	
O&M Needs	O&M consistent with that of a newly installed pipe.
Repair Requirements for Rehabilitated Sections	Consistent with that of a newly installed pipe.
V. Costs	
Key Cost Factors	• Excavation of pits • Bypass pumping • Material costs are dependent on the selection of the new pipe to be installed. • Region of the country
Case Study Costs	• In West Vancouver, Canada: approx. $2,000/lateral (15 upper laterals, 2003) • Goleta, CA, $2.5 million total project cost. Pipe-burst 7,000 linear feet of mostly 27 inches sewer, and replace with 36” HDPE. (2001) • Vallejo Sanitation & Flood Control District, CA (2009) • 10,000 linear feet. 300 laterals reconnected; total project cost: $780,000 • Replace mostly 6 and 8 inches VCP sewer with 8 inches HDPE • Typical installed cost range is $50 to $170 per linear feet (manufacturer’s quote)
VI. Data Sources	
References	www.tttechnologies.com; Guidelines for Pipe Bursting (TTC).

Datasheet A-21. Grundomat® Pipe Extraction and Replacement

Technology/Method	**Grundomat® with Pipe-Pushing Adapter/Pipe extraction and replacement**
I. Technology Background	
Status	Innovative
Date of Introduction	Not available
Utilization Rates	Not available
Vendor Name(s)	**TT Technologies** Aurora, IL Phone: (650) 208-9035 Email: corton@tttechnologies.com Website: www.tttechnologies.com
Practitioner(s)	• Ash Fork Water Services, AZ. A ½ inch galvanized water pipe was extracted, a 2 inches HDPE sleeve was pulled in and a new ¾ inch HDPE pipe inserted). Tool: 3.33 inches diameter Grundomat® piercing tool • Mammoth Community Water District (MCWD), CA (a 1 inch galvanized water pipe was extracted and replaced with a new 1.5 inches HDPE pipe, 80 feet long) • Team Construction Nashville, TN (a 50-feet steel casing was first rammed under a highway, and subsequently replaced with a new 6 inches steel gas main). Tool: 5.75 inches diameter Grundomat® P-145 with a ramming adapter.
Description of Main Features	A pneumatic piercing tool developed for horizontal boring can be used with a pipe-pushing adapter for pipe extraction and replacement.
Main Benefits Claimed	• Minimal disruption to traffic, buildings, and other utilities • Avoids sizable surface damage and costly restoration required for trenching methods • Fast installation • Easy to set up and operate. Minimal crew size. • Installs a new pipe • Ability to increase pipe size
Main Limitations Cited	• Requires entry and exit pits • Applicable for small diameters only
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other:____________________________
II. Technology Parameters	
Service Application	Water, gas, sewer, and electrical industries. Used for services/laterals, crossings, and small diameter mains over short segments between access pits.
Service Connections	Not applicable
Structural Rating Claimed	Depends on the selection of the new pipe to be installed.
Materials of Composition	Depends on the selection of the new pipe to be installed.
Diameter Range, inches	1 ¾ to 7 inches
Thickness Range, inches	Depends on the selection of the new pipe to be installed.
Pressure Capacity, psi	Depends on the selection of the new pipe to be installed.
Temperature Range, °F	Depends on the selection of the new pipe to be installed.
Renewal Length, feet	150 feet
Other Notes	Not available
III. Technology Design, Installation, and QA/QC Information	
Product Standards	Depends on the selection of the new pipe to be installed.
Design Standards	Depends on the selection of the new pipe to be installed.
Design Life Range	Depends on the selection of the new pipe to be installed.
Installation Standards	Not available
Installation Methodology	A pipe-pushing adapter is placed on the front of the piercing tool. The tool's percussive force is then used to literally drive out an existing service line and, at the same time, a new pipe is pulled in. Several pipe-pulling clamps and adapters are available for pulling a wide variety of pipes, including PVC, HDPE, copper,

Technology/Method	**Grundomat® with Pipe-Pushing Adapter/Pipe extraction and replacement**
	and steel.
Qualification Testing	Depends on the selection of the new pipe to be installed.
QA/QC	Depends on the selection of the new pipe to be installed.
IV. Operation and Maintenance Requirements	
O&M Needs	O&M consistent with that of a newly installed pipe.
Repair Requirements for Rehabilitated Sections	Consistent with that of a newly installed pipe.
V. Costs	
Key Cost Factors	Pit excavation
Case Study Costs	Not available
VI. Data Sources	
References	www.tttechnologies.com

Datasheet A-22. Grundotugger® Lateral Pipe Bursting

Technology/Method	**Grundotugger®/Lateral pipe bursting, static pull**
I. Technology Background	
Status	Conventional
Date of Introduction	Offered since 2000. Used worldwide.
Utilization Rates	Not available
Vendor Name(s)	**TT Technologies** Aurora, IL Phone: (650) 208-9035 Email: corton@tttechnologies.com Website: www.tttechnologies.com
Practitioner(s)	• District of West Vancouver, Canada, Saleem Mahmood, (604) 925-7027, smahmood@westvancouver.net (replaced 15 upper laterals in 2003) • City of Santa Rosa, CA (Mark Powell) • City of Grand Rapids, MI (replaced 100 feet of deteriorated 3 inches cast iron sewer laterals) • King County, WA (in Spokane, replaced 60 feet of 4 inches VCP and concrete laterals)
Description of Main Features	A tool for pipe bursting of sewer lateral by static pull, this lightweight system (no component over 70 lb) includes everything needed for bursting operations, including bursting heads for 4 and 6 inches pipe, winch cable, power pack and pipe fusion equipment.
Main Benefits Claimed	• Minimal disruption to traffic, buildings, and other utilities • Avoids sizable surface damage and costly restoration required for trenching methods • Fast installation • Negotiates turns and bends up to 45° • Easy to set up and operate (no component over 75 lb) • Uses low-pressure hydraulics • Installs a new pipe • Ability to increase pipe size
Main Limitations Cited	• Requires entry and exit pits • Applicable for small diameters only
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other:___________________________
II. Technology Parameters	
Service Application	Sewer laterals
Service Connections	Not applicable
Structural Rating Claimed	Depends on the selection of the new pipe to be installed.
Materials of Composition	Depends on the selection of the new pipe to be installed.
Diameter Range, inches	4 and 6 inches
Thickness Range, inches	Depends on the selection of the new pipe to be installed.
Pressure Capacity, psi	Depends on the selection of the new pipe to be installed.
Temperature Range, °F	Depends on the selection of the new pipe to be installed.
Renewal Length, feet	150 feet
Other Notes	Not available
III. Technology Design, Installation, and QA/QC Information	
Product Standards	Depends on the selection of the new pipe to be installed.
Design Standards	Depends on the selection of the new pipe to be installed.
Design Life Range	Depends on the selection of the new pipe to be installed.
Installation Standards	Not available
Installation Methodology	Pits are excavated and, at the same time, the replacement pipe sections are butt-fused together into a continuous pipe. The pipe is attached to the bursting head. A winch is placed inside the exit pit. A pulling cable is strung through the lateral pipe and attached to the bursting head. The bursting head is pulled through the

Technology/Method	**Grundotugger®/Lateral pipe bursting, static pull**
	lateral pipe, breaking it while simultaneously pulling in the replacement pipe. The new pipe is reconnected and the surface restored.
Qualification Testing	Depends on the selection of the new pipe to be installed.
QA/QC	Depends on the selection of the new pipe to be installed.
IV. Operation and Maintenance Requirements	
O&M Needs	O&M consistent with that of a newly installed pipe.
Repair Requirements for Rehabilitated Sections	Consistent with that of a newly installed pipe.
V. Costs	
Key Cost Factors	• Pit excavation (mostly depth of pipe, but not very much on the length) • Region of the country • Who performs the work (a plumber replacing single laterals or a utility contractor replacing a large number of laterals)
Case Study Costs	Not available
VI. Data Sources	
References	www.tttechnologies.com; Guidelines for Pipe Bursting (TTC).

Datasheet A-23. Herrenknecht Crush-Lining Replacement Technology

Technology/Method	**Crush-Lining/Pipe Eating**
I. Technology Background	
Status	Conventional
Date of Introduction	Not available
Utilization Rates	Not available
Vendor Name(s)	**Herrenknecht AG.** Schelhenweg 2 Schwanau, Germany Phone: (497) 824-3020; 49-872-430-2579 Email: info@herrenknecht.de Website: www.herrenknecht.com
Practitioner(s)	Not available
Description of Main Features	Excavation of the existing pipe and replacement with a new pipe that is jacked into place.
Main Benefits Claimed	• Fast installation of the entire system • Simple technology, easy handling • Direct depositing of mucked material possible • Pipe-eating of reinforced pipes possible • High advance rates
Main Limitations Cited	• Alignment cannot be changed • Lowering of groundwater level required • Pipe to be replaced must not be completely destroyed prior to replacement
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other:____________________________
II. Technology Parameters	
Service Application	Wastewater applications.
Service Connections	Services need to be excavated before eating and reconnected to the new pipe after pull-in and then backfilled.
Structural Rating Claimed	Depends on the selection of the new pipe to be installed.
Materials of Composition	Depends on the selection of the new pipe to be installed.
Diameter Range, inches	2 to 32 inches
Thickness Range, inches	Depends on the selection of the new pipe to be installed.
Pressure Capacity, psi	Depends on the selection of the new pipe to be installed.
Temperature Range, ^{o}F	Depends on the selection of the new pipe to be installed.
Renewal Length, feet	750 feet
Other Notes	Not available
III. Technology Design, Installation, and QA/QC Information	
Product Standards	Depends on the selection of the new pipe to be installed.
Design Standards	Depends on the selection of the new pipe to be installed.
Design Life Range	Depends on the selection of the new pipe to be installed.
Installation Standards	Not available
Installation Methodology	Herrenknecht Crush-Lining technology allows the no-dig replacement of existing, defective pipelines. Old pipelines made of vitrified clay or concrete are crushed, if need be, together with the surrounding soil with a pneumatic drill hammer. The cutter head is guided with a pilot head in the old pipe to secure an alignment identical to the old pipe. A cost and time-intensive control system is therefore not necessary. The excavated material is crushed and mucked out pneumatically or through screws to the launch shaft and from there to the surface in buckets. The process can be carried out in almost any loose ground.
Qualification Testing	Not available
QA/QC	A post-installation CCTV inspection is conducted to ensure the new pipe is free of defects.

Technology/Method	**Crush-Lining/Pipe Eating**
IV. Operation and Maintenance Requirements	
O&M Needs	O&M consistent with that of a newly installed pipe.
Repair Requirements for Rehabilitated Sections	Consistent with that of a newly installed pipe. Existing pipe fragments are removed during the installation process.
V. Costs	
Key Cost Factors	Requires entry and exit pits, as well as pits at the location of each lateral for reconnection. Bypass pumping is required to divert the flow during installation. Material costs are dependent on the selection of the new pipe to be installed.
Case Study Costs	Not available
VI. Data Sources	
References	www.herrenknecht.com; www.istt.com; Guidelines for Pipe Bursting (TTC).

Datasheet A-24. Hobas CCFRPM Sliplining Pipe

Technology/Method	**Hobas CCFRPM/Sliplining with non-pressure CCFRPM pipe**
I. Technology Background	
Status	Conventional
Date of Introduction	Developed in Switzerland in 1957; in U.S. since 1984. Used worldwide (Europe, Far East, Americas, Middle East, Africa, Asia)
Utilization Rates	Approx. 37,000 miles installed over the years
Vendor Name(s)	**Hobas Pipe USA** Houston, TX Phone: (800) 856-7473 Email: rturkopp@hobaspipe.com Website: www.hobaspipe.com
Practitioner(s)	• The Metropolitan Water Reclamation District of Greater Chicago, IL, Amreek Paintal, 312-751-4020, Amreek@mwrdgc.dst.il.us (approx. 7,000 LF of 120 inches semi-elliptic sewer sliplined with Hobas flush reline pipe in 2009, as follows: 2,000 LF of ID/OD 110/114 inches and 5,000 LF of 104/108 inches) (see References: Hobas Pipe USA, Mar 2009) • Jacksonville, FL (approx. 11,000 LF of 42, 48 and 54 inches RCP sewer was sliplined with 36, 42, and 48 inches Hobas pipes with low profile bell-spigot joints in 1999) • City of Houston, TX, approx. 6,000 LF of 84 inches sewer pipe, sliplined with 72 inches Hobas pipe in 1996
Description of Main Features	A new pipe (non-pressure CCFRPM pipe) of smaller diameter is pushed directly into the deteriorated sewer pipe. Annular space created between the host pipe and the liner is subsequently grouted with a cementitious material.
Main Benefits Claimed	• High-strength, corrosion/abrasion-resistant, and thin-walled pipe • Leak tightness • Smooth consistent inner surface (hydraulics) and outer surface (sliplining) • Light weight (easy to handle, transport, and lay) • Simple installation • Bypass flow is not required (live insertion) • Capable of accommodating large-radius bends • Long operational lifetime • Economical rehabilitation
Main Limitations Cited	• Excavation of pits is generally required • Grouting of annular space is required • Reduction in flow area, but flow capacity recovered or increased • Sufficient work area must be available (periodic pit above host line)
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other:______________________
II. Technology Parameters	
Service Application	Sewage, raw water and irrigation, drainage, and industry applications
Service Connections	Normally excavated (Note: not many service connections are encountered in these diameters)
Structural Rating Claimed	Fully structural
Materials of Composition	The composite is made predominantly of glass (commercial-grade e-glass), resin (thermosetting polyester, also available vinyl ester) and sand (precisely graded aggregates). The pipe wall cross-section is a non-homogeneous composite with the following layers: (1) outer layer - sand and resin; (2) heavily reinforced layer - chopped glass and resin; (3) transition layer - glass, resin, mortar; (4) core - polymer mortar; (5) transition layer - glass, resin, mortar; (6) heavily reinforced layer - chopped glass and resin; and (7) liner – high elongation liner. The positioning of glass fibers toward the outer surface and the inner surface, on

<table>
<tr><th>Technology/Method</th><th>Hobas CCFRPM/Sliplining with non-pressure CCFRPM pipe</th></tr>
<tr><td></td><td>either side of the bending neutral axis, makes for the most efficient use of reinforcement (this cross section reacts similarly to an I-beam).

Pipe material properties (based on manufacturer’s data):

<table>
<tr><th>Property</th><th>Value</th></tr>
<tr><td>Hoop flexural modulus</td><td>1,900,000 psi</td></tr>
<tr><td>Hoop tensile modulus</td><td>500,000 psi +/-</td></tr>
<tr><td>Axial tensile modulus</td><td>1,000,000 psi +/-</td></tr>
<tr><td>Hoop tensile strength</td><td>6,000 psi +/-</td></tr>
<tr><td>Axial tensile strength</td><td>1500 to 2000 psi</td></tr>
<tr><td>Compressive strength</td><td>10,500 psi +/-</td></tr>
<tr><td>Manning’s “n”</td><td>0.009</td></tr>
</table></td></tr>
<tr><td>Diameter Range, inches</td><td>18 to 110 inches (standard pipe lengths of 10 and 20 feet)</td></tr>
<tr><td>Thickness Range, inches</td><td>0.38 to 4 inches</td></tr>
<tr><td>Pressure Capacity, psi</td><td>Gravity pipes have short-term burst capacity of 200 psi+</td></tr>
<tr><td>Temperature Range, °F</td><td>Typically ambient, but can be used up to 120°F</td></tr>
<tr><td>Renewal Length, feet</td><td>Short to 10,000 feet (length of a single push depends on pipe weight/buoyancy, equipment, friction)</td></tr>
<tr><td>Other Notes</td><td>Not available</td></tr>
<tr><td colspan="2">III. Technology Design, Installation, and QA/QC Information</td></tr>
<tr><td>Product Standards</td><td>ASTM D3262 Std Spec for Fiberglass Sewer Pipe
ASTM D 4161 Std Spec for “Fiberglass” (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe Joints Using Flexible Elastomeric Seals</td></tr>
<tr><td>Design Standards</td><td>AWWA M45</td></tr>
<tr><td>Design Life Range</td><td>100 years +</td></tr>
<tr><td>Installation Standards</td><td>None</td></tr>
<tr><td>Installation Methodology</td><td>Pipe segments (with either low-profile bell spigot joints developed specifically for sliplining or flush bell spigot joints) are assembled into the continuous pipe prior to push-in. Grouting of annular space completes the installation.</td></tr>
<tr><td>Qualification Testing</td><td>• Mechanical properties 21.5 years after the original manufacturing date (Stork Materials Technology, Houston, TX, 2008)
• ASTM D3681 in 1N sulfuric acid (Southwest Labs, Houston TX, 2003)</td></tr>
<tr><td>QA/QC</td><td>Systematically implemented from incoming to final inspection, the quality assurance system guarantees that only precisely tested raw materials are used and only approved pipe systems leave the plant. Regular laboratory equipment includes two universal machines for testing tensile strength and stiffness.</td></tr>
<tr><td colspan="2">IV. Operation and Maintenance Requirements</td></tr>
<tr><td>O&M Needs</td><td>None</td></tr>
<tr><td>Repair Requirements for Rehabilitated Sections</td><td>Prior to sliplining, pipe should be cleaned and repaired to allow liner pipe insertion passage.</td></tr>
<tr><td colspan="2">V. Costs</td></tr>
<tr><td>Key Cost Factors</td><td>• Pit excavation, mobilization, pipe cleaning/dewatering, site restoration, material cost (pipe, grout).</td></tr>
<tr><td>Case Study Costs</td><td>• Typical installed cost range is $6 to $10 per diameter inch per foot</td></tr>
<tr><td colspan="2">VI. Data Sources</td></tr>
<tr><td>References</td><td>www.hobaspipe.com
Hobas Pipe USA, Mar 2009: “110-inch HOBAS Slipline,” *Pipeline,* No. 62, newsletter, http://www.hobaspipe.com/pdf/March-09News.pdf, downloaded on 07/28/09, Hobas Pipe USA</td></tr>
</table>

Datasheet A-25. Hobas FRP Panel Lining System

Technology/Method	**Hobas FRP panels/FRP Person-Entry Panels**
I. Technology Background	
Status	Conventional
Date of Introduction	1957
Utilization Rates	60,000 km over the years
Vendor Name(s)	**Hobas Pipe USA** Houston, Texas Phone: (281) 821-2200 Email: cmooney@hobaspipe.com Website: www.hobas.com
Practitioner(s)	Not available
Description of Main Features	A fiberglass-reinforced resin panel system is used for the lining and protection of structures. Person entry is required to place the panels. Sliplining pipes also are available (see separate data sheet).
Main Benefits Claimed	• High abrasion resistance • High level of corrosion resistance • Smooth surface of panels • Light weight • Ease of handling, transport, and laying • Long operational lifetime • Leak tightness • Low energy costs • Sophisticated long-term safety and design concept
Main Limitations Cited	Person-entry required
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other:______________________________
II. Technology Parameters	
Service Application	• Sewage • Raw water and irrigation • Drainage • Industry applications
Service Connections	Person entry – handle individually
Structural Rating Claimed	Not available
Materials of Composition	Fiber glass and unsaturated polyester resin, as well as minerals as a structural filler in an optimal grain-size distribution.
Diameter Range, inches	2 to 20 feet
Thickness Range, inches	Not available
Pressure Capacity, psi	Not applicable
Temperature Range, °F	Not available
Renewal Length, feet	No special restriction
Other Notes	Not available
III. Technology Design, Installation, and QA/QC Information	
Product Standards	Including NSF 61 Listing (for potable water applications)
Design Standards	Tailored to project
Design Life Range	Not available
Installation Standards	Not available
Installation Methodology	Panels and segments are assembled with tongue and groove or bell-spigot joints sealed with adhesives. Grouting of the residual annulus completes the installation.
Qualification Testing	See QA/QC.
QA/QC	Systematically implemented from incoming to final inspection, the quality assurance system guarantees that only precisely tested raw materials are used and only approved pipe systems leave the plant. Regular laboratory equipment

Technology/Method	**Hobas FRP panels/FRP Person-Entry Panels**
	includes two universal machines for testing tensile strength and pressure, and one burst pressure unit engineered by HOBAS. The testing machines generally have a capacity of 50 and 100 kN, depending on the pipe classes to be produced.
IV. Operation and Maintenance Requirements	
O&M Needs	No special requirements
Repair Requirements for Rehabilitated Sections	No special requirements
V. Costs	
Key Cost Factors	• Person entry • Labor costs • Material costs
Case Study Costs	Not available
VI. Data Sources	
References	www.hobas.com

Datasheet A-26. Impactor® (Hammerhead) Pipe Bursting Using HDD Rig

Technology/Method	**Impactor®/Pneumatic Pipe Bursting with HDD**
I. Technology Background	
Status	Conventional
Date of Introduction	1980
Utilization Rates	Not available
Vendor Name(s)	**HammerHead® Trenchless Equipment** Oconomowoc, Wisconsin Phone: (800) 331-6653 Website: www.hammerheadmole.com
Practitioner(s)	**New York Underground** Brooklyn, New York (3,300 feet of 12 inches Asbestos Cement replaced with 12 inches HDPE) HammerHead® News Bulletin, Volume 4, Issue 1, July 2002 **Gastony Directional Boring** Van Buren, Arkansas (400 feet of 18 inches VCP with 20 inches HDPE) Construction News, Des Moines, Iowa, July 2008
Description of Main Features	The hammer is activated when pull force is applied to the hammer. Once the drill operator stops pulling, the air-supply vents and shuts off the hammer. The Impactor® is designed to float on the distributor shaft, isolating the drill stem from impact. With Smart Hammer technology, the power increases as the job progresses, producing up to 500 blows per minute at only 110 to 200 psi (8 to 14 bar). Impactors can be adapted to a variety of other machines like static-bursting systems, winches, cable pullers and various HDD manufacturer drills. This provides more versatility.
Main Benefits Claimed	Excavation is significantly reduced by retrieving the Impactor from the receiving manhole.
Main Limitations Cited	Requires bypass pumping, entry and exit pits, and excavations at each lateral location. Difficulty when used in expansive soils, in close proximity to other services, and in host pipes with collapsed sections.
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other:____________________________
II. Technology Parameters	
Service Application	Water and wastewater applications.
Service Connections	Services need to be excavated before bursting and reconnected to the new pipe after bursting and then backfilled.
Structural Rating Claimed	Depends on the selection of the new pipe to be installed.
Materials of Composition	Depends on the selection of the new pipe to be installed.
Diameter Range, inches	8 to 12 inches
Thickness Range, inches	Depends on the selection of the new pipe to be installed.
Pressure Capacity, psi	Depends on the selection of the new pipe to be installed.
Temperature Range, °F	Depends on the selection of the new pipe to be installed.
Renewal Length, feet	750 feet
Other Notes	Not available
III. Technology Design, Installation, and QA/QC Information	
Product Standards	Depends on the selection of the new pipe to be installed.
Design Standards	Depends on the selection of the new pipe to be installed.
Design Life Range	Depends on the selection of the new pipe to be installed.
Installation Standards	Guideline Specification for the Replacement of Mainline Sewer Pipes by Pipe Bursting. (IPBA, NASSCO), Guidelines for Pipe Bursting (TTC).

Technology/Method	**Impactor®/Pneumatic Pipe Bursting with HDD**
Installation Methodology	The Impactor® device, when connected to a horizontal directional drill, uses a high volume of compressed air that causes the internal striker of the device to impact the device's body. The striker only impacts the body, not the drill rod. The directional drill's special starter rod is connected to the device's ball joint, needing only an air supply and pull force to actuate the impactor. Connecting a 2 inches air-line downstream of the directional drill's pump allows compressed air to flow through a conventional swivel and down the pipe. The device operates when the drill rod is being pulled back. The device will stop when changing drill rods, if a drill rod is not being pulled back, or if a drill rod is pushed forward. During operation, no rotation is used as the device bursts and compacts the existing utility.
Qualification Testing	Depends on the selection of the new pipe to be installed.
QA/QC	A post-installation CCTV inspection is conducted to ensure the new pipe is free of defects.
IV. Operation and Maintenance Requirements	
O&M Needs	O&M consistent with that of a newly installed pipe.
Repair Requirements for Rehabilitated Sections	Consistent with that of a newly installed pipe.
V. Costs	
Key Cost Factors	Requires entry and exit pits, as well as pits at the location of each lateral for reconnection. Bypass pumping is required to divert the flow during installation. Material costs are dependent on the selection of the new pipe to be installed.
Case Study Costs	$50 to $170/LF (Survey of Bid Prices, TTC)
VI. Data Sources	
References	www.hammerheadmole.com; Guidelines for Pipe Bursting (TTC).

Datasheet A-27. Inliner® CIPP Pull-in-Place or Inversion

Technology/Method	**CIPP/Pull-In-Place or Inversion**
I. Technology Background	
Status	Conventional
Date of Introduction	1986
Utilization Rates	9 million ft installed from inception.
Vendor Name(s)	**Inliner® CIPP** Inliner Technologies, LLC (a Layne Christensen company and subsidiary of Reynolds Inliner, LLC) 1468 West Hospital Rd. Paoli, Indiana 47454 Phone: (812) 723-0704 Email: gyothers@inliner.net Website: www.inliner.net
Practitioner(s)	Gwinnet County Storm Sewer Improvements 25,000 ft of CIPP, diameters 15” to 72” Gwinnet County Watershed Manager 684 Winder Highway Lawrenceville, GA 30045 Phone (678) 376-7068 Frank Matticola White Creek Project – Nashville, TN 90,000 ft of CIPP, 800 service lateral renewals – 41% I&I reduction CTE Engineers 220 Athens Way, Suite 200 Nashville, TN 37228 Phone: (615) 244-8864 Charlie Brown
Description of Main Features	Resin-impregnated felt tube that can be either installed by the inversion method or pulled into place. The felt tube is made by Inliner Products, Inc. (subsidiary) and sized to fit the host pipe, taking any bends and diameter transitions into consideration. Resin impregnation is usually done offsite in a controlled environment. The catalyzed resin-impregnated tube can be stored for up to 2 weeks in a refrigerated environment. Isophthalic polyester, vinylester and epoxy resin systems can be accommodated. Inliner CIPP incorporates two patented features: StretchGuard™ and ResinGuard™.
Main Benefits Claimed	• No dig or limited excavation renewal • 40% to 50% less costly than traditional open-cut replacement • Minimum 50-year service life
Main Limitations Cited	• No long-term pressure regression or tensile testing has been done.
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other:
II. Technology Parameters	
Service Application	Gravity and low-pressure wastewater
Service Connections	Small-diameter laterals opened by remote cutter, large-diameter by man-entry. Pressure connections not accommodated.
Structural Rating Claimed	Class II, III, or IV
Materials of Composition	Inliner Technologies uses isophthalic polyester resin, epoxy vinyl ester, and “enhanced” polyesters. The enhanced resin is a filled isophthalic polyester. Inliner fills their isophthalic polyester resin with a variety of materials based on the application. The non-woven needled felt tube is made of polyester fibers. An outer layer of impermeable thermoplastic material (polyethylene or polyurethane) is used to protect the resin from water and contaminants. If using the pulled-in-place installation method, an inner calibration hose or removable bladder is used. The calibration hose is constructed of thin dry felt coated with an impermeable plastic

<table>
<tr><th>Technology/Method</th><th>CIPP/Pull-In-Place or Inversion</th></tr>
<tr><td></td><td>membrane. The felt is saturated with excess resin in the pulled-in-place liner and becomes part of the finished liner. The removable bladder, a thermoplastic membrane, is used in short laterals and point repairs, where it is preferred so as not to cut the ends of the installed CIPP liner.
The following table shows the properties of the Inliner CIPP product, depending on the type of resin used:
<table>
<tr><th>Property</th><th>Isophthalic</th><th>Enhanced</th></tr>
<tr><td>Flexural modulus, psi</td><td>250,000-380,000</td><td>400,000-450,000</td></tr>
<tr><td>Flexural strength, psi</td><td>4,500-6,600</td><td>4,500-7,000</td></tr>
<tr><td>Tensile modulus, psi</td><td>290,000-360,000</td><td>290,000-400,000</td></tr>
<tr><td>Tensile strength, psi</td><td>3,000-6,000</td><td>3,000-5,000</td></tr>
<tr><td>Tensile elongation, %</td><td>1-3</td><td>2-4</td></tr>
</table></td></tr>
<tr><td>Diameter Range, inches</td><td>4 to 120 inches</td></tr>
<tr><td>Thickness Range, inches</td><td>0.12 inch to 2.4 inches (3mm – 60mm)</td></tr>
<tr><td>Pressure Capacity, psi</td><td>Recommended < 60 psi operating pressure</td></tr>
<tr><td>Temperature Range, ^{o}F</td><td>Recommended for effluents of 140^{o}F or less</td></tr>
<tr><td>Renewal Length, feet</td><td>Lengths from 5 feet to 2,400 feet have been installed</td></tr>
<tr><td>Other Notes</td><td>Inliner is not NSF 61-listed, so not appropriate for potable water.</td></tr>
<tr><td colspan="2">III. Technology Design, Installation, and QA/QC Information</td></tr>
<tr><td>Product Standards</td><td>ASTM D5813</td></tr>
<tr><td>Design Standards</td><td>ASTM F1216, Appendix XI (Design Considerations)</td></tr>
<tr><td>Design Life Range</td><td>50-year design life</td></tr>
<tr><td>Installation Standards</td><td>ASTM F1216 for inversion; ASTM F1743 for pull-in-place</td></tr>
<tr><td>Installation Methodology</td><td>The CIPP tube is inserted by either inversion using water or air, or pulled into place. For inversion, the tube is inflated by either water or air pressure. If using the pull-in-place method, a calibration hose or removable bladder is inverted inside the felt tube after the tube is pulled into position. Curing is by either hot water or hot air (steam) in either case.</td></tr>
<tr><td>QA/QC</td><td>Prior to lining, the line should be cleaned and CCTV performed to locate laterals, connections, offsets, diameter transitions, etc. After lining, CCTV is performed again to locate any anomalies or defects (bulges, wrinkles, etc.). Either restrained samples, or specially made flat-plate samples, using the same resin and felt fabric, are made and tested for conformance to minimum flexural properties.</td></tr>
<tr><td colspan="2">IV. Operation and Maintenance Requirements</td></tr>
<tr><td>O&M Needs</td><td>Standard CCTV inspection and water cleaning</td></tr>
<tr><td>Repair Requirements for Rehabilitated Sections</td><td>CIPP short sectional point repairs readily available from several contracting firms</td></tr>
<tr><td colspan="2">V. Costs</td></tr>
<tr><td>Key Cost Factors</td><td>Mobilization affects cost when contract contains minimal segments of CIPP lining. Generally speaking, a project of 3,000 linear ft or more will offset any effect of mobilization on cost. Diversion or bypass pumping requirements can have a significant impact on cost. Material–wise, recent fluctuations in the cost of the resin and fuel have impacted costs of the installed CIPP.</td></tr>
<tr><td>Case Study Costs</td><td>Not available.</td></tr>
<tr><td colspan="2">VI. Data Sources</td></tr>
<tr><td>References</td><td>Inliner Design Guide (March 2008), Inliner Technical Brochure (no date)</td></tr>
</table>

Datasheet A-28. Inner Seal™ Spray Polyurea Lining

<table>
<tr><th>Technology/Method</th><th>Inner Seal Lo-Mod Structural Liner/Sprayed Polyurea Lining</th></tr>
<tr><td colspan="2">I. Technology Background</td></tr>
<tr><td>Status</td><td>Innovative</td></tr>
<tr><td>Date of Introduction</td><td>Developed in U.S. in 2007</td></tr>
<tr><td>Utilization Rates</td><td>Not available</td></tr>
<tr><td>Vendor Name(s)</td><td>**Innovative Painting & Waterproofing Inc.**
Brea, CA
Phone: (714) 257-0200 Ext. 103
Email: don@waterproofingcontractor.com
Website: www.waterproofingcontractor.com</td></tr>
<tr><td>Practitioner(s)</td><td>Not available</td></tr>
<tr><td>Description of Main Features</td><td>A two-component, spray-applied polyurea elastomer for infrastructure rehabilitation that forms a very tough composite upon final cure. The product cures rapidly, i.e., 5 to 8 seconds gel time, 12 to 15 seconds tack-free time, and 24 hours return to full service. Application thicknesses from 1/8” to 1” can easily be achieved (a high-built liner).

The product can be sprayed directly onto concrete, metal, wood, or brick substrates. If substrate is uneven or slightly damp, a primer is recommended. Inner Seal Primer Filler is a water-blown, high-density foam that fills voids and creates an even surface.</td></tr>
<tr><td>Main Benefits Claimed</td><td>• Structural liner
• 100% solids with zero VOCs
• Excellent resistance to many chemicals, temperature, and humidity
• Rapid cure and quick return to service
• Thorough cleaning of the existing pipe is not essential with high-built application.</td></tr>
<tr><td>Main Limitations Cited</td><td>• Flow bypass required
• Requires expertise</td></tr>
<tr><td>Applicability
(Underline those that apply)</td><td>Force Main Gravity Sewer Laterals Manholes Appurtenances
Water Main Service Lines Other:___________________________</td></tr>
<tr><td colspan="2">II. Technology Parameters</td></tr>
<tr><td>Service Application</td><td>Wastewater, raw water, industrial, and power.</td></tr>
<tr><td>Service Connections</td><td>Treatment depends on thickness of lining applied</td></tr>
<tr><td>Structural Rating Claimed</td><td>Fully structural</td></tr>
<tr><td>Materials of Composition</td><td>Materials are polyurea and primer. The installed liner has the following physical properties (based on manufacturer’s data):
<table>
<tr><th>Property</th><th>Test Method</th><th>Value</th></tr>
<tr><td>Flexural modulus</td><td>ASTM F1216</td><td>250,000 psi,
400,000 psi enhanced resin</td></tr>
<tr><td>Hardness</td><td>ASTM D2240</td><td>80 to 85D</td></tr>
<tr><td>Flexural strength</td><td>ASTM D790</td><td>14,351 psi</td></tr>
<tr><td>Compressive strength</td><td></td><td></td></tr>
<tr><td>Tensile strength</td><td>ASTM D412</td><td>8,631 psi</td></tr>
<tr><td>Tensile elongation</td><td>ASTM D412</td><td>10.79%</td></tr>
<tr><td>Tear Strength</td><td>ASTM D624C</td><td>632 psi</td></tr>
</table></td></tr>
<tr><td>Diameter Range, inches</td><td>4 to 108 inches</td></tr>
<tr><td>Thickness Range, inches</td><td>0.35 to 1.00 inch (depends on depth and condition of existing host pipe)</td></tr>
<tr><td>Pressure Capacity, psi</td><td>150 psi @ wall thickness of 0.35 inch</td></tr>
<tr><td>Temperature Range, °F</td><td>No special requirements</td></tr>
<tr><td>Renewal Length, feet</td><td>1,000 feet to 3,000 feet</td></tr>
</table>

Technology/Method	**Inner Seal Lo-Mod Structural Liner/Sprayed Polyurea Lining**
Other Notes	System is seamless, fast-curing pipe restoration that can be sprayed at any normal temperature and any humidity level.
III. Technology Design, Installation, and QA/QC Information	
Product Standards	ASTM D1784 – rigid poly (vinyl chloride) (PVC) compound and chlorinated poly (vinyl chloride) (CPVC) compounds. ASTM D3350 – polyethylene plastic pipe and fitting materials
Design Standards	ASTM F1216
Design Life Range	50 years
Installation Standards	ASTM F1216, Section 7, or ASTM F1743.
Installation Methodology	Pipe is prepared for relining by completing all necessary spot repairs, removing any obstructions, and thoroughly cleaning with high-pressure water. The service on the line is maintained with bypass pumping, if required.
Qualification Testing	Chemical resistance testing under way (Trenchless Technology Center, Louisiana Tech University)
QA/QC	Not available
IV. Operation and Maintenance Requirements	
O&M Needs	No special requirements
Repair Requirements for Rehabilitated Sections	No special requirements
V. Costs	
Key Cost Factors	• Cost of materials • Mobilization and setup • Part of country • Scope of project (length)
Case Study Costs	Not available
VI. Data Sources	
References	Personal communication; www.waterproofingcontractor.com

Datasheet A-29. Insituform® CIPP Liner

Technology/Method	**Insituform /CIPP iPlus Infusion™**
I. Technology Background	
Status	Conventional
Date of Introduction	Since 1976 in U.S. Also used worldwide (Europe, Asia, Australia, Africa)
Utilization Rates	Over 16,500 miles installed worldwide
Vendor Name(s)	**Insituform Technologies, Inc** Chesterfield, MO Phone: (636) 530-8045 Email: losborn@insituform.com Website: www.insituform.com
Practitioner(s)	• St. Louis Metropolitan Sewer District, Ron Moore, (314) 768-6388 (thousands of feet of small-, medium-, and large-diameter CIPP) • Clark County Reclamation District, Steve Weber, (702) 668-8150 (43 miles of small-, medium-, and large-diameter CIPP) • Reno, NV, Gene Jones, (775) 334-2350 (38,265 feet of 8” to 45”)
Description of Main Features	A resin-impregnated tube is inverted or pulled into the pipe where it is expanded and cured using hot water or steam. Service connections are reinstated using a robotic cutter in smaller diameter or man-entry cutting in medium and larger diameters.
Main Benefits Claimed	• Limited excavation (typically removal of a manhole casting, frame, and cone section) • Can be designed for infiltration reduction or for full structural renewal • Minimizes/eliminates environmental concerns that can be associated with more traditional methods like excavation • Quick installation • One-piece (jointless) final product • Limited cross-sectional area reduction • Improved flow characteristics • Improved maintainability • Has ability to negotiate bends • Has ability to rehabilitate different-shaped host pipes • Minimal traffic disruption • Cost-effective, allowing rehabilitation dollars to be maximized • Proven technology
Main Limitations Cited	• Thorough cleaning of the existing pipe is required. • Bypassing of flow is required. • Requires expertise • Thermosetting product with limited shelf life once catalyzed
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other:
II. Technology Parameters	
Service Application	Wastewater, stormwater, raw water, process piping, industrial, and power
Service Connections	In small diameters, service laterals are restored internally with robotically controlled cutting devices. In medium and large diameters, service connections are opened by man-entry cutting.
Structural Rating Claimed	Fully structural
Materials of Composition	Tube is one or more layers of absorbent, non-woven felt fabric. Resin is polyester or vinylester. Coating is a permanently bonded, continuous layer of polypropylene. The installed CIPP has the following typical physical properties:

Technology/Method	**Insituform /CIPP iPlus Infusion™**
	Property: ASTM: Value: Flexural modulus F1216 400,000 psi Flexural strength D790 4,500 psi
Diameter Range, inches	6” to 96”
Thickness Range, inches	4.5 mm to 50 mm (depends on depth and condition of existing host pipe)
Pressure Capacity, psi	Not available
Temperature Range, °F	140°F maximum
Renewal Length, feet	200 ft to 1,000 ft (typical installation lengths)
Other Notes	Not available
III. Technology Design, Installation, and QA/QC Information	
Product Standards	ASTM D5813 ASTM DF1216 ASTM F1743
Design Standards	ASTM F1216
Design Life Range	100 years
Installation Standards	ASTM F1216, Section 7, or ASTM F1743.
Installation Methodology	The host pipe is measured for proper length and diameter. The CIPP tube is manufactured to the site-specific requirements and the tube is vacuum-impregnated with resin (wet-out) under controlled conditions. In the case of larger or longer-length installations, the wetout process may occur in the field in an over-the-hole setup. After wet-out, the tube is inverted or pulled into place through an existing manhole or other access point. Care is taken during the installation so as not to overstress the felt fiber. A lubricant may be poured in the inversion water or applied directly to the tube to reduce friction during inversion. In the case of steam installations, end canisters may be placed on the CIPP ends after the inversion or pull-in process is complete. Hot water or steam is circulated through the expanded CIPP to accelerate the resin cure. After initial cure is reached, the temperature is held at or raised to the post-cure temperature. The post-cure temperature is held for a period, during which time the recirculation of the water, hot air, or steam is maintained to ensure the appropriate interface temperatures are maintained. The new CIPP is then cooled to a temperature below 100°F. Cooldown is accomplished by the introduction of cool water or air, either ambient or chilled, into the CIPP. In the case of water cure, the curing water is drained from a small hole made in the downstream end. Care is taken in the release of head so that a vacuum does not develop that could damage the newly installed pipe. After the new pipe has been cured, the ends are cut open and the existing active service connections are reconnected from the interior of the pipeline by means of a television camera and a remote-controlled or manual cutting device. A post-construction video is completed and samples, if applicable, are sent to an appropriate laboratory for verification of physical properties.
Qualification Testing	• Flexural Properties (Bodycote Materials Testing Ltd, 2001) • Design Life (Trenchless Technology Center at Louisiana Tech University, 1994) • Flow capacity (Sverdrup Corporation and Southeast Environmental Services, Inc, 1990) • Soil cell test structural integrity (Utah State University, 1988)
QA/QC	• In some cases, CIPP samples are prepared and tested for each installation. More commonly, a random sampling of 20% to 25% of the installations are completed. Restrained end samples are common in smaller diameters less than 18 inches, and plate samples are typically accepted for all diameters.

Technology/Method	**Insituform /CIPP iPlus Infusion™**
	• Pipe physical properties are tested in accordance with ASTM F1216 or ASTM F1743, Section 8. The flexural properties (ASTM D790) must meet or exceed the required values. • Wall thickness of samples determined as described in ASTM F1743 paragraph 8.1.6 (the minimum wall thickness at any point must not be less than 87½% of the submitted minimum design wall thickness). • Visual inspection of the CIPP in accordance with ASTM F1743, Section 8.6.
IV. Operation and Maintenance Requirements	
O&M Needs	O&M needs would mirror those required for a typical sanitary sewer, with the exception that frequency of operations like cleaning can be reduced, since the CIPP flow characteristics are significantly improved over the host pipe. Mechanical cleaning devices, such as buckets, should be avoided.
Repair Requirements for Rehabilitated Sections	Repair with CIPP point repairs or hand lay-up techniques.
V. Costs	
Key Cost Factors	• Thickness of the CIPP and hence cost of materials • Mobilization, setup, and project restrictions (working hours) • Scope of project (length and diameters) • Wastestream components (compositions and temperature ranges) and hence potential need for specialty resins • Application type • Bypass requirements • Accessibility of the lines requiring renewal
Case Study Costs	Cost varies greatly based on project parameters.
VI. Data Sources	
	www.insituform.com; Personal communication

Datasheet A-30. Insituform I-Plus™/Composite CIPP

Technology/Method	**I-Plus™/Composite CIPP**
I. Technology Background	
Status	Innovative
Date of Introduction	Since 2003 in U.S. Also used worldwide (Europe, Asia, Australia)
Utilization Rates	Over 45,000 feet installed in USA, over 50,000 feet worldwide
Vendor Name(s)	**Insituform Technologies, Inc** Chesterfield, MO Phone: (636) 530-8045 Email: losborn@insituform.com Website: www.insituform.com
Practitioner(s)	• City of Tacoma, WA, Kari Prussen, (253) 502-2183 (1,800 feet of 24-inch) • City of Tamp, FL, Jack Ferras, (813) 274-8095 (870 feet of 72-inch) • San Diego Airport Authority, Omneya Salem, (619) 400-2227 (1,700 feet of 96-inch) • St. Cloud, MN, Bob Jopp, (320) 255-7241 (4,000 feet of 60-inch)
Description of Main Features	A composite CIPP tube with reinforcing fibers (glass or carbon) with greater strength and stiffness than traditional CIPP for rehabilitation of medium- to large-diameter pipes. The installation is the same as with traditional CIPP (i.e., a resin-impregnated tube is inverted or pulled into the pipe where it is expanded and cured using hot water or steam). Service connections are reinstated using man-entry cutting.
Main Benefits Claimed	• Greater strength and stiffness than traditional CIPP • Limited excavation (typically removal of a manhole casting, frame, and cone section) • Can be designed for infiltration reduction or for full structural renewal • Minimizes/eliminates environmental concerns that can be associated with more traditional methods like excavation • Quick installation • One piece (jointless) final product • Limited cross-sectional area reduction minimizes wall thickness • Improved flow characteristics • Improved maintainability • Has ability to negotiate bends • Has ability to rehabilitate different-shaped host pipes • Minimal traffic disruption • Cost-effective, allowing rehabilitation dollars to be maximized • Proven technology
Main Limitations Cited	• Cleaning of the existing pipe is required; all debris is removed • Bypassing of flow is required • Requires expertise • Thermosetting product with limited shelf life once catalyzed • Not suitable for pipes under 24 inches • Not cost-effective for all pipe size/thickness combinations
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other:
II. Technology Parameters	
Service Application	Wastewater, stormwater, process piping, industrial, and power
Service Connections	In medium and large diameters, service connections are opened by man-entry cutting.
Structural Rating Claimed	Fully structural
Materials of Composition	Tube is a felt material sandwiched between layers reinforced with carbon and/or glass fiber (glass is typically the material of choice for both layers in the composite CIPP; carbon is used when a higher stiffness composite is required, or in industrial settings where higher corrosion resistance is needed).

<table>
<tr><th>Technology/Method</th><th>I-Plus™/Composite CIPP</th></tr>
<tr><td></td><td>The resin used is standard isophthalic polyester resin.

Coating made of thermoplastic material (polypropylene) is added to the tube for corrosion protection.

The installed CIPP has the following typical physical properties (based on manufacturer's data for 18.5-mm thick tube):

<table><tr><th>Property</th><th>Test Method</th><th>Value</th></tr><tr><td>Flexural modulus</td><td>F1216</td><td>750,000 psi minimum</td></tr><tr><td>Flexural strength</td><td>D790</td><td>7,500 psi minimum</td></tr></table></td></tr>
<tr><td>Diameter Range, inches</td><td>24" to 96"</td></tr>
<tr><td>Thickness Range, inches</td><td>12 to 40 mm</td></tr>
<tr><td>Pressure Capacity, psi</td><td>Not available</td></tr>
<tr><td>Temperature Range, °F</td><td>140°F maximum</td></tr>
<tr><td>Renewal Length, feet</td><td>750 feet (max installation length)</td></tr>
<tr><td>Other Notes</td><td>Not available</td></tr>
<tr><td colspan="2">III. Technology Design, Installation, and QA/QC Information</td></tr>
<tr><td>Product Standards</td><td>ASTM D5813
ASTM F1216
ASTM F1743</td></tr>
<tr><td>Design Standards</td><td>ASTM F1216</td></tr>
<tr><td>Design Life Range</td><td>100 years</td></tr>
<tr><td>Installation Standards</td><td>ASTM F1216, Section 7, or ASTM F1743.</td></tr>
<tr><td>Installation Methodology</td><td>The host pipe is measured for proper length and diameter. The lining tube is manufactured to the site-specific requirements, and the tube is vacuum-impregnated with resin (wet-out) under controlled conditions. In the case of larger or longer-length installations, the wet-out process may occur in the field in an over-the-hole setup.

After wet-out, the tube is inverted or pulled into place through an existing manhole or other access point. Care is taken during the installation so as not to overstress the felt fiber. A lubricant may be poured in the inversion water or applied directly to the tube to reduce friction during inversion.

Hot water or steam is circulated through the expanded tube to accelerate the resin cure. After initial cure is reached, the temperature is held at or raised to the post-cure temperature. The post-cure temperature is held for a period, during which time the recirculation of the water, hot air or steam is maintained to ensure the appropriate interface temperatures are maintained. The new CIPP is then cooled to a temperature below 100°F. Cool-down is accomplished by the introduction of cool water or air, either ambient or chilled, into the CIPP. In the case of water cure, the curing water is drained from a small hole made in the downstream end. Care is taken in the release of head so that a vacuum does not develop that could damage the newly installed pipe.

After the new pipe has been cured, the ends are cut open and the existing active-service connections are reconnected from the interior of the pipeline by means of a television camera and a remote-controlled or manual cutting device. A post-construction video is completed, and samples, if applicable, are sent to an appropriate laboratory for verification of physical properties.</td></tr>
<tr><td>Qualification Testing</td><td>• Strain Corrosion (2007, Hauser Laboratories)
• Creep (2007, Owens Corning)
• F1216 (2004, Mark Greenwood)</td></tr>
<tr><td>QA/QC</td><td>• In some cases, CIPP samples are prepared and tested for each installation. More commonly, a random sampling of 20% to 25% of the installations are completed. Plate samples are typically accepted for all diameters.
• Pipe physical properties are tested in accordance with ASTM F1216 or ASTM</td></tr>
</table>

Technology/Method	**I-Plus™/Composite CIPP**
	F1743, Section 8. The flexural properties (ASTM D790) must meet or exceed the required values. • Visual inspection of the CIPP in accordance with ASTM F1743, Section 8.6.
IV. Operation and Maintenance Requirements	
O&M Needs	O&M needs would mirror those required for a typical sanitary sewer, with the exception that frequency of operations like cleaning can be reduced, since the CIPP flow characteristics are significantly improved over the host pipe. Mechanical cleaning devices, such as buckets, should be avoided.
Repair Requirements for Rehabilitated Sections	Repair with CIPP point repairs or hand lay-up techniques.
V. Costs	
Key Cost Factors	• Thickness of the CIPP and hence cost of materials • Mobilization, setup, and project restrictions (working hours) • Scope of project (length and diameters) • Wastestream components (compositions and temperature ranges) and hence potential need for specialty resins • Application type • Bypass requirements • Accessibility of the lines requiring renewal
Case Study Costs	Cost varies greatly based on project parameters.
VI. Data Sources	
	www.insituform.com; Personal communication; iPlus™ Composite, product brochure

Datasheet A-31. IPEX/TT Technologies Drive-and-Pull/Tight-in-Pipe

Technology/Method	**IPEX M-34 Drive-and-Pull Pipe/Pipe for modified sliplining, pipe bursting**
I. Technology Background	
Status	Emerging
Date of Introduction	Under development 2006-2009
Utilization Rates	Not available
Vendor Name(s)	**IPEX, Inc.** Mississauga, ON, Canada Phone: (800) 463-9572, Ext.550 Email: andpot@ipexinc.com Website: www.ipexinc.com
Practitioner(s)	City of Ruston, LA (about 100 ft of 8" pipe in a field testing in 2009)
Description of Main Features	A PVC pipe, produced in 3-ft-long sections, bell-and-spigot; however, with no profile socket, for trenchless pipe rehabilitation or replacement. Two installation methods will be mainly used: modified sliplining (drive or pull) and pipe bursting (pull pipes). In pull systems, a lock ring is added to the pipe prior to insertion to prevent disengagement of the pipe during the pull phase. Two d-shaped gaskets are installed on the spigot side for both products (push and pull) to provide a tight seal of the system.
Main Benefits Claimed	• Does not require pit excavation (installation from manhole to manhole, without destroying the manholes) • Less reduction in cross section (loss of ID) than sliplining • Ideal for tight working conditions • Deep installation depths
Main Limitations Cited	• Upsize installation is not possible • Bypass pumping is required to divert the flow during installation.
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other:_____________________________
II. Technology Parameters	
Service Application	Wastewater laterals and small sewer mains and water mains
Service Connections	Services need to be excavated before bursting and reconnected to the new pipe after bursting and then backfilled.
Structural Rating Claimed	Depends on the selection of the new pipe to be installed.
Materials of Composition	PVC pipe, SDR-21 (4"-12") The pipe has the following minimum physical properties (manufacturer's data): Property — ASTM — Value Impact resistance — D 1784 — 0.65 ft-lbf/in of notch Tensile strength — D 1784 — 7,000 psi Modulus of elasticity — D 1784 — 400,000 psi Deflection temp under load, 264 psi — D 1784 — 212°F
Diameter Range, inches	4, 6, 8, 10, and 12 inches
Thickness Range, inches	5-15 mm, depending on ID (SDR-21)
Pressure Capacity, psi	Not applicable
Temperature Range, °F	0°F to 140°F
Renewal Length, feet	500 feet
Other Notes	Not Available

Technology/Method	**IPEX M-34 Drive-and-Pull Pipe/Pipe for modified sliplining, pipe bursting**
III. Technology Design, Installation, and QA/QC Information	
Product Standards	Material • ASTM D1784 *“Standard Specification for Rigid Poly(Vinyl Chloride) (PVC) Compounds and Chlorinated Poly Vinyl Chloride) (CPVC) Compounds”* • ASTM F477 *“Standard Specification for Elastomeric Seals (Gaskets) for Joining Plastic Pipe”* • NSF 61 • Extruded Pipe • ASTM D3212 *“Standard Specification for Joints for Drain and Sewer Plastic Pipes Using Flexible Elastomeric Seals”* • ASTM D2241 *“Standard Specification for Poly Vinyl Chloride (PVC) Pressure Rated Pipe (SDR Series)”* • CSA B137.3 *“Rigid Polyvinyl Chloride (PVC) Pipe for Pressure Applications”*
Design Standards	Not available
Design Life Range	50 years
Installation Standards	Not available
Installation Methodology	**Tight-in-place (TIP) method.** The TIP unit is set up in the launch pit. The rod stem is pushed from the launching pit through the host pipe to the exit pit. At the exit pit, the realignment head is slipped over the rod, and the entire rod string is pulled back just until the realignment head engages the host pipe. The first section of pipe is then slid over the rods until it butts against the rear of the realignment head. A new rod is added, and a pneumatic clamping device is slid onto the end of the rod string. The clamping device simultaneously grips slots cut in the rods, as well as locks into the new pipe. A jacking system within the clamping device is then used to thrust the new pipe segment against the liner column. This pre-compression force prevents the joints from opening during the bursting process. After each section is pulled in, the clamping machine is removed to allow the addition of the needed number of guide rods, as well as a new section of pipe. The entire pipe column assembly is then pulled into the hole through the length of the replacement segments, and the cycle repeats. **Pipe bursting.** Pipe bursting is performed in the same manner as described above for the TIP method. The difference is that the realignment head is replaced with a burst head. Rather than realigning the damaged or dislocated host pipe, the burst head expands the original pipe. The annular space created allows for a larger replacement pipe when compared to the TIP method.
Qualification Testing	• Required pulling loads with static pipe bursting between manholes in VCP pipe (Louisiana Tech, Ruston, LA, 2009) • Full-scale field testing of TIP method (Louisiana Tech, Ruston, LA, 2009)
QA/QC	A post-installation CCTV inspection is conducted to ensure the new pipe is free of defects. Pressure testing may be carried out, if required.
IV. Operation and Maintenance Requirements	
O&M Needs	O&M consistent with that of a newly installed pipe.
Repair Requirements for Rehabilitated Sections	Fragments of the original pipe surround the new pipe, but they are likely to be less disturbed than in full pipe bursting operations.
V. Costs	
Key Cost Factors	• Pipe size and SRD • Location accessibility • Host-pipe integrity
Case Study Costs	• Product is under development; no cost summary is available at this time.
VI. Data Sources	
References	Drive and Pull Report (2009); LA Municipal Forum (2008)

Datasheet A-32. Jabar Static/Pneumatic Pipe Bursting

Technology/Method	**Static Pipe Bursting /On-Demand Pneumatic Pipe Bursting**
I. Technology Background	
Status	Conventional
Date of Introduction	Since 1995
Utilization Rates	Not available
Vendor Name(s)	**Jabar** Calhoun, LA Phone: (318) 396-6160 Email: pipeburst@jabarcorp.com Website: www.itsmfg.com
Practitioner(s)	• City of Laurel, MS, Bill Keener • City of Oxford, MS
Description of Main Features	Rapid advance pipe bursting with on-demand pneumatic hammering action
Main Benefits Claimed	• The combination of a high-speed static pull and on-demand pneumatic hammer provides a low cost and high success rate for pipe bursting, with long bursting runs possible. • Allows an increase in the size and flow characteristics • New pipe is installed.
Main Limitations Cited	• Requires bypass pumping, entry and exit pits, and excavations at each lateral location. • Difficulty when used in expansive soils, in close proximity to other services, and in host pipes with collapsed sections.
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other:____________________
II. Technology Parameters	
Service Application	Waterlines, sewer lines, gas lines and storm sewers
Service Connections	Services need to be excavated before bursting and reconnected to the new pipe after bursting and then backfilled.
Structural Rating Claimed	Depends on the selection of the new pipe to be installed.
Materials of Composition	Depends on the selection of the new pipe to be installed.
Diameter Range, inches	2 to 36 inches
Thickness Range, inches	Depends on the selection of the new pipe to be installed.
Pressure Capacity, psi	Depends on the selection of the new pipe to be installed.
Temperature Range, ^{o}F	Depends on the selection of the new pipe to be installed.
Renewal Length, feet	750 feet
Other Notes	Not available
III. Technology Design, Installation, and QA/QC Information	
Product Standards	Depends on the selection of the new pipe to be installed.
Design Standards	Depends on the selection of the new pipe to be installed.
Design Life Range	Depends on the selection of the new pipe to be installed.
Installation Standards	Guideline Specification for the Replacement of Mainline Sewer Pipes by Pipe Bursting. (IPBA, NASSCO), Guidelines for Pipe Bursting (TTC).
Installation Methodology	An entry or launch pit is dug at one end of the failed line. An exit pit is dug at the other end of the failed line. Pits at service laterals are dug prior to the bursting operations to disconnect the service lines from the pipe to be burst. The bursting equipment features a rod-gripping arrangement that allows simultaneous pulling and rod removal. High bursting speeds allow the new pipe to be pulled in with less chance of hole collapse around the new pipe, which increases pull loads and slows the bursting process. An on-demand hammer has been added to the system to provide additional bursting capabilities at prior pipe repairs, etc. Following the bursting operation, the laterals are reconnected to the main line.
Qualification Testing	Depends on the selection of the new pipe to be installed.
QA/QC	A post-installation CCTV inspection is conducted to ensure the new pipe is free

Technology/Method	**Static Pipe Bursting /On-Demand Pneumatic Pipe Bursting**
	of defects.
IV. Operation and Maintenance Requirements	
O&M Needs	O&M consistent with that of a newly installed pipe.
Repair Requirements for Rehabilitated Sections	No special requirements
V. Costs	
Key Cost Factors	• Pit excavation • Bypass pumping • Cost of replacement pipe (not a big factor)
Case Study Costs	Not available
VI. Data Sources	
References	www.itsmfg.com; Guidelines for Pipe Bursting (TTC).

Datasheet A-33. Janssen Lateral Connection Repair

Technology/Method	**Janssen Lateral Rehabilitation System/Lateral connection robotic repair**
I. Technology Background	
Status	Innovative
Date of Introduction	In U.S. since 2006; in Germany since 1999
Utilization Rates	Over 12,000 lateral connections repaired in Europe; 61 demo repairs in US
Vendor Name(s)	**The Janssen Process LLC** 662 Dug Hill Road Brownsboro, AL 35741 Phone: (256) 509-2204 Email: janssenprocess@comcast.net Website: www.janssen-umwelttechnik.de/E
Practitioner(s)	• Washington Suburban Sanitary Commission (WSSC), MD, Ed Carpenetti, (301) 206-7081, ecarpen@wsscwater.com (41 lateral connections repaired in 2009; planned to renovate approx. 3,500 laterals each year for next 5 to 10 years) • Howard County, MD, Jeff Mozal, (410) 313-4978, 2 laterals (2007) • Marietta, GA, Tom Jones, P.E., (770) 794-5186, 3 laterals (2007) • Clayton Co., GA, Charles Ecton, (770) 960-5205, 3 laterals (2007)
Description of Main Features	A robotic repair of lateral connection extending 18 to 24 inches into the lateral that uses a silica-based resin to provide a full structural repair of the damaged connection and form a sealing collar of material around the pipe, thus stopping infiltration into the sewer system.
Main Benefits Claimed	• Access to the lateral connection is through the mainline and does not require cleanouts • Quick installation (1.5 to 2.0 hours per lateral) • Stabilizes the soil envelope around the pipe, thus eliminating the infiltration in the future; fills voids surrounding lateral connection • Provides a full structural repair of damaged pipes • Resin can be injected in the presence of high groundwater infiltration.
Main Limitations Cited	• Limited pool of qualified contractors, since this is a new product (Reynolds Inliner is currently the only licensed contractor in US) • Durability of repair must be proven. • Manhole inverts require 25 inches straight section for insertion of robotic devices.
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other:______________________
II. Technology Parameters	
Service Application	Wastewater
Service Connections	Not applicable
Structural Rating Claimed	Fully structural**;** resin forms mechanical bond with prepared lateral and main pipe surfaces; entire resin mass re-establishes spring line support for lateral pipe.
Materials of Composition	Silica-based resin, JaGoSil, is a two-component silicate-isocyanate resin that is mixed at the nozzle and cures in 20 to 30 minutes.
Diameter Range, inches	Lateral ID 4-12 inches
Thickness Range, inches	Not applicable (thickness of sealing collar in the ground depends upon the make-up of soils/bedding and size of voids, if any. Approximately 30 lb of resin are required per connection to re-secure bedding.)
Pressure Capacity, psi	Not applicable
Temperature Range, °F	25° to 100°F
Renewal Length, feet	24 inches into lateral and 24 inches in the mainline
Other Notes	Not available

Technology/Method	**Janssen Lateral Rehabilitation System/Lateral connection robotic repair**
III. Technology Design, Installation, and QA/QC Information	
Product Standards	No ASTM standards yet
Design Standards	No ASTM standards yet
Design Life Range	50 years minimum
Installation Standards	No ASTM standards yet
Installation Methodology	A cutting robot is moved through the mainline to the lateral opening to remove approximately 2 inches of entire circumference of the lateral pipe at the main and, in addition, any damaged portion of the lateral pipe wall. A packer with an inflatable bladder is used to apply the resin. Guided by four CCTV cameras, the packer is positioned at the lateral opening, the bladder extended into the lateral connection, and both the packer and the bladder inflated to closely fit the lateral connection and create a temporary mold. The resin is injected to penetrate into the soil and voids behind the pipe and fill pipe cavity removed during cutting. After resin cure, the bladder is deflated and the packer removed through the mainline.
Qualification Testing	• Mechanical properties (Stork Twin City Testing Co, Minneapolis, MN, 2005) • Environmental impact of resin on groundwater (Hygiene Institute DES Ruhrgebiets, 2002)
QA/QC	Contractor supplies resin sample each day, coded with resin batch number for future reference/testing if required.
IV. Operation and Maintenance Requirements	
O&M Needs	No special requirements
Repair Requirements for Rehabilitated Sections	If relining of mainline and connecting laterals is required, it should be completed first (resin injection afterwards creates mechanical bond within resin mass).
V. Costs	
Key Cost Factors	• Density of laterals on the mainline between two manholes (i.e., the frequency of setting up the lateral equipment) • Preparation work required (cleaning, removal of roots and any protruding laterals, removal of damaged area of pipe by grinding, or drilling of holes in the damaged area of pipe for resin insertion into the soil) • Cost of material
Case Study Costs	• $2,200 to $2,700 per lateral (manufacturer's quote)
VI. Data Sources	
References	• WERF, 2006. Methods for Cost-Effective Rehabilitation of Private Lateral Sewers, 02CTS5, Water Environment Research Foundation, Alexandria, VA, 436p. • www.janssen-umwelttechnik.de/E

Datasheet A-34. KA-TE Lateral Connection and Pipe Repair Robot

Technology/Method	**KA-TE Robotic System/Lateral connection robotic repair**
I. Technology Background	
Status	Innovative (in U.S.)
Date of Introduction	In U.S. since 1992; in Switzerland since 1986
Utilization Rates	Approx. 4,000 lateral connections in US, and 500,000 worldwide
Vendor Name(s)	**KA-TE Robotic System** Phone: +41-55- 415-5858 Email: pheenan@kate-pmo.ch Website: http://www.kate-pmo.com/index_e.html **SAF-r-DIG Utility Surveys, Inc** Palm Desert, CA Phone: (760) 776-8274 Email: jMarcinek@safrdig.com Website: www.safrdig.com/kate/kt.htm
Practitioner(s)	Not available
Description of Main Features	A robotic repair of lateral connection that uses an epoxy resin to provide a full structural repair of the damaged connection and optionally create a sealing collar of material around the pipe, thus stopping infiltration into the sewer system.
Main Benefits Claimed	• Access to the lateral connection is through the mainline and does not require cleanouts. • Provides a full structural repair of damaged lateral connection • Very suitable for repair of break-in protruding laterals
Main Limitations Cited	• Reaches only a very short distance (6") into the lateral • Very limited pool of qualified contractors in U.S. • Relatively long installation (5 hours per lateral) • The old model was rather complicated for use in the field.
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other:_________________________
II. Technology Parameters	
Service Application	Wastewater
Service Connections	In situ repair
Structural Rating Claimed	Fully structural repair
Materials of Composition	A two-component epoxy resin that cures in 4 hours. After repair, the resin has the following physical properties: Property — Test Method — Value Flexural strength — ASTM C580 — 9,400 psi Tensile strength — ASTM D4541 — 2,500 psi
Diameter Range, inches	Lateral ID 4-6 inches, mainline ID 8-24 inches
Thickness Range, inches	Not applicable
Pressure Capacity, psi	Not applicable
Temperature Range, °F	Not available
Renewal Length, feet	4 inches into lateral
Other Notes	This technology is often used for lateral reopening after mainline relining.
III. Technology Design, Installation, and QA/QC Information	
Product Standards	None
Design Standards	None
Design Life Range	50 years minimum
Installation Standards	None

Technology/Method	**KA-TE Robotic System/Lateral connection robotic repair**
Installation Methodology	A robot is moved through the mainline to the lateral opening. The surface of damaged connection is prepared (any protruding lateral cut off or ground away; the damaged piece of pipe is ground to depth to expose the virgin material or completely removed; and the area flushed with water). The early model used a special filling robot in conjunction with spatula tool to apply the resin; however, the current model (since mid-1990s) utilizes a "lateral shoe" (a flexible plastic plate in the mainline from which a lateral bladder is expanded into the lateral). The bladder is inflated to closely fit the lateral connection, creating a temporary mold. The resin is injected to fill any cavity in the lateral connection and optionally penetrate into the soil behind the pipe. After resin cure, the bladder is deflated and the robot removed from the mainline.
Qualification Testing	IKT testing of performance
QA/QC	CCTV inspection
IV. Operation and Maintenance Requirements	
O&M Needs	No special requirements
Repair Requirements for Rehabilitated Sections	No special requirements
V. Costs	
Key Cost Factors	• Density of laterals on the mainline between two manholes (i.e., the frequency of setting up the lateral equipment) • Preparation work required (cleaning, removal of roots and any protruding laterals, removal of damaged area of pipe by grinding) • Cost of material
Case Study Costs	• $1,000 to $1,500 per lateral (manufacturer's quote)
VI. Data Sources	
References	• WERF, 2006. Methods for Cost-Effective Rehabilitation of Private Lateral Sewers, 02CTS5, Water Environment Research Foundation, Alexandria, VA, 436p. • http://www.janssen-umwelttechnik.de/E • www.safrdig.com/kate/kt.htm

Datasheet A-35. Linabond Co-Liner™ Panel Liner

Technology/Method	**Linabond Co-Liner™/Panel lining system**
I. Technology Background	
Status	Conventional
Date of Introduction	1981
Utilization Rates	See project list at Linabond Website
Vendor Name(s)	**Linabond, Inc.** 12950 Bradley Avenue Sylmar, CA 91342 Phone: (818) 362-7373 Email: info@linabond.com Website www.linabond.com
Practitioner(s)	A list of projects since 1981 can be found at the Linabond Website. Some recent U.S. projects include: • 2008, Lake Hills Elliot Bay Interceptors, Seattle, Washington, Rehabilitation of Force Main Discharge & Manhole Structures • 2008, South Plant DAFT Tanks Repair, Renton, Washington, T-Lock Failure Repair • 2008, Juanita Bay Pump Station, Tacoma, Washington, Corrosion Protection of New Construction
Description of Main Features	The Linabond Co-Liner™ system is for the repair and protection of damaged structures or new construction, including pipelines, wet wells, conveyance and diversion structures, grit chambers, sludge digesters, clarifiers, process and storage tanks, and other areas needing structural repair or reinforcement, corrosion protection, or gas/liquid containment. Main features include: • A structural polymer core and an extruded liner face combined in a sandwich composite with the host structure (similar to that used in the aerospace industry). • Continuously bonded to the surface • Prevents the migration of gases and liquids • Protects its own fastening system, as well as the substrate • Ensures corrosion protection • Provides structural reinforcement
Main Benefits Claimed	• Corrosion protection • Containment • Structural rehabilitation • Infiltration/inflow (I/I) prevention • Groundwater contamination prevention • For municipal wastewater treatment and collection infrastructure • Suitable for both new construction and rehabilitation of existing structures • Partial liners can be installed in large-diameter sewers during low-flow periods without the need for by-passing • Improved flow capacity
Main Limitations Cited	Person-entry required
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other: Wet wells, conveyance and diversion structures, grit chambers, clarifiers, sludge digesters, process, and storage tanks.
II. Technology Parameters	
Service Application	Wastewater, stormwater, raw water, industrial, power, waterfront
Service Connections	Person entry – handled individually
Structural Rating Claimed	Structural capability
Materials of Composition	Structural polymer and PVC panels
Diameter Range, inches	Any person entry
Thickness Range, inches	Liner typically extends 0.04 to 0.2 inches above the surface of the original un-corroded structure, so there is essentially no loss in hydraulic diameter. Voids in coarse and deeply corroded surfaces (e.g., with exposed aggregate) are filled

Technology/Method	**Linabond Co-Liner™/Panel lining system**
	with the structural polymer.
Pressure Capacity, psi	Tested 2,500 psi of water pressure
Temperature Range, °F	Up to 212°F (with Linabond Thermoline™ system)
Renewal Length, feet	No special limitations
Other Notes	Not available
III. Technology Design, Installation, and QA/QC Information	
Product Standards	Greenbook, Standard Specifications for Public Works Construction, 21A-2.5.1 Rigid PVC Liners for Structures, Manholes, and Pipes.
Design Standards	Not available
Design Life Range	Cited as 100 years plus by manufacturer
Installation Standards	Not available
Installation Methodology	The existing surface of the structure to be lined is cleaned and prepared to provide a sound substrate for the new liner. The new co-liner™ is formed by spraying a polymer coating onto the existing structure and then embedding semi-rigid PVC sheets into the uncured coating layer to form a composite structure. This composite structure conforms to and is bonded to the existing structure. Seams are chemically welded with a 4-inch-wide overlap. A cross-link activator is used to bind the PVC sheets to the polymer layer. A primer layer may be used on the surface of the existing structure prior to application of the polymer layer.
Qualification Testing	Not available
QA/QC	• Material testing on PVC panels and polymer material. • In situ bond strengths using pull tests. • Linabond field inspector present at all times during the lining system installation. • Project monitoring by Engineers, Construction Management, Contractors, and Owners via dedicated Extranet quality control database.
IV. Operation and Maintenance Requirements	
O&M Needs	No special requirements
Repair Requirements for Rehabilitated Sections	No special requirements
V. Costs	
Key Cost Factors	• Person-entry • Labor costs
Case Study Costs	Available from the vendor upon request.
VI. Data Sources	
References	www.linabond.com

Datasheet A-36. Link-Pipe Grouting Sleeve Repair

Technology/Method	**Grouting Sleeve™ internal repair sleeve**
I. Technology Background	
Status	Innovative
Date of Introduction	Not available
Utilization Rates	Not available
Vendor Name(s)	**LINK-PIPE, Inc.** Richmond Hill, ON Phone: (800) 265-5696 Email: lmaimets@linkpipe.com Website: www.linkpipe.com
Practitioner(s)	Not available
Description of Main Features	Repair features a finished stainless-steel patch in the sewer pipe. The sleeve carries its own required sealant. The installation is safe in cracked vitrified clay and other fragile pipes if installed as directed by the manufacturer.
Main Benefits Claimed	• Structural repairs of longitudinal cracks, circumferential cracks, multiple cracks, broken pipes, holes, laterals before CIPP relining, avoiding service lateral closing. • Reinstates partially collapsed pipes; totally collapsed or missing pipe; separated, misaligned, and offset joints • Can retard root growth • Seals exfiltrating of gravity flow pipes and abandoned services
Main Limitations Cited	Not available
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other:____________________________
II. Technology Parameters	
Service Application	Gravity sewer repair
Service Connections	Not applicable
Structural Rating Claimed	GROUTING SLEEVE™ is structurally designed to carry 5 psi. (33kPa) external hydraulic pressure *with a minimum* Factor of Safety of 2.5. The design follows AWWA M11 standard for Flexible Tunnel Liners. Stainless-steel core provides the sleeve with the essential strength needed to support a damaged pipe.
Materials of Composition	Structural Core: The material is SST-316 or higher alloy for domestic sewers. For saltwater pipes and tropical climate, higher stainless-steel alloys are recommended.
Diameter Range, inches	6, 8, 10, 12, 15, 18, 21, 24, 27, 30, 33, 36, 42, 48, and 54 inches
Thickness Range, inches	Not available
Pressure Capacity, psi	Not applicable
Temperature Range, °F	Wide temperature range
Renewal Length, feet	Standard Lengths: 12, 18, 24, and 36 feet
Other Notes	Not available
III. Technology Design, Installation, and QA/QC Information	
Product Standards	The stainless steel used meets ASTM testing standards A267 and A240.
Design Standards	*GROUTING SLEEVE™* resists a wide range of aggressive chemicals, including H_2SO_4, HCl, and seawater.
Design Life Range	Designed to last 100 years
Installation Standards	Not available
Installation Methodology	1. Line cleaning and CCTV inspection 2. Installation 2.1 After preparatory work, the repair must proceed without delay. The entire process of inserting and installing shall be recorded on videotape and a copy submitted to the owner after completion of each sewer section. 2.2 Length of the repair is determined by adding a minimum of 16 inches to the

Technology/Method	**Grouting Sleeve™ internal repair sleeve**
	total longitudinal length of the defect. 2.3 If access to the line is limited, such that only short sleeves can be passed through, then two or more sleeves shall be used. In that case, the first sleeve flared at both ends shall be installed, followed by subsequent sleeves flared only at one end. The non-flared end overlapping the flared end of the previously installed sleeve shall be used to create the continuity. 2.4 Urethane grout supplied with each sleeve is applied directly to the black sleeve gasket, following installation instructions in Grouting Sleeve™ brochure. 2.5 The prepared Grouting Sleeve^{TM} is then installed on the plug. 2.6 The plug and camera shall then be positioned in the manhole channel, and the sleeve doused with water wetting the entire gasket. From this point onward, the installation must be completed within 20 minutes. 2.7 If the effluent flow is too high to allow full viewing of the sleeve installation, the CCTV camera must be placed downstream of the repair site, or sewer plugs installed at the upstream manhole. 2.8 When the plug assembly is properly positioned over the point of repair, the plug shall be inflated just enough to let the leading edge of the stainless-steel sleeve lock behind the opposing fingers protruding from the face of the sleeve wall. The locking is usually accompanied by clicking sounds as the leading edge slides over the locks. As the sound stops, or the recommended pressure is achieved, the plug shall be deflated without delay. 2.9 At this point, the deflated plug shall be pulled out of the sleeve and the camera drawn into the sleeve to verify that the leading edge of the sleeve has been secured behind all of the lock fingers. If not completely secured, the plug shall be repositioned on the sleeve and re-inflated at 5 psi (0.33 bar) over the pressure used previously. This process shall be repeated until the edge is safely tucked behind all of the fingers. At this point, the installation of the sleeve is complete.
Qualification Testing	WRc assessed the performance, the strength, and effectiveness of the Link-Pipe GROUTING SLEEVE™ sewer repair system by conducting loading tests on soil-embedded sleeves.
QA/QC	Manufacturing follows ISO 9001-2000 certified Quality Control procedures. When all sleeves have been installed in a sewer section, the entire sewer section shall be inspected from manhole to manhole using the plug to retard flow for better visibility. The inspection is recorded on a videotape. This tape and associated inspection log "Post Installation Record" shall be turned over to the owner forming the "as-built record" of the completed work. The project is considered completed when: • All damaged pipe is fully covered by the repair sleeve(s). • Verify that all locks on each installed sleeve have been engaged. • Verify no groundwater intrusion is entering the pipe from behind the sleeve. Contractor shall keep one copy of the preliminary inspection tape, the installation, post inspection tape, associated inspection forms, and the Manufacturer limited 10-year warranty, giving a second copy to the owner.
IV. Operation and Maintenance Requirements	
O&M Needs	Cleaning methods that will not damage the exposed ends of the repair clamp should be used.
Repair Requirements for Rehabilitated Sections	Not applicable
V. Costs	
Key Cost Factors	Not available
Case Study Costs	Not available
VI. Data Sources	
References	www.linkpipe.com; personal communication

Datasheet A-37. Link-Pipe Insta-Liner™ Segmental Liner System

Technology/Method	**Link-Pipe Insta-Liner™**
I. Technology Background	
Status	Innovative
Date of Introduction	Not available
Utilization Rates	Not available
Vendor Name(s)	**LINK-PIPE, Inc.** Richmond Hill, ON Phone: (800) 265-5696 Email: lmaimets@linkpipe.com Website: www.linkpipe.com
Practitioner(s)	Not available
Description of Main Features	Link-Pipe Insta-Liner™ is made up of short links of stainless-steel sleeves, which are coupled to create a continuous liner of a specified length. Individual links are coupled and are pulled through the host pipe by a cable from the opening at the far end of the host pipe. A continuous stainless-steel liner is thus formed. A specially formulated cement grout is then pumped to fill the annular space between the host pipe and the Insta-Liner™. The grout flows into all cracks and joints, joining the Insta-Liner™ and all old pipe sections into a solid and unified structure. The SST-316 Insta-Liner™ is selected for the purpose of providing a repair that lasts at least 100 years in a city culvert, sanitary sewer, and storm sewer environment.
Main Benefits Claimed	Link-Pipe Insta-Liner™ forms a composite structure with the damaged or eroded host pipe and creates a new pipe, even where the old pipe is missing. The new composite pipe combines the strength of the new liner with sections and pieces of the host pipe, all bonded together with a cementitious grout. • No excavation • No traffic holdups • No damage to utilities • No expensive installation equipment needed • Only one crew of three persons is needed to perform the repair. • Repair segment installation requires very short setup and installation time. • 100-year long service life • 10-Year limited manufacturer warranty
Main Limitations Cited	Not available
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other:______________________
II. Technology Parameters	
Service Application	Gravity mainlines and service lines
Service Connections	No information available
Structural Rating Claimed	Suitable for fully deteriorated pipes
Materials of Composition	Standard Link-Pipe Insta-Liner™ segments and chemical grout
Diameter Range, inches	6, 8, 10, 12, 15, 18, 21, 24, 27, 30, 33, 36, 42, 48, and 54 inches
Thickness Range, inches	Not available
Pressure Capacity, psi	Not applicable
Temperature Range, °F	Wide range of temperature applicability
Renewal Length, feet	Standard Lengths: 12, 18, 24, and 36 inches
Other Notes	
III. Technology Design, Installation, and QA/QC Information	
Product Standards	Standard Link-Pipe Insta-Liner™ segments are made of SST-316 or SST-316L. Chemical grout is tested and meets ASTM D1010, D1638, D3574, D412, and

Technology/Method	**Link-Pipe Insta-Liner^{TM}**
	D1042 standards. Insta-Liner™ resists a wide range of aggressive chemicals, including H_2SO_4, HCl, and seawater. (Chemical resistance tables are available on request.)
Design Standards	The stainless steel used meets ASTM testing standards A267 and A240.
Design Life Range	Link-Pipe Insta-Liner™ can be ordered with a 50-year, 100-year, or any custom-designed service life.
Installation Standards	Not available
Installation Methodology	• Inspection: Prior to commencing any work in the pipe, an inspection is needed to determine what conditions in the pipe are encountered and what scope of work has to be done. • Cleaning: The host pipe needs to be cleaned of any debris, intrusions, deformations, mineral deposits, etc. • Installation: One at a time, the Link-Pipe Insta-Liner™ links are coupled and are pulled into the existing host pipe by a winch from the far host-pipe opening. Often, only pulling by hand is required. End-Sealers: Once the liner has been installed, End-Sealers are inserted at each end of the new liner. This prevents the grout from escaping when it is pumped into the annular space. The grout is then injected into the annular space, either through a plug into the individual sections, or by pumping through an end nipple throughout the length of the liner. • Grouting: End-to-end: This is a very convenient method of grouting. Only one point of entry is required, which can be located at either end of the original host pipe.
Qualification Testing	See product standards and QA/QC.
QA/QC	Manufacturing follows ISO 9001-2000 certified Quality Control procedures. Manufacturer offers a 10-Year Limited Warranty subject to full project data being submitted at the time the request to enact the warranty is made.
IV. Operation and Maintenance Requirements	
O&M Needs	No special requirements.
Repair Requirements for Rehabilitated Sections	No special requirements. Care required at ends of rehabilitated sections.
V. Costs	
Key Cost Factors	High material cost
Case Study Costs	Not available
VI. Data Sources	
References	www.linkpipe.com; Personal communication.

Datasheet A-38. LMK CIPMH™ Manhole Chimney Liner

Technology/Method	**LMK CIPMH Chimney/CIP liners**
I. Technology Background	
Status	Innovative
Date of Introduction	First installations in March 2007
Utilization Rates	Over 4,000 feet installed since 2005
Vendor Name(s)	**LMK Enterprises, Inc** Ottawa, IL Phone: (888) 433-1275 Email: LMKLiner@aol.com Website: www.performanceliner.com
Practitioner(s)	• Cincinnati MSD, OH, Mike Stevens, Michael.stevens@cincinnati-oh.gov, (513) 352-4941 (625 liners installed in the past several years, of which 1,000 were without fiberglass and 104 with fiberglass) • City of Springfield, MO, Kevin Swearengin, (417) 864-1928; (cell is (417) 838-8754), kswearengin@springfieldmo.gov (about 500 liners installed between 2007 and 2009), • St. Louis Sewer District (STL MSD), MO, Ron Moore, krlmoor@stlmds.com, (314) 768-6388, cell– (314) 229-3713 (about 300 liners installed between 2005-2009) • Waterford Township, MI, Terry Beiderman, (248) 618-7451 • City of Burton, MI, Mike Holzer, (810) 743-1500 • Grand Blanc Township, MI, Dave Hobson, (810) 424-2600
Description of Main Features	A CIP product for manhole chimney relining usually installed with a short overlap onto the cone section (3 to 4 inches).
Main Benefits Claimed	• Eliminates inflow by renewing the adjustment rings and the brick and mortared sections, while structurally repairing the defects in the manhole chimney area. These defects are often found while the rest of manhole, the pre-cast concrete, is in good condition. • Resistant to cracking under extreme freeze-thaw cycles • No manhole entry required • Quick installation (1 hour) • Liner stretches from 22 to 40 inches (conforms to oddly shaped manholes)
Main Limitations Cited	• Early liners (those installed without fiberglass) had some failures a year or so after installation, in locations where high groundwater levels contributed to expansion/contraction from freeze-thaw.
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other:____________________________
II. Technology Parameters	
Service Application	Wastewater
Service Connections	Not applicable
Structural Rating Claimed	Repairs fully or partially deteriorated chimney
Materials of Composition	Tube material is stretchable, non-woven polyester. Resin is silicate-based thermo-set. Reinforcing coating is a sheet of fiberglass. The installed liner has the following min. physical properties (in manufacturer's specifications): Test Method — Value Compressive strength — ASTM D695 — 1,500 psi Hardness — ASTM D2240 — 74 Bond — Peel test — concrete failure
Diameter Range, inches	"One size fits all" (i.e., a 22" tube will stretch to 60").
Thickness Range, inches	Nominal liner thickness, 4.5 mm
Pressure Capacity, psi	Full-depth hydrostatic pressure
Temperature Range, °F	-20°F to 115°F
Renewal Length, feet	6 to 120 inches, average depth 24 inches

Technology/Method	**LMK CIPMH Chimney/CIP liners**
Other Notes	Not available
III. Technology Design, Installation, and QA/QC Information	
Product Standards	ASTM F1216
Design Standards	Nominal liner thickness 4.5 mm
Design Life Range	50 years
Installation Standards	LMK/OTIS
Installation Methodology	In situ resin vacuum impregnation of fabric tube, followed with manual inversion of the tube and a sheet of reinforced fiberglass wrapped onto the tube. The assembly is lowered into the manhole and temporarily held in place by a holding collar. The installation device (bladder) is inserted, and spacing rings are placed on top of the manhole to hold the installation device at a correct depth. Resin ambient temperature (typically 1 hour). After curing is complete, the installation device is removed and the liner trimmed flush with the manhole cover.
Qualification Testing	• Impact test (O'Sullivan Trenchless Installation Services (OTIS)/LMK, 06/2006) • Freeze/thaw test (O'Sullivan Trenchless Installation Services (OTIS)/ LMK, 08/2005) • Simulated inflow test (City of Blue Springs, MO)
QA/QC	Prior to lining, the surfaces must be stringently pressure-washed (a min. of 5,000 psi at 5 gal/min pressure washer); any leaking stopped by patching with a quick-set hydraulic cement and any large voids in the manhole surface repaired.
IV. Operation and Maintenance Requirements	
O&M Needs	Properly clean chimney and remove ladder rungs that prevent insertion of the liner.
Repair Requirements for Rehabilitated Sections	Any large voids must be filled with hydraulic cement (small voids may go un-patched); any active inflow must be temporarily stopped, or installation can be postponed until a more suitable time exists when there isn't active infiltration and inflow. There are no special requirements for future repair.
V. Costs	
Key Cost Factors	• Preparation work required (cleaning, repairs) • Cost of material • Traffic control
Case Study Costs	• In Cincinnati MSD, OH: $800 to $1,000 per chimney • Manufacturer's quote: $300 to $600 per vertical foot, depending on quantity, average depth, and the extent of preparation needed (i.e., cleaning)
VI. Data Sources	
References	• http://www.perma-liner.com/; www.performanceliner.com • Personal communication • Davidson, G.R., 2005. *Freeze/Thaw Test of CIPMH Manhole Chimney Liner*, Write-up from a third-party observer of the testing, Allgeier, Martin and Associates, Inc, Jopin, Mon. Aug 24, 2005, 10 p. • OTIS, 2006. *CIPM Chimney Liner Impact Test*, Test Summary Report, June 2006, O'Sullivan Trenchless Installation Services, Inc., Lamar, MO, 4 p. • Reed, T., 2006. "New Cured-In-Place System for Manhole Chimneys," *Underground Construction*, May 2006, p. 56

Datasheet A-39. LMK CIPP Performance Liner

Technology/Method	**Performance Liner /Conventional CIPP, sectional repair**
I. Technology Background	
Status	Mature
Date of Introduction	1994
Utilization Rates	Over 20,000 feet since 1994
Vendor Name(s)	**LMK Enterprises, Inc** Ottawa, IL Phone: (888) 433-1275 Email: LMKLiner@aol.com Website: www.performanceliner.com
Practitioner(s)	• City of Portland, OR – Scott Weaver (503) 823-1744 • City of Tulsa, OK – Mark Rogers/Joe Cramer (918) 669-6101 • City of Wichita, KS – Calvin Fugit (316) 268-4024 • City of Tacoma, WA – Hugh Messer (253) 594-7825 • City of Salem, OR – Eric Johnson (503) 588-6063 • City of Vancouver, BC, Canada – Ben Dias (604) 326-4858 • Veolia ES, Vacaville, CA – Jay Fox (707) 446-8222 • Walden Associated Technologies, Glen Carbon, IL – James Bohn (618) 397-9840
Description of Main Features	A CIPP product for sectional rehabilitation of wastewater mainlines installed by inversion from a launching device.
Main Benefits Claimed	• Eliminates I/I and repairs structural defects in mainlines • Capable of conforming to offset joints, bells, and disfigured pipe sections • Provides smooth pipe interior surface • Provides smooth transition from host pipe to CIPP by engineering design • Quick installation (2 hours or less) • Up to 50 feet length of repairs at a time • No resin contamination, no resin loss during liner insertion, and accurate placement of spot repair liner • CIPP liner is pulled and then inverted through damage section, and not pushed through the damaged section of pipe • Holding pressure is 5 to 6 psi because bladder is sized per the diameter of the pipe, eliminating the risk of causing further damage to the already damaged pipe.
Main Limitations Cited	• Flow bypass required if heavy flow exists
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other:______________________________
II. Technology Parameters	
Service Application	Wastewater, raw water, industrial, and power.
Service Connections	Service laterals are restored internally with robotically controlled cutting devices.
Structural Rating Claimed	Fully structural
Materials of Composition	Tube material is one or more layers of flexible needled felt or an equivalent non-woven material. Resin is polyester or vinyl ester with proper catalysts as designed for the specific application. The installed liner has the following min physical properties (from manufacturer): Property Test Method Value Min. flexural modulus ASTM F1216 250,000 psi 400,000 psi (enhanced resin) Min. flexural stress ASTM F1216 4,500 psi 4,500 psi (enhanced resin)

Technology/Method	**Performance Liner /Conventional CIPP, sectional repair**
Diameter Range, inches	4-60 inches
Thickness Range, inches	Depends on depth and condition of existing host pipe
Pressure Capacity, psi	Not applicable
Temperature Range, ^{o}F	90°F
Renewal Length, feet	Up to 50 feet
Other Notes	Not available
III. Technology Design, Installation, and QA/QC Information	
Product Standards	ASTM D1784 – rigid poly (vinyl chloride) (PVC) compound and chlorinated poly (vinyl chloride) (CPVC) compounds ASTM D3350 – polyethylene plastic pipe and fitting materials.
Design Standards	ASTM F2599
Design Life Range	50 years
Installation Standards	CIPP installation shall be in accordance with ASTM F1216, Section 7, or ASTM F1743.
Installation Methodology	Thermoset CIPP resin is vacuum-impregnated into a felt or non-woven tube (calibration rollers may be used for uniform thickness), followed by pulling liner/bladder assembly into a launching device. The entire launching device is pulled through the mainline pipe, using a pin and pull-rope assembly. The tube is accurately inverted at the point of repair from the launching device into the pipe by controlled air pressure. Air pressure between 5 to 6 psi is held on the bladder until final cure. Resin ambient temperature (typically 2 hours). After curing is complete, the bladder and launching device are removed from the host pipe with the hose reel. If necessary, service lateral connections are opened using a hydraulic-powered robotic cutting device specifically designed for cutting CIPP.
Qualification Testing	• CIPP Resin (Microbac) May 2008 • Interplastic Corporation, Thermoset Resins Division
QA/QC	Physical properties of installed CIPP (the flexural properties, wall thickness of samples) are tested in accordance with ASTM F2599, F1216, or ASTM F1743. Visual inspection of installed CIPP is done in accordance with ASTM F1743, Section 8.6. The post-installation CCTV inspection is performed to verify the proper cure of the material, the proper opening of service laterals, and the integrity of the seamless pipe.
IV. Operation and Maintenance Requirements	
O&M Needs	None
Repair Requirements for Rehabilitated Sections	Flow bypass is established when required, the pipe cleaned (all roots, debris, and protruding service connections removed), and inspected with a pan/tilt camera prior to lining and reconstruction.
V. Costs	
Key Cost Factors	• Preparation work required (cleaning, repairs) • Cost of material • Set-up (mobilization, traffic control)
Case Study Costs	Not available
VI. Data Sources	
References	• http://www.perma-liner.com/; www.performanceliner.com • Personal communication

Datasheet A-40. LMK T-Liner®

Technology/Method	**LMK T-Liner /Lateral CIP T-liner inverted from the mainline**
I. Technology Background	
Status	Innovative
Date of Introduction	Offered in USA since 1994. Also used in Canada, Australia, South America.
Utilization Rates	Not available
Vendor Name(s)	**LMK Enterprises, Inc** Ottawa, IL Phone: (888) 433-1275 Email: LMKLiner@aol.com
Practitioner(s)	• The Prince William Service Authority, VA, Wayne French, (703) 335-8981, french@pwcsa.org (20 laterals in 2004) • King County, Seattle, WA, Erica Jacobs, (206) 684-1138, erica.jacobs@metrokc.gov (20 liners in 2003) • Boston Water & Sewer Commission, MA, Irene McSweeney, (617) 989-7447, mcsweeneyif@bwsc.org (21 laterals in 1999) • Nashville and Davidson County, TN, Greg Ballard, (615) 862-4922, greg.ballard@nashville.gov (liners installed since 1997) • City of Naperville, IL, John Vose, (630) 420-6741, vosej@naperville.il.us • City of Portland, OR, Scott Weaver, (503) 823-1744, scott.weaver@pdxtrans.org
Description of Main Features	A CIP product for laterals installed from a manhole that includes a short, full-circle mainline liner and a lateral lining. Additional hydrophilic bands in mainline segment give extra protection against water infiltrating between new T-liner and pre-existing mainline liner. T-Liner® can reline up to 200 feet from the mainline. Two shorter versions are also available that do not require any cleanout: Shorty™ can reline up to 3 feet and Stubby™ up to 6 inches into the lateral.
Main Benefits Claimed	• Total sealing of the lateral connection with mainline, plus a long length of the lateral • Can reline through 4 to 6 inches transitions, through multiples bends (up to six soft 90° bends) • Quick installation (2 hours per lateral)
Main Limitations Cited	• Cleanout on the lateral is required for lengths over 3 feet (for proper cleaning, measuring, positioning, and inversion) • Not applicable in laterals with severe mineral buildup, severe offset joints, sags, or protrusions in the pipe • More expensive than other lateral lining systems
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other:________________________
II. Technology Parameters	
Service Application	Gravity wastewater
Service Connections	Not applicable
Structural Rating Claimed	Exceeds ASTM F2561
Materials of Composition	• Tube material is PVC - needled (stitched), knitted, or braided. Two parts, i.e. a full-circle mainline part and a lateral part, are stitched and factory-welded to make a one-piece liner. • Resin is unsaturated Iso-Polyester, epoxy-based vinyl ester, silicate with hardener 100% solids, or epoxy with catalyst. • Protective coating is PVC, thermal plastic urethane (TPU), polyethylene (PE), or polypropylene (PP). The installed liner has the following physical properties (per manufacturer's

Technology/Method	LMK T-Liner /Lateral CIP T-liner inverted from the mainline
	data): Property — Test Method — Value Flexural modulus — ASTM D790 — 250,000 psi Flexural strength — ASTM D790 — 4,500 psi
Diameter Range, inches	Lateral ID 3 to 8 inches and mainline ID 6 to 24 inches
Thickness Range, inches	Nominal liner thickness 3.0 mm or 4.5 mm
Pressure Capacity, psi	Refer to ASTM F2561
Temperature Range, °F	180°F, 200°F, or 250°F (depending on resin used)
Renewal Length, feet	6 inches to 200 feet
Other Notes	Not available
III. Technology Design, Installation, and QA/QC Information	
Product Standards	ASTM F2561-06
Design Standards	ASTM F1216-93, Appendix X1
Design Life Range	50-year minimum
Installation Standards	ASTM F2561-06, ASTM F1216-93, AWWA C950
Installation Methodology	A factory-prepared, T-shaped liner (stitching and welding of a mainline and a lateral piece) is onsite surrounded by a T-shaped translucent bladder forming a liner/bladder assembly. In situ resin impregnation (vacuum). Flow is stopped and a bypass pumping set up, if necessary. The liner/bladder assembly containing the resin-saturated tube is pulled into a launching device and hydrophilic bands are added. The liner/bladder assembly is installed from the mainline by air-pressure inversion. Resin is steam- or ambient-temperature-cured in 30 minutes or 2 hours, respectively. Once the resin curing is completed, the bladder is pulled out and the bypass pumping removed. The hydrophilic gasket seals are now embedded between the new CIPP connection and the host pipe. Both the upstream and downstream openings of the mainline connection are left open after the bladder is removed, as is the upstream termination point of the lateral lining; therefore, no trimming or cutting is necessary.
Qualification Testing	• Chemical resistance (HTSm Inc., Houston, 1998) • Microbac Corrosion Data, May 2008
QA/QC	• Stringent cleaning and removal of all roots, debris, and protruding service connections prior to rehabilitation, and CCTV inspection of the lateral line to determine the overall structural condition of the pipeline. • CCTV inspection is performed to verify the proper cure of the material, the proper trim of service connection, and the integrity of the seamless pipe.
IV. Operation and Maintenance Requirements	
O&M Needs	Properly clean lateral pipe and remove any debris. Provide proper measurements of lateral lengths and diameters.
Repair Requirements for Rehabilitated Sections	Stop active infiltration if infiltration is greater than the inversion and holding pressure of the CIP lining.
V. Costs	
Key Cost Factors	• Density of laterals on the mainline between two manholes (i.e., the frequency of setting up the lateral equipment) • Preparation work required (removal of roots and soft deposits in the lateral pipe, cleaning) • Cost of material • Installation of cleanouts, if necessary
Case Study Costs	• $4,471.32/lateral with cleaning and post-CCTV inspection) in Prince William Service Authority, VA, a total of 20 laterals (2004) • $1,600 to $6,500 per lateral (manufacturer's quote)

Technology/Method	**LMK T-Liner /Lateral CIP T-liner inverted from the mainline**
VI. Data Sources	
References	• WERF, 2006. *Methods for Cost-Effective Rehabilitation of Private Lateral Sewers*, 02CTS5, Water Environment Research Foundation, Alexandria, VA, 436 p. • www.performanceliner.com • McSweeney Woodfall, I., and M. Oliveira, 2000. "Fighting the Tide," *NASTT NO-DIG '00*, Anaheim, CA, Apr 9-12, 2000, pp. 273-289 • Kiest, L., Jr., 2003. "Wisconsin Raises the Bar Utilizing T-Liner," white paper, LMK Enterprises, Inc./Performance Pipelining, Inc, 2 p. • Blyth, J., 2007. “The Next Big Thing in Trenchless: Lateral Lining” white paper, LMK Enterprises, Inc./Benjamin Media • Kiest, K. and R. Gage, 2009. “Lateral Lining Helps to Rehab Michigan City’s System,” LMK Enterprises, Inc./Benjamin Media

Datasheet A-41. Logiball Mainline Grouting

Technology/Method	**Logiball Test & Seal Packers/Chemical grouting of mainline joints**
I. Technology Background	
Status	Conventional
Date of Introduction	In U.S. since mid-1990s; in Canada since early 1980s.
Utilization Rates	Estimated millions of ft repaired worldwide.
Vendor Name(s)	**Logiball, Inc.** Jackman, ME Phone: (800) 246-5988 Email: marc@logiball.com Website: www.logiball.com Grout Manufacturers: • Avanti International, www.AvantiGrout.com, Daniel Magill, (800) 877-2570, (713) 252-7881, daniel.magill@avantigrout.com • Prime Resins, www.primeresins.com, Jeremy West, (800) 321-7212, jwest@primeresins.com • DeNeef Construction Chemicals, Inc., www.deneef.com, Ed Paradis, (706) 894-2133, eparadis@deneef.com
Practitioner(s)	Contractors using this technology are listed on: www.sewergrouting.com
Description of Main Features	A grouting repair of mainline joints that uses a chemical grout to create a sealing collar of material outside the pipe that stops infiltration into the sewer system and exfiltration from the sewer into the ground. Chemical grouting is also performed after mainline relining (e.g., CIPP, spirally wound liners), following the laterals reopening, to seal the exposed annular space between the host pipe and the liner at that location. Selection of chemical grout can affect the cost and behavior of installed product in use and longevity of repair.
Main Benefits Claimed	• The most cost-effective rehabilitation option for joints • No excavation • Fast installation (2 hours setup time plus 15 to 30 min per joint; however, depending on the size of the pipe, outside voids, and flow conditions, time will vary).
Main Limitations Cited	• Does not provides a structural repair, although it fills voids on the outside of the pipe, stabilizing the soil around the structures • Sometimes cannot be applied (i.e., the isolated section cannot be pressurized and pipe must be structurally sound) • Shorter longevity of repair compared to other trenchless methods, although successful case studies show good performance of installed grouts 10 to 20 years after the rehabilitation
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other:____________________________
II. Technology Parameters	
Service Application	Wastewater
Service Connections	Not applicable
Structural Rating Claimed	None

<table>
<tr><th>Technology/Method</th><th>Logiball Test & Seal Packers/Chemical grouting of mainline joints</th></tr>
<tr><td>Materials of Composition</td><td>Different chemical grouts can be used.
<table>
<tr><th></th><th>Acrylamide</th><th>Acrylate</th><th>Acrylic resins</th><th>Urethane</th></tr>
<tr><td>Example grout</td><td>Avanti AV-100</td><td>De Neef AC-400</td><td>Avanti AV-118</td><td>Prime Resins Hydrogel SX</td></tr>
<tr><td>Description</td><td>Powder</td><td>Liquid</td><td>Liquid</td><td>Liquid</td></tr>
<tr><td>Catalyst</td><td>Chemical</td><td>Chemical</td><td>Chemical</td><td>Water</td></tr>
<tr><td>Water-to-resin</td><td>1:1</td><td>1:1</td><td>1:1</td><td>8:1</td></tr>
<tr><td>Gel times</td><td>5 sec to few hrs</td><td>5 sec to few hrs</td><td>5 sec to few hrs</td><td>Approx. 1 min</td></tr>
<tr><td>Viscosity, cps</td><td>1 to 2</td><td>1 to 3</td><td>1 to 2</td><td>10 to 20</td></tr>
<tr><td>Compressive strength, psi</td><td>130</td><td>130</td><td>N/A</td><td>200</td></tr>
<tr><td>Density, g/cm3</td><td>1.04</td><td>1.08</td><td>N/A</td><td>N/A</td></tr>
<tr><td>Cost</td><td>Low</td><td>Increased</td><td>Increased</td><td>High</td></tr>
<tr><td>Delivery systems required</td><td>Common</td><td>Common</td><td>Common</td><td>Urethane delivery systems</td></tr>
<tr><td>Familiar to most contractors</td><td>Yes</td><td>Yes</td><td>No</td><td>No</td></tr>
<tr><td>Toxic when uncured</td><td>Yes</td><td>No</td><td>No</td><td>No</td></tr>
</table>
Optional additives to chemical grouts:

Latex emulsion/reinforcing agent (increase in compressive and tensile strength)
Dichlobenil (inhibits root growth)
Ethylene glycol (protection against freezing and drying out)
Dietomaceous earth (increases gel content)
Potassium ferricyanide (extends gel time for acrylamide and acrylate)
Accelerators (speed up gel time, for urethane)
</td></tr>
<tr><td>Diameter Range, inches</td><td>6 inches and up</td></tr>
<tr><td>Thickness Range, inches</td><td>Not applicable</td></tr>
<tr><td>Pressure Capacity, psi</td><td>Not applicable</td></tr>
<tr><td>Temperature Range, °F</td><td>From grout manufacturers</td></tr>
<tr><td>Renewal Length, feet</td><td>Usually 500 to 700 feet</td></tr>
<tr><td>Other Notes</td><td>Not available</td></tr>
<tr><td colspan="2">III. Technology Design, Installation, and QA/QC Information</td></tr>
<tr><td>Product Standards</td><td>Varies according to grout</td></tr>
<tr><td>Design Standards</td><td>Not available</td></tr>
<tr><td>Design Life Range</td><td>Minimum 15 years

Note: 15.6 years was calculated in the Oregon study (Whitaker, 1991); some field applications already show 20 years (Thompson, 2008)</td></tr>
<tr><td>Installation Standards</td><td>ASTM F2304-03 Standard Practice for Rehabilitation of Sewers Using Chemical Grouting
NASSCO Specification Guidelines, 2007, Wastewater Collection System</td></tr>
<tr><td>Installation Methodology</td><td>The repair is performed by applying a test-and-seal procedure.

For joint grouting, a packer is moved through the mainline to cover the joint and the portion of the pipe around the joint is isolated (the sleeve is inflated on both ends). For annular space sealing, a packer is moved through the mainline to the lateral connection and the portion of the system is isolated (the lateral grouting plug is inverted into the lateral, the mainline sleeve inflated, and the lateral</td></tr>
</table>

Technology/Method	**Logiball Test & Seal Packers/Chemical grouting of mainline joints**
	grouting plug expanded). The air test is performed. If the test fails, the chemical grout is pressure-injected into the voids and out into the soil, or/and to fill the annular space. After the grout cure, the packer is deflated and moved to the next joint or lateral connection on the mainline.
Qualification Testing	From grout manufacturers
QA/QC	Contractor's application knowledge is essential for the success of chemical grouting (i.e., experience with the chemical pump rates, discharge pressures, injection point pressures, and chemical cure times). Air-pressure testing (part of technology application) per ASTM F2304-03
	IV. Operation and Maintenance Requirements
O&M Needs	None
Repair Requirements for Rehabilitated Sections	The pipe must be free of roots, debris, grease, and dirt that would prevent the passage or proper seating of the rubber bladder in the host pipe. Flow bypass is typically not required: the packer in the mainline is only inflated for a few minutes at a time, and the CCTV camera that monitors the progress of work can usually be set downstream of the connection.
	V. Costs
Key Cost Factors	• Number of joints or laterals on the mainline between two manholes • Preparation work required (cleaning, removal of roots, etc.) and volume of grout needed (cost of material) • Accessibility to manholes • Location (prices vary across the country)
Case Study Costs	Not available
	VI. Data Sources
References	• http://www.janssen-umwelttechnik.de/E • www.logiball.com • Thompson, G., 2008. "Acryamide Grout Aces 20-Year Test," Trenchless Technology, May 2008, pp.34-35. • Whitaker, T.B. 1991. Sewer System Rehabilitation and the Effectiveness of Chemical Grouting, M.S. Thesis, Oregon State University, 1991, 120 p, Corvallis, OR. • Lee, R.K., 2008. "Packer Injection Grouting for the Long Term – An Engineering Perspective," WEFTEC 2008 Collection Systems, Chicago, IL, Oct 2008, Session 6, pp. 366-383.

Datasheet A-42. Logiball Push Packer Grouting

Technology/Method	**Logiball Flexible Push-Type Packers/Chemical grouting of laterals**
I. Technology Background	
Status	Conventional
Date of Introduction	In U.S. since early 1990s; in Canada since mid-1980s.
Utilization Rates	Estimated 5,000 laterals repaired worldwide.
Vendor Name(s)	**Logiball, Inc.** Jackman, ME Phone: (800) 246-5988 Email: marc@logiball.com Website: www.logiball.com Grout manufacturers: • Avanti International, www.AvantiGrout.com, Daniel Magill, (800) 877-2570, (713) 252-7881, daniel.magill@avantigrout.com • Prime Resins, www.primeresins.com, Jeremy West, (800) 321-7212, jwest@primeresins.com • DeNeef Construction Chemicals, Inc., www.deneef.com, Ed Paradis, (706) 894-2133, eparadis@deneef.com
Practitioner(s)	• City of Surrey, BC, Canada, contractor: Mar-Tech Underground Services, Ron Ferenczi, (604) 888-2223, ronferenczi@mar-tech.ca (approx 200 laterals grouted over 3 years) • City of Burnaby, BC, Canada, contractor: Mar-Tech Underground Services, Ron Ferenczi, (604) 888-2223, ronferenczi@mar-tech.ca (approx 100 laterals grouted over 1 year) • City of North Vancouver, BC, Canada, contractor: Mar-Tech Underground Services, Ron Ferenczi, (604) 888-2223, ronferenczi@mar-tech.ca (approx. 100 laterals grouted over 1 year) • Sewer Specialty Services, Jamie Fagan, (585) 382-3111 SSSjf@frontiernet.net • Great lakes TV Seal, Jeff Healy, (920) 863- 3663 jeff@greatlakestvseal.com
Description of Main Features	A grouting repair of a lateral's entire length that uses a chemical grout to create a sealing collar of material outside the pipe to stop infiltration into the sewer system and exfiltration from the sewer into the ground. Selection of chemical grout can affect the cost, behavior of installed product in use, and longevity of repair.
Main Benefits Claimed	• The least expensive rehabilitation option for lateral sealing • Access through the cleanouts enables the entire length of lateral to be sealed. • Fast installation (30 to 60 min per lateral, depending on configuration and length of laterals)
Main Limitations Cited	• Does not provide a structural repair, although it fills voids on the outside of the pipe to stabilize the soil around the structures • Sometimes cannot be applied, i.e., the isolated section cannot be pressurized (pipe must be structurally sound) • Shorter longevity of repair compared to other trenchless methods, although successful case studies continue to show good performance of installed grouts 10 to 20 years after the rehabilitation.
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other:____________________________
II. Technology Parameters	
Service Application	Wastewater
Service Connections	Not applicable
Structural Rating Claimed	None

<table>
<tr><th>Technology/Method</th><th>Logiball Flexible Push-Type Packers/Chemical grouting of laterals</th></tr>
<tr><td>Materials of Composition</td><td>Different chemical grouts can be used.
<table>
<tr><th></th><th>Acrylamide</th><th>Acrylate</th><th>Acrylic</th><th>Urethane</th></tr>
<tr><td>Example grout</td><td>Avanti AV-100</td><td>De Neef AC-400</td><td>Avanti AV-118</td><td>Prime Resins Hydrogel SX</td></tr>
<tr><td>Description</td><td>Powder</td><td>Liquid</td><td>Liquid</td><td>Liquid</td></tr>
<tr><td>Catalyst</td><td>Chemical</td><td>Chemical</td><td>Chemical</td><td>Water</td></tr>
<tr><td>Water-to-resin</td><td>1:1</td><td>1:1</td><td>1:1</td><td>8:1</td></tr>
<tr><td>Gel times</td><td>5 sec to a few hrs</td><td>5 sec to a few hrs</td><td>5 sec to a few hrs</td><td>Approx. 1 min</td></tr>
<tr><td>Viscosity, cps</td><td>1 to 2</td><td>1 to 3</td><td>1 to 2</td><td>10 to 20</td></tr>
<tr><td>Compressive strength, psi</td><td>130</td><td>130</td><td>N/A</td><td>200</td></tr>
<tr><td>Density, g/cm^3</td><td>1.04</td><td>1.08</td><td>N/A</td><td>N/A</td></tr>
<tr><td>Cost</td><td>Low</td><td>Increased</td><td>Increased</td><td>High</td></tr>
<tr><td>Delivery systems required</td><td>Common</td><td>Common</td><td>Common</td><td>Urethane delivery systems</td></tr>
<tr><td>Familiar to most contractors</td><td>Yes</td><td>Yes</td><td>No</td><td>No</td></tr>
<tr><td>Toxic when uncured</td><td>Yes</td><td>No</td><td>No</td><td>No</td></tr>
</table>
Optional additives to chemical grouts:

Latex emulsion/reinforcing agent (increase in compressive and tensile strength)
Dichlobenil (inhibits root growth)
Ethylene glycol (protection against freezing and drying out)
Diatomaceous earth (increases gel content)
Potassium ferricyanide (extends gel time, for acrylamide and acrylate)
Accelerators (speed up gel time, for urethane)
</td></tr>
<tr><td>Diameter Range, inches</td><td>Lateral ID 4, 5, or 6 inches</td></tr>
<tr><td>Thickness Range, inches</td><td>Not applicable</td></tr>
<tr><td>Pressure Capacity, psi</td><td>Not applicable</td></tr>
<tr><td>Temperature Range, ^{o}F</td><td>From grout manufacturers</td></tr>
<tr><td>Renewal Length, feet</td><td>Up 75 feet from the cleanout</td></tr>
<tr><td>Other Notes</td><td>Not available</td></tr>
<tr><th colspan="2">III. Technology Design, Installation, and QA/QC Information</th></tr>
<tr><td>Product Standards</td><td>Not available</td></tr>
<tr><td>Design Standards</td><td>Not available</td></tr>
<tr><td>Design Life Range</td><td>Minimum 15 years
Note: 15.6 years were calculated in the Oregon study (Whitaker, 1991); some field applications already show 20 years (Thompson, 2008)</td></tr>
<tr><td>Installation Standards</td><td>ASTM F2454 - 05 Standard Practice for Sealing Lateral Connections and Lines From the Mainline Sewer Systems by the Lateral Packer Method, Using Chemical Grouting
NASSCO Specification Guidelines, 2007, Wastewater Collection System</td></tr>
<tr><td>Installation Methodology</td><td>The repair is performed by applying a test-and-seal procedure. The packer is attached to a semi-rigid hose assembly and inserted into the lateral through a cleanout and pushed to the farthest joint. The packer is inflated, isolating the portion of the lateral (3 to 5 feet long). The air test is performed. If the test fails, the chemical grout is pressure-injected into the voids and out into the soil. After the grout cure, the lateral packer is deflated and pulled back for the length of the sealed portion, and the test-and-seal procedure is done again. The procedure is repeated until the entire length of lateral has been covered. The procedure leaves some residual grout inside the lateral, especially if there are diameter changes</td></tr>
</table>

Technology/Method	**Logiball Flexible Push-Type Packers/Chemical grouting of laterals**
	along the lateral, which washes away itself and need not be jet-cleaned.
Qualification Testing	From grout manufacturers
QA/QC	• Contractor’s application knowledge is essential for the success of chemical grouting, (i.e. experience with the chemical pump rates, discharge pressures, injection point pressures, and chemical cure times). • Air-pressure testing (part of technology application) per ASTM F2454
IV. Operation and Maintenance Requirements	
O&M Needs	None
Repair Requirements for Rehabilitated Sections	The pipe must be free of roots, debris, grease, and dirt that would prevent the proper seating of the rubber bladder in the host pipe. Mineral buildup must be removed. Flow bypass is typically not required; the packer is only inflated for a few minutes at a time.
V. Costs	
Key Cost Factors	• Length, configuration, finding cleanouts, cleanout configuration • Preparation work required (cleaning, removal of roots, etc.) • Cost of material • Location (prices vary across the country)
Case Study Costs	$350 to $700 per lateral (manufacturer’s quote; see key cost factors)
VI. Data Sources	
References	• WERF, 2006. *Methods for Cost-Effective Rehabilitation of Private Lateral Sewers*, 02CTS5, Water Environment Research Foundation, Alexandria, VA, 436 p. • http://www.janssen-umwelttechnik.de/E • www.logiball.com • Thompson, G., 2008. "Acryamide Grout Aces 20-Year Test," *Trenchless Technology*, May 2008, pp.34-35 • Whitaker, T.B. 1991. *Sewer System Rehabilitation and the Effectiveness of Chemical Grouting*, M.S. Thesis, Oregon State University, 1991, 120 p, Corvallis, OR • Lee, R.K. 2008. "Packer Injection Grouting for the Long-Term – An Engineering Perspective," *WEFTEC 2008 Collection Systems*, Chicago, IL, Oct 2008, Session 6, pp. 366-383

Datasheet A-43. Logiball Test & Seal Grouting

Technology/Method	**Logiball Test & Seal Packers/Chemical grouting of lateral connections**
I. Technology Background	
Status	Conventional
Date of Introduction	In U.S. since early 1990s; in Canada since early 1980s
Utilization Rates	Estimated 200,000 repaired worldwide.
Vendor Name(s)	**Logiball, Inc.** Jackman, ME Phone: (800) 246-5988 Email: marc@logiball.com Website: www.logiball.com Grout manufacturers: • Avanti International, www.AvantiGrout.com, Daniel Magill, (800) 877-2570, C. (713) 252-7881, daniel.magill@avantigrout.com • Prime Resins, www.primeresins.com, Jeremy West, (800) 321-7212, jwest@primeresins.com • DeNeef Construction Chemicals, Inc., www.deneef.com, Ed Paradis, (706) 894-2133, eparadis@deneef.com
Practitioner(s)	• South Fayette Township Municipal Authority, PA, Jerry Brown, (412) 221-1665, jbrown@sftwp.com (test-and-seal lateral connections, plus typically 8 ft into the lateral, and up to 10 ft, as follows: 59 laterals in 1997; 499 laterals in 2000; 350 laterals between 2005-2008) • Village of Brown Deer, WI Larry Neitzel, (414) 357-0120, vbdpwlarry@sbcglobal.net (tested 24 and grouted 22 lateral connections reaching 30 ft into the lateral, 2005) • Village of Genoa, WI, John Wrzeszcz, (262) 279-6472, gcpw@genevaonline.com (lateral connections and the first 1 to 10 ft in 1993 and 1996) • City of North Vancouver, Canada, Dave Adams, Superior City Services Ltd., (604) 591-3434 (installed Acrylamide grouts 20 years ago)
Description of Main Features	A grouting repair of lateral connections that uses a chemical grout to create a sealing collar of material outside the pipe that stops infiltration into the sewer system and exfiltration from the sewer into the ground. Selection of chemical grout can affect the cost and behavior of installed product in use and longevity of repair.
Main Benefits Claimed	• The least expensive rehabilitation option for lateral connections and portion of laterals near the mainline • Access to the lateral connection is through the mainline and does not require cleanouts nor access to private property • Fast installation (2 hours setup time plus 15 to 30 min per lateral)
Main Limitations Cited	• Does not provides a structural repair, although it fills voids on the outside of the pipe, stabilizing the soil around the structures • Sometimes cannot be applied (i.e., the isolated section cannot be pressurized and pipe must be structurally sound) • Shorter longevity of repair compared to other trenchless methods, although successful case studies show good performance of installed grouts 10 to 20 years after the rehabilitation
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other:____________________________
II. Technology Parameters	
Service Application	Wastewater
Service Connections	Not applicable
Structural Rating Claimed	None

<table>
<tr><th>Technology/Method</th><th>Logiball Test & Seal Packers/Chemical grouting of lateral connections</th></tr>
<tr><td>Materials of Composition</td><td>Different chemical grouts can be used.
<table>
<tr><th></th><th>Acrylamide</th><th>Acrylate</th><th>Acrylic resins</th><th>Urethane</th></tr>
<tr><td>Example grout</td><td>Avanti AV-100</td><td>De Neef AC-400</td><td>Avanti AV-118</td><td>Prime Resins Hydrogel SX</td></tr>
<tr><td>Description</td><td>Powder</td><td>Liquid</td><td>Liquid</td><td>Liquid</td></tr>
<tr><td>Catalyst</td><td>Chemical</td><td>Chemical</td><td>Chemical</td><td>Water</td></tr>
<tr><td>Water-to-resin</td><td>1:1</td><td>1:1</td><td>1:1</td><td>8:1</td></tr>
<tr><td>Gel times</td><td>5 sec to few hrs</td><td>5 sec to few hrs</td><td>5 sec to few hrs</td><td>Approx. 1 min</td></tr>
<tr><td>Viscosity, cps</td><td>1 to 2</td><td>1 to 3</td><td>1 to 2</td><td>10 to 20</td></tr>
<tr><td>Compressive strength, psi</td><td>130</td><td>130</td><td>–</td><td>200</td></tr>
<tr><td>Density, g/cm3</td><td>1.04</td><td>1.08</td><td>–</td><td>–</td></tr>
<tr><td>Cost</td><td>Low</td><td>Increased</td><td>Increased</td><td>High</td></tr>
<tr><td>Delivery systems required</td><td>Common</td><td>Common</td><td>Common</td><td>Urethane delivery systems</td></tr>
<tr><td>Familiar to most contractors</td><td>Yes</td><td>Yes</td><td>No</td><td>No</td></tr>
<tr><td>Toxic when uncured</td><td>Yes</td><td>No</td><td>No</td><td>No</td></tr>
</table>
Optional additives to chemical grouts:

Latex emulsion/reinforcing agent (increase in compressive and tensile strength)
Dichlobenil (inhibits root growth)
Ethylene glycol (protection against freezing and drying out)
Diatomaceous earth (increases gel content)
Potassium Ferricyanide (extends gel time for acrylamide and acrylate)
Accelerators (speed up gel time, for urethane)
</td></tr>
<tr><td>Diameter Range, inches</td><td>Lateral ID 4, 5, or 6 inches; mainline ID 6 to 30 inches</td></tr>
<tr><td>Thickness Range, inches</td><td>Not applicable</td></tr>
<tr><td>Pressure Capacity, psi</td><td>Not applicable</td></tr>
<tr><td>Temperature Range, ^{o}F</td><td>From grout manufacturers</td></tr>
<tr><td>Renewal Length, feet</td><td>Usually 1 to 6 feet into the lateral (up to 30 feet)</td></tr>
<tr><td>Other Notes</td><td>Not available</td></tr>
<tr><td colspan="2">III. Technology Design, Installation, and QA/QC Information</td></tr>
<tr><td>Product Standards</td><td>Not available</td></tr>
<tr><td>Design Standards</td><td>Not available</td></tr>
<tr><td>Design Life Range</td><td>Minimum 15 years
Note: 15.6 years were calculated in the Oregon study (Whitaker, 1991); some field applications already show 20 years (Thompson, 2008)</td></tr>
<tr><td>Installation Standards</td><td>ASTM F2454 - 05 Standard Practice for Sealing Lateral Connections and Lines From the Mainline Sewer Systems by the Lateral Packer Method, Using Chemical Grouting
NASSCO Specification Guidelines, 2007, Wastewater Collection System</td></tr>
<tr><td>Installation Methodology</td><td>The repair is performed by applying a test-and-seal procedure. The packer is moved through the mainline to the lateral connection and the portion of the system isolated (the lateral grouting plug is inverted into the lateral, the mainline sleeve inflated, and the lateral grouting plug expanded). The air test is performed. If the test fails, the chemical grout is pressure-injected into the voids and out into the</td></tr>
</table>

Technology/Method	**Logiball Test & Seal Packers/Chemical grouting of lateral connections**
	soil. After the grout cure, the lateral grouting plug is vacuumed back within the packer, and the packer moved to the next lateral connection on the mainline.
Qualification Testing	From grout manufacturers
QA/QC	• Contractor’s application knowledge is essential for the success of chemical grouting, i.e. experience with the chemical pump rates, discharge pressures, injection-point pressures, and chemical cure times. • Air-pressure testing (part of technology application) per ASTM F2454
IV. Operation and Maintenance Requirements	
O&M Needs	None
Repair Requirements for Rehabilitated Sections	The pipe must be free of roots, debris, grease, and dirt that would prevent the complete inversion of the lateral bladder or proper seating of the rubber bladder in the host pipe. Mineral buildup must be removed, and taps protruding more than 5/8” into the mainline must be cut off (hammer taps or light root intrusion do not hinder the test-and-seal procedure and need not be fixed). Flow bypass is typically not required: the packer in the mainline is only inflated for a few minutes at a time, and the CCTV camera that monitors the progress of work can usually be set downstream of the connection.
V. Costs	
Key Cost Factors	• Density of laterals on the mainline between two manholes (more laterals within a pipe section brings down the cost) • Length within the lateral being sealed and associated preparation work required (cleaning, removal of roots, etc.) and volume of grout needed (cost of material) • Location (prices vary across the country)
Case Study Costs	• $400 to $500 per tested connection, $450 to $575 per grouted connection in South Fayette Township Municipal Authority, PA in 1997 to 2000, using acrylamide Avanti AV-100 • $480 per tested connection and $585 per grouted connection (on average) in South Fayette Township Municipal Authority, PA in 2005-2008, which can be broken down as follows: $105 for CCTV, $375 for air testing, $105 for sealing (using Acrylamide Avanti AV-100) • $350 to $1,200 per lateral (manufacturer’s quote; see key cost factors)
VI. Data Sources	
References	• WERF, 2006. *Methods for Cost-Effective Rehabilitation of Private Lateral Sewers*, 02CTS5, Water Environment Research Foundation, Alexandria, VA, 436 p. • http://www.janssen-umwelttechnik.de/E • www.logiball.com • Thompson, G., 2008. "Acryamide Grout Aces 20-Year Test," *Trenchless Technology*, May 2008, pp. 34-35 • Whitaker, T.B. 1991. *Sewer System Rehabilitation and the Effectiveness of Chemical Grouting*, M.S. Thesis, Oregon State University, 1991, 120 p, Corvallis, OR • Lee, R.K. 2008. "Packer Injection Grouting for the Long-Term – An Engineering Perspective," *WEFTEC 2008 Collection Systems*, Chicago, IL, Oct 2008, Session 6, pp. 366-383

Datasheet A-44. Masterliner Performance CIPP Liner

Technology/Method	**Masterliner Performance Liner/CIPP**
I. Technology Background	
Status	Conventional
Date of Introduction	Not available
Utilization Rates	Not available
Vendor Name(s)	**Masterliner, Inc.** Hammond, LA Phone: (888) 344-3733 Email: ed@masterliner.com Website: www.masterliner.com
Practitioner(s)	Not available
Description of Main Features	Conventional CIPP product consisting of a polyester felt tube coated with a polyurethane coating for chemical resistance. The tube is impregnated (saturated) with an isothalic polyester resin or vinyl ester resin system.
Main Benefits Claimed	• No excavation • High strength and corrosion-resistant resins • Jointless renovation • Full range of pipe sizes • Custom pipe diameters and wall thickness • Complete encapsulation system • Long-term structural solutions • Improves flow characteristics • Minimizes infiltration and exfiltration • Inversion tubes, service lateral lining, and spot repair liners
Main Limitations Cited	• Requires expertise for proper installation • Flow bypass required
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other:____________________________
II. Technology Parameters	
Service Application	Wastewater, raw water, industrial, and power.
Service Connections	Service laterals are restored internally with robotically controlled cutting devices.
Structural Rating Claimed	Minimum flexural modulus 250,000 psi by ASTM F1216 and, for enhanced resin, 400,000 psi. Minimum flexural stress 4,500 psi by ASTM F1216 and 4,500 psi for enhanced resin. The required structural CIPP wall thickness shall be based, as a minimum, on the physical properties in Section 5.5 or greater values, if substantiated by independent lab testing.
Materials of Composition	Tube - Tube shall consist of one or more layers of absorbent non-woven felt fabric and meet the requirements of ASTM F1216, Section 5.1, or ASTM F1743, Section 5.2.1, or ASTM D 5813, Sections 5 and 6. Resin - The resin system shall be a corrosion-resistant polyester or vinyl ester system, including all required catalysts, initiators that, when cured within the tube, create a composite that satisfies the requirements of ASTM F1216, ASTM D5813, and ASTM F1743.
Diameter Range, inches	4 to 108 inches
Thickness Range, inches	Depends on depth and condition of existing host pipe.
Pressure Capacity, psi	Not applicable
Temperature Range, °F	Not available
Renewal Length, feet	1,000 to 3,000 feet
Other Notes	Not available
III. Technology Design, Installation, and QA/QC Information	
Product Standards	ASTM D1784 – rigid poly (vinyl chloride) (PVC) compound and chlorinated poly (vinyl chloride) (CPVC) compounds. ASTM D3350 – polyethylene plastic pipe and fitting materials

Technology/Method	**Masterliner Performance Liner/CIPP**
Design Standards	ASTM F1216
Design Life Range	50 years
Installation Standards	CIPP installation shall be in accordance with ASTM F1216, Section 7, or ASTM F1743.
Installation Methodology	Inspection of area finds a fully deteriorated condition. Roots have penetrated the system, causing sluggish flow. Area is cleaned and structural spot repair is pulled into place through an existing manhole. The repair process begins. Curing is accomplished by inflating with air, steam, or water. Within minutes, the customized resin crosslinks to form a hard impermeable pipe. The structural spot repair is fully cured and the system is now flowing smoothly. The pipe is tightly sealed with the Masterliner system, eliminating the need for any future repair.
Qualification Testing	Chemical Resistance - The CIPP shall meet the chemical resistance requirements of ASTM F1216, Appendix X2. CIPP samples for testing shall be of tube and resin system similar to that proposed for actual construction. It is required that CIPP samples with and without plastic coating meet these chemical-testing requirements. Hydraulic Capacity - Overall, the hydraulic cross section shall be maintained as large as possible. The CIPP shall have a minimum of the full flow capacity of the original pipe before rehabilitation. Calculated capacities may be derived using a commonly accepted roughness coefficient for the existing pipe material, taking into consideration its age and condition. CIPP Field Samples - When requested by the owner, the contractor shall submit test results from field installations of the same resin system and tube materials as proposed for the actual installation. These test results must verify that the CIPP physical properties specified in Section 5.5 have been achieved in previous field applications. Samples for this project shall be made and tested as described in Section 10.1.
QA/QC	CIPP samples shall be prepared for each installation designated by the owner/engineer, or approximately 20% of the project’s installations. Pipe physical properties will be tested in accordance with ASTM F1216 or ASTM F1743, Section 8, using either method proposed. The flexural properties must meet or exceed the values listed in the table on page 4 of this specification, Table 1 of ASTM F1216, or the values submitted to the owner/engineer by the contractor for this project’s CIPP wall design, whichever is greater. Wall thickness of samples shall be determined as described in paragraph 8.1.6 of ASTM F1743. The minimum wall thickness at any point shall not be less than 87½% of the submitted minimum design wall thickness, as calculated in paragraph 5.6 of this document. Visual inspection of the CIPP shall be in accordance with ASTM F1743, Section 8.6.
IV. Operation and Maintenance Requirements	
O&M Needs	No special requirements
Repair Requirements for Rehabilitated Sections	Not available
V. Costs	

Technology/Method	**Masterliner Performance Liner/CIPP**
Key Cost Factors	Materials - resin, instrument set-up cost.
Case Study Costs	Not available
VI. Data Sources	
References	www.masterliner.com Specification for cured-in-place pipe TTC technical report

Datasheet A-45. National Liner® CIPP Pull-in-Place or Inversion

Technology/Method	**CIPP/Direct Inversion/Pull-in-Place/Hot Water and Steam Cured**
I. Technology Background	
Status	Conventional
Date of Introduction	1995
Utilization Rates	Install approx. 200 miles of liner per year. Have only started pressure-pipe installations in past several years.
Vendor Name(s)	**National Liner®** National EnviroTech Group 12707 North Freeway, Suite 490 Houston, TX 77060 Phone: (281) 874-0111 Email: info@nationalliner.com Website: www.nationalliner.com
Practitioner(s)	Not available.
Description of Main Features	National Liner is a CIPP product made of a non-woven, needled, polyester felt that is shop- or site-impregnated with a thermosetting polyester resin. Vinylester resins are used for pressure applications. A new composite structure, incorporating glass-fiber reinforcement, is being developed for pressure applications.
Main Benefits Claimed	• No-dig (or minimum excavation) renovation. • Excess resin mechanically locks tube to host pipe by filling in cracks. • Smooth interior surface for improved flow characteristics. • 7 licensed and trained installation contractors covering US market.
Main Limitations Cited	• No ASTM product standard for CIPP pressure-pipe liners. • No long-term tensile or pressure regression data for pressure applications. • Limited experience with pressure (force main) projects.
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other: Storm Sewers
II. Technology Parameters	
Service Application	Gravity and Low-Pressure Wastewater
Service Connections	Reinstate gravity laterals remotely. No provisions for reinstating pressure connections.
Structural Rating Claimed	Class II/III – Semi-Structural for felt; Class IV – Structural for glass
Materials of Composition	Non-woven polyester felt material (from Applied Felts) is saturated with either an isophthalic or vinylester polyester resin, depending on application. Force mains use vinylester. A new composite structure that incorporates glass fiber for higher pressure is being developed.
Diameter Range, inches	6 to 120 inches
Thickness Range, inches	4.5 mm to 33.5 mm with felt tubes are typical, but greater thickness are possible.
Pressure Capacity, psi	50 psi with polyester felt tube, higher with glass-fiber composite
Temperature Range, °F	w/PE resin up to 205°F; w/VE resins up to 248°F
Renewal Length, feet	Small diameters up to 800 feet; large diameters up to 2,000 feet in one installation.
Other Notes	BOH Brothers and Visu-Sewer Clean & Seal both have reported doing sewer force mains.
III. Technology Design, Installation, and QA/QC Information	
Product Standards	ASTM D5813 (Gravity Sewer) – none for pressure applications
Design Standards	ASTM F1216, Appendix X1, WRc, and standard engineering design using resources such as RERAU report R4A2-18
Design Life Range	50 years
Installation Standards	ASTM F1216, ASTM F1743
Installation Methodology	All mains to be cleaned and CCTV performed before start of lining. The

Technology/Method	**CIPP/Direct Inversion/Pull-in-Place/Hot Water and Steam Cured**
	resin-saturated tube is inverted into the main using a column of water or pressurized air. The pressure required to properly expand the tube to the host pipe is given by the tube manufacturer. Once in place, the liner is cured by heating the water or air up to the temperature required to initiate polymerization of the resin system.
QA/QC	The host pipe is cleaned and CCTV performed prior to installation of the liner. Any changes in dimensions or offsets can be accommodated in the design of the liner so it is best if this is done well in advance of the planned installation. Samples of the cured liner are taken per 8.1.1 or 8.1.2 of Practice ASTM F1216. In addition to dimensional checks of the liner samples (outside diameter, wall thickness), flexural properties (ASTM D790) and tensile properties (ASTM D638) are also determined.
IV. Operation and Maintenance Requirements	
O&M Needs	The condition of the CIPP should be monitored and maintained on a routine basis consistent with that of other piping in the system. The conditions should be coded per a standardized methodology. Should a defect appear requiring repairs, those repairs should be as warranted by the type of defect discovered, using the techniques available for those types of repairs.
Repair Requirements for Rehabilitated Sections	For restoration of water-tightness to the CIPP wall where damage has occurred or a defect identified, install a part-liner. Where delamination of the PU coating occurs (quite rare), mill off the detached portion of the coating.
V. Costs	
Key Cost Factors	CIPP costs are driven by length of reaches that can be done in a single installation, diameter and thickness of the liners to be installed (material costs), and contractor efficiency.
Case Study Costs	Not available.
VI. Data Sources	
References	www.nationalliner.com; Personal communication

Datasheet A-46. Nordipipe™ CIPP Glass-Fiber-Reinforced (JC)

Technology/Method	**CIPP/Glass Fiber Reinforced**
I. Technology Background	
Status	Innovative
Date of Introduction	2002 in Sweden, 2004 in Hong Kong and Canada
Utilization Rates	12 miles/year
Vendor Name(s)	**Nordipipe™** Norditube Technologies (A Sekisui-CPT Company) 501 N. El Camino Real, Suite 224 San Clemente, CA 92672 Phone: (714) 267-1030 Website: www.cpt-usa.com/info
Practitioner(s)	Mr. Jean Lemire, Eng. City of Cornwall 1225 Ontario Street Cornwall (Ontario) Canada K6H 5T9 Tel. (613) 930-2787 Email jelemire@cornwall.ca Mr. Tony Di Fruscia, Eng. P.Eng. City of Montreal 13301, Sherbrooke Street East Suite 209 Montreal (Quebec) Canada H1A 1C2 Tel. (514) 872-6678 Email tonydifruscia@ville.montreal.qc.ca Ms. Annie Fortier, Eng. City of Dorval 60 Martin Avenue Dorval (Quebec) Canada H9S 3R4 Tel. (514) 633-4244 Email afortier@ville.dorval.qc.ca
Description of Main Features	Norditube is a CIPP system that incorporates a glass-fiber-reinforced layer between two felt layers, impregnated with epoxy or vinylester resin. A PE coating is on the interior. Resin impregnation is done by the installation contractor, either at his/her facility or onsite.
Main Benefits Claimed	• Fully structural – no support of the host pipe required for internal or external loads • NSF 61 listing (cold water, up to 78^{o}F) and BNQ approval for potable water • High-pressure resistance • Negotiate bends up to 45 degrees
Main Limitations Cited	• 48 inches maximum diameter • No U.S. installations
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other:
II. Technology Parameters	
Service Application	Pressure water and wastewater
Service Connections	Internal cut and external re-instatement by excavation
Structural Rating Claimed	Class IV – Fully structural
Materials of Composition	Polyethylene coating in contact with potable water, non-woven felt, and glass-fiber chopped mat, with epoxy or vinyl ester resin. Epoxy is used for potable water projects (NSF listing), and vinyl ester for other applications.

Technology/Method	**CIPP/Glass Fiber Reinforced**
	Vinyl ester resin is half the cost of the epoxy.
Diameter Range, inches	5 to 48 inches
Thickness Range, inches	0.18 to 0.94 inches (4.6 mm to 24 mm)
Pressure Capacity, psi	6 inches to 250 psi and 48 inches to 60 psi
Temperature Range, ^{o}F	100ºF with epoxy and 160ºF with vinylester
Renewal Length, feet	500 to 600 feet
Other Notes	12 inches force main installation in Hamburg, Germany, using vinylester , and 16 inches force main in the UK using epoxy resin
III. Technology Design, Installation, and QA/QC Information	
Product Standards	No product standards, NSF 61 listing (cold water, up to 78°F)
Design Standards	ASTM F1216 Appendix X1
Design Life Range	50-year design
Installation Standards	ASTM F1216
Installation Methodology	Air inversion with air/steam cure, or water column inversion with circulated water cure; service reinstatement by internal robotics or external with saddles. Resin impregnation is usually done at the contractor’s facility, but onsite is also possible.
QA/QC	Resin yield check for impregnation; pressure gauges for air inversion; temperature monitoring during cure; hydrostatic pressure test and post installation CCTV.
IV. Operation and Maintenance Requirements	
O&M Needs	Protection of the PE coating during inspection or cleaning
Repair Requirements for Rehabilitated Sections	Install a spool piece with mechanical adapter; Link-Pipe ring repair
V. Costs	
Key Cost Factors	• Set-up costs - pit excavation (civil work), mobilization, pipe cleaning/dewatering, site restoration, traffic control, temporary by-pass, including road crossings and disinfection, hydrostatic testing, valves, hydrants, tee’s (mechanical work), installation and cure, video inspection. • Material costs – liner, resin, spool pieces, new valves, tee’s and hydrants.
Case Study Costs	None available.
VI. Data Sources	
References	Norditube brochure; Personal communication

Datasheet A-47. Nowak InneReam® Pipe Reaming System

Technology/Method	**InneReam® System/Pipe Reaming**
I. Technology Background	
Status	Conventional
Date of Introduction	In US since 1996. Also used in Australia and New Zealand (possibly in UK)
Utilization Rates	Approximately 20 miles
Vendor Name(s)	**Nowak Pipe Reaming, Inc.** Goddard, KS Phone: 316-794-8898 Email: nowaknodig@aol.com Website: www.pipereaming.com
Practitioner(s)	• City of Coffeyville, KS, Shawn Turner, Turner Engr, (620) 331-3999 (approx. 4,000 feet of 8 inches VCP replaced with 8 inches HDPE in 2006) • City of Modesto, CA, Lori Jones, Brown & Caldwell, (530) 204-5213 (approx. 3,000 feet of 18 inches VCP replaced with 24 inches HDPE and 5,000 feet of 24 inches RCP replaced with 30 inches HDPE, in 2006) • City of McCormick, SC, Ben Lewis, (946) 993-4176 (3,000 feet of 8 inches VCP replaced with 8 inches HDPE in 2007), • CMUD, Charlotte, NC, (4,000 feet of 8" VCP replaced with 8 inches HDPE in 2006-2007) • City of Lawrence, KS, John Fishburn, (704) 357-6067 (1,400 feet of 12 inches VCP replaced with 16 inches HDPE, in 2007) • Rod Hofer, Professional Engineering Consultants, (785) 233-8300 • City of Lawrence, KS, David Hamby, BG Consultants, (785) 749-4474 (3,647 feet of 12 inches VCP replaced with 16" HDPE, on 2006) • City of El Paso, TX, Francisco J. "Kiko" Martinez, (800) 460-5366 (2,554 feet of 18 inches VCP replaced with 28" HDPE in 2007) • City of Kansas City, MO, Karine Papikian, (816) 513-0300 (2,014 feet of 10, 12, and 15 inches replaced with 18 and 20 inches HDPE in 2007) • Fort Bragg, NC, Don Arbaugh, (803) 649-3397 (352 feet of 8 inches VCP replaced with 8 inches HDPE in 2009) • City of Blackwell, OK, Joe Smith, (316) 674-9600 (2,150 feet of 8 inches VCP replaced with 8 inches HDPE in 2007) • City of Baton Rouge, LA, Bill Selig, (225) 355-7787 (2,587 feet of 12 and 15 inches replaced with 18 and 22 inches HDPE in 2005)
Description of Main Features	A variation of horizontal directional drilling (HDD) technology that is used for pipe replacement. An HDD drill with a modified back reamer is used to fracture the existing pipe into small pieces during "back reaming." Fragments are suspended in the drilling fluid and transported to the recovery pit where they are removed with a vacuum truck or slurry pump. Simultaneously a new pipe is being pulled in.
Main Benefits Claimed	• New pipe is installed • Reduced costs for surface restoration • Minimized negative public reaction and business losses created by street and driveway closures • Reduced safety hazards involved with deep trenches • Elimination of critical utility outages common with open-cut methods
Main Limitations Cited	• Bypass pumping is required • Excavation of entry and exit pits is required. Manholes through which the reamer must pass have the invert removed sufficiently to allow the reamer to pass without deflection. • Excavation at each lateral location is required • Sags in pipeline (unless minor) require point repairs
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other:_________________________

Technology/Method	**InneReam® System/Pipe Reaming**
II. Technology Parameters	
Service Application	Wastewater, stormwater
Service Connections	Local open-cut excavations required to make connections
Structural Rating Claimed	Depends on the selection of the new pipe to be installed.
Materials of Composition	Depends on the selection of the new pipe to be installed. The replacement pipe is generally high-density polyethylene (HDPE), restrained-joint PVC, fusible PVC, or restrained-joint ductile iron pipe.
Diameter Range, inches	4–24 inches
Thickness Range, inches	Depends on the selection of the new pipe to be installed.
Pressure Capacity, psi	Depends on the selection of the new pipe to be installed.
Temperature Range, °F	Depends on the selection of the new pipe to be installed.
Renewal Length, feet	Up to 1,500 feet
Other Notes	Not available
III. Technology Design, Installation, and QA/QC Information	
Product Standards	Depends on the selection of the new pipe to be installed.
Design Standards	Depends on the selection of the new pipe to be installed.
Design Life Range	Depends on the selection of the new pipe to be installed.
Installation Standards	Not available
Installation Methodology (Basic)	• Establish HDD unit size • Determine entry/exit profile consistent with drill pipe and new pipe bend radii. • Install bypass • Remove manhole inverts • Disconnect services • Insert drill rod; attach reamer and new pipe. • Ream out existing pipe, removing debris as it accumulates. • Seal pipe at manholes • Reconnect services
Qualification Testing	Material properties and dimensioning of the replacement pipe chosen.
QA/QC	A post-installation CCTV inspection is conducted to ensure the new pipe is free of defects. Line and grade may also be checked for acceptability.
IV. Operation and Maintenance Requirements	
O&M Needs	O&M consistent with that of a newly installed pipe.
Repair Requirements for Rehabilitated Sections	Sags in pipeline (unless minor) require point repairs
V. Costs	
Key Cost Factors	Wage rates, surface improvements, subsurface conditions, number of service connections, depth, length, groundwater conditions, bypass pumping, environmental controls, degree of upsize, subsidiary items, equipment selection, and the assignment of an acceptable amount of risk dollars.
Case Study Costs	Manufacturer's quote: Price can range widely, depending on many variables (see key cost factors), e.g., between $20 and $80 per LF for an 8 inches pipe size
VI. Data Sources	
References	www.pipereaming.com; Guidelines for Pipe Bursting (TTC).

Datasheet A-48. NPC Internal Joint Seal

Technology/Method	**NPC Internal Joint Seal**
I. Technology Background	
Status	Innovative
Date of Introduction	October 1994 in U.S.
Utilization Rates	Not available
Vendor Name(s)	**NPC, Inc.** Milford, NH, Phone: (800) 626-2180 Website: www.npc.com
Practitioner(s)	**1. Mission, Texas** A United Irrigation District inverted siphon below a Rio Grande Railroad switching line and Business Hwy 83 in Mission, Texas, was losing irrigation water through the joints in the three 72 inches diameter pipelines. The irrigation water was ponding along the rail lines and coming up through the asphalt pavement and standing on the highway. The leaking water was not only damaging the street, it was creating a safety hazard for local traffic. It became necessary for the railroad to perform maintenance along the switching tracks much more frequently than other sections of the line. To repair the lines, the flow of irrigation water had to be stopped. A coffer dam was constructed and the three 72 inches diameter lines were pumped out. United Irrigation District, the Texas Department of Transportation (TXDOT), and the onsite contractor identified 38 of 90 pipe joints to be sealed using NPC's 10.5 inches -wide Internal Joint Seals. TXDOT pre-ordered 15 seals which were on site to begin the repairs. Because the canal is the water supply for the area farmers and the City of Mission's Water Purification Plant, the work had to be completed in just 5 days. Twenty-three additional seals were ordered and shipped to the site in time to complete the project ahead of schedule. The siphon and lines were returned to United Irrigation after just 4 working days. The leaking of irrigation water was completely eliminated and Business Hwy 83 and the railroad switching yard are dry. **2. Beloit, Wisconsin** Water infiltrating through a defective joint in a newly constructed 36 inches sanitary sewer line was carrying so much fine sand and silt that it could not be placed in service. The capacity of the line had become severely limited. Green Bay, Wisconsin contractor; Great Lakes TV & Seal selected NPC's 10.5-inch Internal Joint Seal to install at the offending joint. The Internal Joint Seal prevents future infiltration by bridging the joint with a flexible rubber seal that is compressed against the inside diameter of the pipe with the WedgeLock expansion bands. The line was cleaned and the seal installed in just a few hours, enabling the utility to place the line in service.
Description of Main Features	NPC Internal Joint Seals stop leaking joints by bridging the joint with a flexible rubber seal and compressing the rubber seal against the inside diameter of the pipe on either side of the joint with the expansion bands. NPC Internal Joint Seals are designed to seal leaking pipe joints in most types of pipe, including concrete, reinforced concrete, cast iron, ductile iron, steel, vitrified clay, PVC, and HDPE. They are designed to withstand external head pressure of 34 feet (15 psi) and internal head pressure of 70 feet (30 psi).
Main Benefits Claimed	The NPC Internal Joint Seal economically eliminates groundwater infiltration from offset, corroded, cracked, or deflected pipe joints and manhole barrel joints. The Internal Joint Seal prevents infiltration by bridging the joint with a flexible rubber seal and compressing the rubber against the pipe wall, using the unique WedgeLock Expansion Bands without expensive special tools. (1) WedgeLock Expansion Bands provide uniform distribution of sealing force. (2) Quickly installed by contractors or municipal employees

Technology/Method	**NPC Internal Joint Seal**
	(3) Seals available for pipe diameters from 18” to 122” (4) Internal Joint Seals can be installed in concrete, smooth-wall HDPE, PVC, FRP, steel, clay, and cast iron (5) Elliptical and arched Internal Joint Seals available upon request (6) Nitrile seals for extreme environments may be special-ordered
Main Limitations Cited	Not available
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other:______________________________
II. Technology Parameters	
Service Application	NPC Internal Joint Seals are designed to seal leaking pipe joints in most types of pipe, including concrete, reinforced concrete, cast iron, ductile iron, steel, vitrified clay, PVC, and HDPE. They are designed to withstand external head pressure of 34 feet (15 psi) and internal head pressure of 70 feet (30 psi).
Service Connections	Not applicable
Structural Rating Claimed	Internal and external pressure-resistant.
Materials of Composition	NPC Internal Joint Seals consist of a rubber seal, 304 stainless-steel expansion bands, and WedgeLock assemblies.
Diameter Range, inches	Not available
Thickness Range, inches	Not available
Pressure Capacity, psi	30 psi
Temperature Range, °F	Not available
Renewal Length, feet	Not applicable
Other Notes	Not available
III. Technology Design, Installation, and QA/QC Information	
Product Standards	Not available
Design Standards	Not available
Design Life Range	Not available
Installation Standards	Not available
Installation Methodology	Place the External Seal on the product with one pipe clamp channel on either side of the joint to be sealed. Using the pipe clamp restraint and torque wrench, tighten the pipe clamps alternately to 30-inch pounds first and then to 60-inch pounds, working around the product to ensure equal torque. Inspect the assembly to ensure that the pipe clamps are all seated in the clamp channels and that they have been fully torqued. If desired, the clamps can be re-torqued before backfilling.
Qualification Testing	Following the ASTM C923-02 Material Properties
QA/QC	Not available
IV. Operation and Maintenance Requirements	
O&M Needs	Recommended Torque Values Minimum: 45 foot-pounds Maximum: 75 foot-pounds
Repair Requirements for Rehabilitated Sections	Remove joint seal and install a new seal if necessary.
V. Costs	
Key Cost Factors	Cost of fitting Site labor cost and pipe entry requirements
Case Study Costs	Not available
VI. Data Sources	
References	www.npc.com

Datasheet A-49. Paraliner PW and Paraliner FM CIPP Inversion

Technology/Method	**CIPP/ Inversion and Hot Water or Steam Cured**
I. Technology Background	
Status	Emerging
Date of Introduction	October 2007
Utilization Rates	Approximately 10,000 ft of potable water lined in first year
Vendor Name(s)	**Paraliner PW and Paraliner FM** NOVOC Performance Resins, LLC 3687 Enterprise Dr. Sheboygan, WI 53083 Phone: (877) 803-1700 Website: www. NOVOC.com
Practitioner(s)	Placer County Water – Auburn, CA (News release Feb. 2009)
Description of Main Features	Paraliner PW or FM is a resin-impregnated flexible fiberglass/felt tube manufactured by NOVOC Performance Resins. The tube is impregnated by the installation contractor with a 100% solids NOVOC vinylester resin. The tube is installed either by the inversion method using a head of water or pulled into place by a winch and inflated with air. The resin is cured by either circulating hot water or steam. Once installed, the liner shall extend from start to end in a continuous tight-fitting, watertight liner.
Main Benefits Claimed	• Trenchless installation with minimal interruption. • Liner can be cured using hot water or steam. • Short cure times – resins contain no styrene, curing time reduced 30% to 50% over other CIPP liners. • Minimal shrinkage to ensure tight fit to host pipe–100% solids. • Green solution – patented NOVOC resin is environmentally responsible with no styrene and no EPA-reportable components • NSF 61 listed – okay for potable water • Utilizes licensees to install potable water product • Patent pending service connection fittings
Main Limitations Cited	• Bypass required during lining and cure. • Main must be well-cleaned with mechanical scrappers or power boring. • No long-term pressure regression or tensile testing to confirm a hydrostatic design basis for 50-year design life.
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other:
II. Technology Parameters	
Service Application	Water – potable and raw water, wastewater – force mains, gravity sewer
Service Connections	Reinstate after curing. Can be done robotically from within for corporation connections. Larger connections must be excavated and reinstated mechanically.
Structural Rating Claimed	Class IV – Structural, designed to carry full internal and external loads
Materials of Composition	The tube consists of one or more layers of absorbent non-woven felt fabric. Fiberglass is also included. The outside layer of the tube is coated with an impermeable, flexible membrane that contains the resin and allows monitoring of the impregnation (wet-out) process. The resin is NOVOC 4900 PW (for potable water) and is a 100% solids, zero HAP, vinyl ester resin. The resin system emits less than 1% VOC's. It has a glass transition temperature of 591^{o}F. Mean physical properties of the reinforced resin (initial) as follows: Property / Test Method / Value Flexural strength / ASTM D790 / 16,000 psi Flexural modulus / ASTM D790 / 940,000 psi Tensile strength, / ASTM D638 / 16,000 psi Tensile modulus / ASTM D638 / 900,000 psi Water Aging / / 0.4%
Diameter Range, inches	6 to 96 inches, and larger

Technology/Method	**CIPP/ Inversion and Hot Water or Steam Cured**
Thickness Range, inches	0.18 inches (4.5 mm) to 2.07 inches (52.5 mm)
Pressure Capacity, psi	230 psi burst pressure (based on 8-dia. x 6 mm thick)
Temperature Range, ^{o}F	220^{o}F
Renewal Length, feet	Approx. 1,000 feet, depending on diameter
Other Notes	Include specific notes here, such as Water Quality, I/I control, other
III. Technology Design, Installation, and QA/QC Information	
Product Standards	No product standards, NSF 61 (for potable water applications) from Underwriters Laboratories
Design Standards	ASTM F1216, Appendix X.1.
Design Life Range	50 years
Installation Standards	ASTM F1216, Section 7 and/or ASTM F1743, Section 6
Installation Methodology	• The main is first CCTV-inspected and cleaned. • The installation contractor impregnates the tube with the NOVOC vinylester resin. The liner is then inserted into the main either by direct inversion using water head or pulled in by a winch. The use of a lubricant is recommended. The liner can be installed through a 45^{o} elbow. The pressure head or steam/air pressure needs to fall within NOVOC's recommended guidelines to ensure a proper finished thickness and that the liner fits snug to the existing pipe wall, producing dimples at service connections and flared ends at the entrance and exit points. • After inflation, the liner is cured using either circulating hot water or steam. Thermocouples are placed between the liner and the invert of the manhole or end of the host pipe and used to monitor the temperature and time of the exothermic reaction. • Once cured, the liner is cooled down to a temperature of 100^{o}F before relieving the pressure. • The liner is cut to the appropriate length to allow fitting of end seals (Miller Pipe "Weko-Seals" or equal) or Full-Circle Pressure Clamps or MJ Fittings.
QA/QC	CCTV of the main is performed after cleaning; location of service connections is logged. CCTV is also performed on the line after the temperature cools to under 100^{o}F to make sure liner was properly installed. The line is pressure tested after CCTV inspection and before reinstating connections, to a minimum of 120% of the normal operating pressure. CCTV will be performed again after service connections are reinstated.
IV. Operation and Maintenance Requirements	
O&M Needs	None identified.
Repair Requirements for Rehabilitated Sections	Paraliner products can be relined and or point-repaired.
V. Costs	
Key Cost Factors	• To determine whether a CIPP application is more cost-effective than other alternatives, such as slip-lining or dig and replace • If there are environmental sensitivities • Determining the reduction of flow capacity vs. other alternatives • The structural integrity of the existing host pipe • Service downtime
Case Study Costs	No cost case studies available.
VI. Data Sources	
References	www. NOVOC.com

Datasheet A-50. Permacast Spin-Cast Manhole Lining

Technology/Method	**Permacast /Spin-applied mortar coating for manholes**
I. Technology Background	
Status	Conventional
Date of Introduction	Since 1995 in U.S. Also used in Canada, Iceland, Ireland, UK, Denmark, Norway, Germany, Italy, Singapore, and the Caribbean.
Utilization Rates	>10,000 manholes per year
Vendor Name(s)	**AP/M Permaform** Johnston, IA Phone: (800) 662-6465 Email: info@permaform.net Website: www.permaform.net
Practitioner(s)	• City of Chicago, IL, Wallace Davis, III, (312) 742-1204, wdavis@cityofchicago.org (over 4,000 manholes rehabilitated between 2005 and 2008) • City of Hampton, VA, Barry Dobbins, (757) 726-2994 bdobbins@hampton.gov (3,000 manholes rehabilitated between 2003 and 2008) • City of Casa Grande, AZ, Jerry Anglin, (520) 421-8625, janglin@casagrandeaz.gov (65 manholes rehabilitated in 2006)
Description of Main Features	A cementitious liner centrifugally applied to the inside of the existing manhole from the spinner head in the center axis of the manhole. Multiple passes ensure thorough and complete coverage. For protection against microbiologically induced corrosion, antibacterial admixture (Con^{mic}Shield) may be added. For protection against severe corrosion, polymer topcoat (COR+GARD®) may be applied over the freshly applied PERMACAST® mortar. The polymer topcoat is also applied from a spincaster, which eliminates pin holes and ensures proper application thickness.
Main Benefits Claimed	• Uniform application, precise thickness, and densely compacted liner • Safe operation (no man-entry required) • Prevents corrosion and infiltration/exfiltration • Flows maintained during procedure • Suitable for rehabilitation of Condition I Manholes (*cracking or other signs of structural fatigue, minor corrosion, minor infiltration or exfiltration through precast joints)* • Suitable for rehabilitation of Condition II Manholes (minor cracks, loss of mortar or brick, corrosion less than 0.5 inch deep, cross-sectional distortion less than 10%) • Suitable for rehabilitation of Condition III Manholes (distortion beyond 10%, severe corrosion with exposed reinforcing, or large sections of the existing structure are missing) when applied at greater thickness. • No annular space between liner and existing manhole
Main Limitations Cited	• Active leaks must be stopped with hydraulic cement or chemical injection grout • Cure time of approx. 8 to 12 hours is required for immersion service. • COR+GARD® service temperatures at a constant temperature above 140°F not recommended. • Con^{mic}Shield® is not resistant to chemical corrosion created by industrial waste.
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other: Lift Stations, Wet Wells, Head Works, Clarifiers and Storm Water Manholes & Catch Basins
II. Technology Parameters	
Service Application	Wastewater, stormwater, industrial
Service Connections	Not applicable
Structural Rating Claimed	Fully structural

<table>
<tr><th>Technology/Method</th><th>Permacast /Spin-applied mortar coating for manholes</th></tr>
<tr><td>Materials of Composition</td><td>
Ultra-high-strength mortars based on Portland Cement, made with additives such as micro silica, calcium aluminate cement, or other advanced chemical additives.

Con^{mic}Shield® is an antibacterial admixture that kills bacteria responsible for microbiologically induced corrosion.

COR+GARD® coating is 100% solids, high build, light-green epoxy.
The finished liner has the following minimum physical properties (from manufacturer):
<table>
<tr><th>Mortar Properties</th><th>Test Method</th><th>Value</th></tr>
<tr><td>Compressive strength, 24 hrs</td><td>ASTM C109</td><td>3,000 psi</td></tr>
<tr><td>Compressive strength, 28 days</td><td>ASTM C109</td><td>10,000 psi</td></tr>
<tr><td>Modulus of elasticity</td><td>ASTM C469</td><td>1,150,000 psi</td></tr>
<tr><td>Shear bond</td><td>ASTM C882</td><td>>1,500 psi</td></tr>
<tr><td>Split tensile strength</td><td>ASTM C496</td><td>>700 psi</td></tr>
<tr><td>Flexural strength</td><td>ASTM C293</td><td>>1,250 psi</td></tr>
<tr><td>Chloride permeability</td><td>ASTM C1202</td><td><550 Coulombs</td></tr>
</table>
<table>
<tr><th>Con^{mic}Shield® Properties</th><th>Test Method</th><th>Value</th></tr>
<tr><td>Resistance to attack by bacteria, yeast, and fungi</td><td>ASTM D4783</td><td>99.99% Kill</td></tr>
</table>
<table>
<tr><th>COR+GARD® Properties</th><th>Test Method</th><th>Value</th></tr>
<tr><td>Compressive strength</td><td>ASTM D695</td><td>10,500 psi</td></tr>
<tr><td>Flexural strength</td><td>ASTM D790</td><td>9,000 psi</td></tr>
<tr><td>Tensile strength</td><td>ASTM D638</td><td>6,000 psi</td></tr>
<tr><td>Hardness</td><td>ASTM D2240</td><td>81 Shore D</td></tr>
<tr><td>Heat distortion</td><td>ASTM D648</td><td>220° F</td></tr>
<tr><td>Ultimate elongation</td><td>ASTM D638</td><td>3.5-4%</td></tr>
<tr><td>Adhesive shear</td><td>ASTM C882</td><td>1000 psi</td></tr>
</table>
</td></tr>
<tr><td>Diameter Range, inches</td><td>24”, 36”, 48”, 54”, 60”, 66”, 72”, 84”</td></tr>
<tr><td>Thickness Range, inches</td><td>0.5” to 3”</td></tr>
<tr><td>Pressure Capacity, psi</td><td>Not applicable</td></tr>
<tr><td>Temperature Range, ^{o}F</td><td>Material-dependent</td></tr>
<tr><td>Renewal Length, feet</td><td>Manhole depth up to 100 feet, or as is practical to pump materials</td></tr>
<tr><td>Other Notes</td><td>Not available</td></tr>
<tr><td colspan="2">III. Technology Design, Installation, and QA/QC Information</td></tr>
<tr><td>Product Standards</td><td>See above</td></tr>
<tr><td>Design Standards</td><td>See above</td></tr>
<tr><td>Design Life Range</td><td>50-years (doubles the useful life of existing structure)</td></tr>
<tr><td>Installation Standards</td><td>ASTM F2551, Standard Practices for Installing a Protective Cement Liner System in Sanitary Sewer Manholes</td></tr>
<tr><td>Installation Methodology</td><td>The synthetic mortar is cast from a patented robotic applicator positioned in the center of the manhole. A dense, uniform layer is compacted in place at any thickness from ¼ inch to 2 inches, depending upon the degree of deterioration and the depth of the manhole. Multiple passes can be made until the specified thickness is attained. In accordance with ASTM F2551.

COR+GARD® may be applied when the mortar has taken a final set (8 to 12 hrs) or when moisture from free-water escape during hydration is no longer observed. The polymer topcoat is also applied from a spincaster. COR+GARD® needs to cure for 4 to 6 hours or until final set is achieved before putting into immersion service.</td></tr>
<tr><td>Qualification Testing</td><td>See QA/QC requirements below</td></tr>
</table>

Technology/Method	Permacast /Spin-applied mortar coating for manholes
QA/QC	• All field work is performed by factory-certified applicators only. • Each product batch is sampled and randomly tested to ensure quality, conformity and consistency. Mortar cube test samples for material strengths are taken randomly for testing, as directed by the inspector in the field and the owner. • Thickness is verified with a wet gage at any random point of the new interior surface. Any area found to be thinner than minimum tolerances immediately receives additional material. Visual inspection verifies a leak-free, uniform appearance. • COR+GARD® thickness is verified with a wet gage at any random point of the newly coated surface. Any area found to be less than the minimum coating thickness immediately receives additional material and is re-tested. Visual inspection shall verify a smooth, glossy finish. • When completely cured, the entire coated interior is tested for pinholes and voids at the prescribed voltage with a holiday detector in the presence of the owner's inspector. Any defects are marked and re-coated.
IV. Operation and Maintenance Requirements	
O&M Needs	No special requirements
Repair Requirements for Rehabilitated Sections	No special requirements
V. Costs	
Key Cost Factors	Accessibility, degree of deterioration, depth, diameter, traffic loading, design thickness, material choice, prevailing wage, insurance, mobilization.
Case Study Costs	• In Casa Grande, AZ: approx. $2,450/manhole • In Chicago, IL: approx. $2,450/manhole • In Hampton, VA: approx. $900/manhole • Manufacturer's quote: $125/VF to $345/VF, depending on variables and selected materials.
VI. Data Sources	
References	http://www.permaform.net

Datasheet A-51. Permaform Manhole Lining

Technology/Method	**Permaform /Cast-in-place concrete liner for manholes**
I. Technology Background	
Status	Conventional
Date of Introduction	Since 1970 in U.S. Also used in Canada and the Caribbean
Utilization Rates	200 manholes per year.
Vendor Name(s)	**AP/M Permaform** Johnston, IA Phone: (800) 662-6465 Email: info@permaform.net Website: www.permaform.net
Practitioner(s)	• City of Brawley, CA, Yazmin Arellano, (760) 344-5800, yazmin.arellano@cityofbrawley.com (9 manholes in 2006) • City of Renner, SD, Ray Pierson, (605) 332-7211 (2 manholes in 2006) • City of Livermore, CA (City Airport), Jerry Valladao, (925) 937-3440 (one manhole rehabilitated in 2003) • City of San Diego, CA, Harry Herman, (858) 654-4225
Description of Main Features	A new structurally independent concrete liner that is cast-in-place within the existing manhole, generally conforming to the inside dimensions and shape of the existing manhole. An internal forming system is utilized for casting the concrete. The new interior liner is constructed of high-strength, ready-mixed concrete. The procedure does not require interruption of sewer flows at the base or at elevated points of entry. For protection against microbiologically induced corrosion, antibacterial admixture (Con^{mic}Shield) may be added to the concrete mixture. For protection against severe chemical corrosion, a plastic liner (PE, PVC, PP, PVDP) can be embedded into the liner.
Main Benefits Claimed	• Successfully used for over 40 years (more than 5,000 installations without a single failure) • Structurally independent of the old structure • Prevents infiltration/exfiltration sealing the manhole throughout, even at pipe openings • Prevents corrosion from both liquids and vapors • The liner is mechanically anchored and does not depend upon an adhesion with the existing manhole wall (special interior surface preparation not required) • Precise, factory-manufactured thickness • Antibacterial admixture (Con^{mic}Shield) impregnates the entire concrete matrix (not a coating that could delaminate, disbond, peel, pinhole, or “wear off” over time). Con^{mic}Shield -fortified structures last for the life of the concrete • Flows maintained during installation (no need for bypass pumping) • Faster and less disruptive than excavation • Cost-effective – less than half the cost of dig and replace • Environmentally friendly
Main Limitations Cited	• Original diameter is reduced about 10% • Active infiltration must be stopped or reduced to an acceptable level.
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other: Round, Square, Rectangular Structures
II. Technology Parameters	
Service Application	Wastewater, stormwater, industrial
Service Connections	Not applicable
Structural Rating Claimed	Fully structural

<table>
<tr><th>Technology/Method</th><th>Permaform /Cast-in-place concrete liner for manholes</th></tr>
<tr><td>Materials of Composition</td><td>The concrete used is Type I/II Portland cement concrete with 5/8” minus coarse aggregate with fiber reinforcement and plasticizers producing an average compressive strength of 4,000 psi at full cure. Other formulations and filler materials may be selected to meet specific needs.

Con^{mic}Shield® is an antibacterial admixture that kills bacteria responsible for microbiologically induced corrosion.

<table>
<tr><th>Mortar Properties and Con^{mic}Shield® Properties</th><th>Test Method</th><th>Value</th></tr>
<tr><td>Compressive Strength at 28 days</td><td>N/A</td><td>4,000 psi</td></tr>
<tr><td>Resistance to attack by bacteria, yeast, and fungi</td><td>ASTM D4783</td><td>99.99% Kill</td></tr>
</table></td></tr>
<tr><td>Diameter Range, inches</td><td>36”, 48”, 54”, 60”, 66”, 72”, 84” and larger</td></tr>
<tr><td>Thickness Range, inches</td><td>1.5” and 3” or more</td></tr>
<tr><td>Pressure Capacity, psi</td><td>Not applicable</td></tr>
<tr><td>Temperature Range, °F</td><td>Material dependent</td></tr>
<tr><td>Renewal Length, feet</td><td>Manhole depth up to 100 ft or as practical</td></tr>
<tr><td>Other Notes</td><td>Not available</td></tr>
<tr><td colspan="2">III. Technology Design, Installation, and QA/QC Information</td></tr>
<tr><td>Product Standards</td><td>ASTM C39 Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens
ASTM C94 Standard Test Method for Ready-Mix Concrete
ASTM C143 Standard Test Method for Slump of Hydraulic Cement Concrete</td></tr>
<tr><td>Design Standards</td><td>See above</td></tr>
<tr><td>Design Life Range</td><td>100-years (with corrosion protection)</td></tr>
<tr><td>Installation Standards</td><td>ACI Standards for concrete placement</td></tr>
<tr><td>Installation Methodology</td><td>A manhole is cleaned to remove loose material and debris. Existing steps which might interfere with the erection of the forms are removed. Precautions are taken to prevent foreign material from entering the active lines. Active infiltration is stopped or reduced to an acceptable level.

Segmented, stackable steel forms are bolted together in cylindrical and conical sections (either eccentric or concentric cones) or flat-top ceilings to conform generally to the interior shape of the existing manhole. The space between the forms and the existing wall is usually 3 inches thick (no less than 1.5 inches). Pipe extensions are placed at the base and at higher points of entry, such as drop inlets, to maintain flows during the procedure. The finished opening has a minimum diameter of 20 inches. The form is sealed at the manhole base to prevent concrete entering the sewer.

Concrete is carefully placed from the bottom up in such a manner as to prevent segregation of the cement and aggregate. The concrete is consolidated to fill all pockets, seams, and cracks within the existing wall. When the concrete has sufficiently cured, the form is disassembled and removed.

A hydrophilic sealing strip is placed around the circumference of the bench where it meets the vertical wall and around all pipe penetrations to form a water stop; an overlay of concrete or MS-10,000 is poured, which is 3 inches thick at the wall and is tapering to ½ inch at the edge of the invert channel.
A flexible chimney seal may be attached or applied to the upper 3 inches portion of the new liner and the lower 3 inches portion of the prepared frame.</td></tr>
<tr><td>Qualification Testing</td><td>See QA/QC description below</td></tr>
</table>

Technology/Method	**Permaform /Cast-in-place concrete liner for manholes**
QA/QC	• All work is performed by factory-certified applicators only. • Cylinder test samples for material strengths may be taken randomly as directed by the inspector in the field for testing as directed by the owner. • Visual inspection verifies a leak-free, uniform appearance. • The new liner is tested with a spark tester after installation. • If the plastic liner is utilized, the entire coated interior is tested for pinholes and voids at the prescribed voltage with a holiday detector in the presence of the owner's inspector. Any defects are marked and re-coated.
IV. Operation and Maintenance Requirements	
O&M Needs	No special requirements
Repair Requirements for Rehabilitated Sections	No special requirements
V. Costs	
Key Cost Factors	Accessibility, degree of deterioration, depth, diameter, traffic loading, design thickness, material choice, prevailing wage, insurance, mobilization.
Case Study Costs	For example: • In Renner, SD: approx. $9,800/manhole • In Brawley, CA: approx. $9,970/manhole • In Livermore, CA: approx. $9,500/manhole • Manufacturer's quote: $3,000 to $12,000/manhole (depending on variables and selected materials).
VI. Data Sources	
References	http://www.permaform.net/

Datasheet A-52. Perma-Liner InnerSeal Lateral CIPP Liner

Technology/Method	**Perma-Liner InnerSeal™/Lateral CIPP, inverted from mainline**
I. Technology Background	
Status	Innovative
Date of Introduction	Available in U.S. since 2005
Utilization Rates	Estimated 1,000+ laterals in U.S. have been rehabilitated with this product.
Vendor Name(s)	**Perma-Liner Industries Inc.** Clearwater, FL Phone: (727) 235-1801 Email: cole@perma-liner.com Website: www.perma-liner.com
Practitioner(s)	Please contact Perma-Liner Industries for a complete list of certified Innerseal installers as this is proprietary information. • Tri State Utilities, Norfolk, VA • Pipe Experts, Turnwater, WA, Nick Patrick, (425) 864-2712, NickP@Insta-Pipe.com • Quality Pipe, Denver, CO • MJC Consulting, Miami, FL, Mat Cudd, (305) 746-1816
Description of Main Features	A CIPP product air inverted remotely from a mainline into the lateral (1 feet to 75 feet) and ambient-temperature-cured (hot water or steam curing is possible). The liner creates a 2” brim around the lateral opening in the mainline and thus repairs both the lateral connection and the lateral pipe.
Main Benefits Claimed	• Repairs lateral-to-mainline connections along with the lateral itself, eliminating I/I and root intrusion in the future • Provides a full structural repair of damaged pipes, along with creating a true airtight system • No digging (access to the lateral is through the mainline) • Quick installation (on average, 3 to 4 can be installed in one day) • Non-styrene resin is used. • Good manufacturer’s training and support (a municipality can have an in-house crew trained in a few days).
Main Limitations Cited	• Not applicable in laterals with severe mineral buildup, severe offset joints, sags, or protrusions in the pipe • Flow isolation required (flow bypass required in some cases)
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other:_______________________
II. Technology Parameters	
Service Application	Wastewater, raw water, stormwater, industrial, and power
Service Connections	Not available
Structural Rating Claimed	Fully structural repair
Materials of Composition	Tube material is an outer PVC coat with a needle-punched felt interior backed by a woven reinforced scrim to prevent stretching. Resin is 100% solids epoxy formulated for ambient cure, but can be modified for hot-water or steam curing. Protective coating is PVC (after installation facing the inside of pipe). The installed liner has the following physical properties (HTS, Inc. Consultants, March 2007): Property — Test Method — Value Flexural modulus — ASTM D790 — 354,666 psi Flexural strength — ASTM D790 — 9,554 psi Compressive strength — ASTM D695 — 3,693 psi Tensile strength — ASTM D638 — 5,727psi Tensile elongation — ASTM D638 — 5.33%
Diameter Range, inches	ID 3 to 8 inches (laterals)

Technology/Method	**Perma-Liner InnerSeal™/Lateral CIPP, inverted from mainline**
	ID 6 to 24 inches (mainlines)
Thickness Range, inches	Depends on depth and condition of existing host pipe.
Pressure Capacity, psi	Not available
Temperature Range, °F	150°F
Renewal Length, feet	1 feet to 75 feet into the lateral
Other Notes	Not available
III. Technology Design, Installation, and QA/QC Information	
Product Standards	ASTM D5813
Design Standards	ASTM F1216
Design Life Range	50 years
Installation Standards	ASTM F1743
Installation Methodology	A resin-saturated liner is loaded into a delivery system that is winched through the mainline and positioned in front of the lateral opening. The saddle portion is inflated to press against the mainline sewer pipe and a tubular portion inverted into the lateral. Air pressure from the pressure apparatus is used to hold the inverted liner during resin cure up to 3 hrs.
Qualification Testing	• Mechanical properties (HTS Inc. Consultants, 03/2007) • Chemical resistance (HTS Inc. Consultants, Houston, TX, 11/2003) • Flow testing-Manning, Hazen Williams (CRT Laboratories, Orange, CA, 02/2005)
QA/QC	Certifications: • IAPMO Certificate C-4397 (IAMPO, 2008) • ANSI/NSF 14 Certificate 0D470-01 (NSF International, 2001) The post-installation CCTV inspection is performed to verify the proper cure of the material and the integrity of seamless pipe.
IV. Operation and Maintenance Requirements	
O&M Needs	None
Repair Requirements for Rehabilitated Sections	The pipe is cleaned (all roots and debris removed), heavy leaks sealed using chemical grouting, and any protrusions into the mainline removed. The lateral pipe is inspected with a pan/tilt camera prior to lining.
V. Costs	
Key Cost Factors	• Density of laterals on the mainline between two manholes (i.e., the frequency of setting up the lateral equipment) • Preparation work required (removal of roots and soft deposits in the lateral pipe, cleaning) • Cost of material
Case Study Costs	• Manufacturer's estimate not available
VI. Data Sources	
References	• www.perma-liner.com • IAMPO, 2008. C*ured-In-Place Thermosetting Resin Conduit Liner*, Certificate No. C-4397 issued to Perma-liner Industries Inc, Apr 2008- Apr 2009, International Association of Plumbing and Mechanical Officials, Ontario, CA • NSF International, 2001. Certificate of Compliance with ANSI/NSF 14 Issued to Perma-Liner Industries, 0D470-01, Dec 10, 2001

Datasheet A-53. Perma-Lateral Lining System

Technology/Method	**Perma-Lateral Lining System /Lateral CIPP, standard**
I. Technology Background	
Status	Innovative
Date of Introduction	Since 1999 in U.S. It is currently being used in several other countries, including Colombia, Japan, Australia, Canada, Hong Kong, Guam, and the Virgin Islands
Utilization Rates	Estimated 2 million linear feet of lateral sewer pipe in the U.S. have been rehabilitated with this product.
Vendor Name(s)	**Perma-Liner Industries, Inc.** Clearwater, FL Phone: (727) 235-1801 Email: cole@perma-liner.com Website: www.perma-liner.com
Practitioner(s)	There are over 500 installers of Perma-Lateral Lining System in the US (Perma-Liner Industries does not employ in-house crews to compete with their installers). • City of Los Angeles, CA (the only approved lateral CIPP product) • City of Tacoma, WA , Rod Rossi, (253) 502-2127, rrossi@ci.tacoma.wa.us (69 upper laterals in 2003, 229 in 2004) • Louisville and Jefferson County, KY, Jeffrey A. Vessels, (502) 540-6838, Vessels@msdlouky.org (405 laterals in 2004/05) • City of Dunedin, FL, Lance H. Parris, (727) 298-3256, lparris@dunedinfl.net (53 laterals in 2004/05) • Village of Brown Deer, WI, Larry Neitzel, (414) 357-0120, vbdpwlarry@sbcglobal.net (55 laterals in 2002) • Miami Dade, FL, Rod Lovett (1,200 laterals in 2006/07)
Description of Main Features	A standard CIPP product for lateral relining installed through a cleanout or a small pit. The liner is air-inverted and ambient-temperature-cured. The final product stops infiltration, eliminates root intrusion, is chemically resistant, and provides full structural repair (can bridge missing pipe sections) and carries a 50-year manufacturer's warranty.
Main Benefits Claimed	• Requires single-access point so laterals can be relined without entering private property • Can reline through 4 to 6 inches transitions, through multiple bends (several 22°, 45°, 90° bends) • Quick installation (3 hours per lateral) • Non-styrene resin is used • Good manufacturer's training and support (a municipality can have an in-house crew trained in a few days)
Main Limitations Cited	• Connection with mainline not sealed • A cleanout on the lateral is required or a small pit (3feet × 3feet) must be excavated. • Not applicable in laterals with severe mineral buildup, severe offset joints, or sags in the pipe • Flow isolation required (flow bypass required in some cases)
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other:____________________________
II. Technology Parameters	
Service Application	Gravity or force lines
Service Connections	Not applicable
Structural Rating Claimed	Fully structural

<table>
<tr><th>Technology/Method</th><th>Perma-Lateral Lining System /Lateral CIPP, standard</th></tr>
<tr><td>Materials of Composition</td><td>Tube material is needled polyester, butt-fuse welded (thermal bonding). Patented Material. Resin is 100% solids epoxy. Protective coating is PVC (after installation facing the inside of pipe).

The installed liner has the following physical properties (HTS Inc. Consultants, July 2007):

<table>
<tr><th>Property</th><th>Test Method</th><th>Value</th></tr>
<tr><td>Flexural modulus</td><td>ASTM D790</td><td>354,888 psi</td></tr>
<tr><td>Flexural strength</td><td>ASTM D790</td><td>11,071 psi</td></tr>
<tr><td>Compressive strength</td><td>ASTM D695</td><td>3,665 psi</td></tr>
<tr><td>Tensile strength</td><td>ASTM D638</td><td>6,475 psi</td></tr>
<tr><td>Tensile elongation</td><td>ASTM D638</td><td>6.00%</td></tr>
</table></td></tr>
<tr><td>Diameter Range, inches</td><td>Lateral ID 2 to 8 inches</td></tr>
<tr><td>Thickness Range, inches</td><td>Nominal liner thickness 3.0 mm</td></tr>
<tr><td>Pressure Capacity, psi</td><td>Not applicable</td></tr>
<tr><td>Temperature Range, °F</td><td>150°F</td></tr>
<tr><td>Renewal Length, feet</td><td>150 feet in single run</td></tr>
<tr><td>Other Notes</td><td>Not available</td></tr>
<tr><td colspan="2">III. Technology Design, Installation, and QA/QC Information</td></tr>
<tr><td>Product Standards</td><td>ASTM D5813-04</td></tr>
<tr><td>Design Standards</td><td>ASTM F1216-03</td></tr>
<tr><td>Design Life Range</td><td>50-year manufacturer’s warranty</td></tr>
<tr><td>Installation Standards</td><td>ASTM 1216-03</td></tr>
<tr><td>Installation Methodology</td><td>In situ resin impregnation (vacuum or rolled in). Liner air-pressure inversion, resin ambient temperature.</td></tr>
<tr><td>Qualification Testing</td><td>• Mechanical properties (HTS Inc. Consultants, 07/2007)
• Chemical resistance (HTS Inc. Consultants, Houston, TX, 11/2003)
• Flow testing–Manning, Hazen Williams (CRT Laboratories, Orange, CA, 02/2005)</td></tr>
<tr><td>QA/QC</td><td>Certifications:
• IAPMO Certificate C-4397 (IAMPO, 2008)
• ANSI/NSF 14 Certificate 0D470-01 (NSF International, 2001)

The post-installation CCTV inspection is performed to verify the proper cure of the material and the integrity of seamless pipe.</td></tr>
<tr><td colspan="2">IV. Operation and Maintenance Requirements</td></tr>
<tr><td>O&M Needs</td><td>No special requirements</td></tr>
<tr><td>Repair Requirements for Rehabilitated Sections</td><td>No special requirements</td></tr>
<tr><td colspan="2">V. Costs</td></tr>
<tr><td>Key Cost Factors</td><td>• Density of laterals on the mainline between two manholes (i.e., the frequency of setting up the lateral equipment)
• Preparation work required (removal of roots and soft deposits in the lateral pipe, cleaning)
• Cost of material</td></tr>
<tr><td>Case Study Costs</td><td>• $900/lateral, $1,110/lateral with CCTV, in Tacoma, WA, with a total of 69 laterals (2003)
• $1,000 to $4,500 per lateral (manufacturer’s quote)</td></tr>
</table>

Technology/Method	**Perma-Lateral Lining System /Lateral CIPP, standard**
VI. Data Sources	
References	• WERF, 2006. Methods for Cost-Effective Rehabilitation of Private Lateral Sewers, 02CTS5, Water Environment Research Foundation, Alexandria, VA, 436p. • Manufacturer's web site www.perma-liner.com • IAMPO, 2008. C*ured-In-Place Thermosetting Resin Conduit Liner*, Certificate No. C-4397 issued to Perma-liner Industries Inc., Apr 2008- Apr 2009, International Association of Plumbing and Mechanical Officials, Ontario, CA • NSF International, 2001. Certificate of Compliance with ANSI/NSF 14 issued to Perma-Liner Industries, 0D470-01, Dec 10, 2001

Datasheet A-54. Perma-Liner™ Point Repair System

Technology/Method	**Perma-Liner Point Repair System/Sectional CIPP**
I. Technology Background	
Status	Innovative
Date of Introduction	Since 1999 in U.S. This product is being used in several countries around the world.
Utilization Rates	Tens of thousands of point repairs have been installed around the world
Vendor Name(s)	**Perma-Liner Industries, Inc.** Clearwater, FL Phone: (727) 235-1801 Email: cole@perma-liner.com Website: www.perma-liner.com
Practitioner(s)	There are over 200 installers of Perma-Liner Point Repair System in the US, all of which practice continued maintenance utilizing this system.
Description of Main Features	A standard CIPP product for sewer mainline relining installed by pulling a bladder with the repair fastened to it into place. The bladder is inflated, releasing the liner and held in place while ambient temperature cured (3 hours). The final product stops infiltration, eliminates root intrusion, is chemically resistant, and provides full structural repair (it can bridge missing pipe sections).
Main Benefits Claimed	• No digging (access to the pipe is through the manhole) • Seals open joints, bridges missing pipe sections • Eliminates I/I and root intrusion • Manufactured and sold in kit packaging • No flow isolation or bypass required (the bladders have a 2 inches flow-through running through them to alleviate upstream head pressure) • Quick installation (3.5 hours per repair) • Non-styrene resin is used • Good manufacturer's training and support (a municipality can have an in-house crew trained in a few days)
Main Limitations Cited	• Not applicable in pipes with severe mineral buildup, severe offset joints, sags in the pipe, or in pipe sections with protruding laterals • Repairs only short sections of pipe (2 feet to 30 feet)
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other: Storm Drains/ Mains
II. Technology Parameters	
Service Application	Gravity or force lines
Service Connections	Not applicable
Structural Rating Claimed	Fully structural
Materials of Composition	The tube consists of an inner liner (non-woven, flexible, needled felt) with a PU/PVC coating and a fiberglass/felt mat reinforcement (an additional layer of reinforced chopped fiberglass and felt). A proprietary epoxy resin is formulated and applied to the inner liner, as well as to the fiberglass/felt mat. The inner liner and fiberglass/felt mat become one with the impregnation of the epoxy resin. The PU/PVC coating will form the inner layer of the finished pipe and is required for enhancement of corrosion. The installed liner has the following physical properties (HTS, Inc., Consultants, June 2003): Property — Test Method — Value Flexural modulus, psi — ASTM D790 — 386,136 psi Flexural strength, psi — ASTM D790 — 10,661 psi Compressive strength, psi — ASTM D695 — 5442 psi Tensile strength, psi — ASTM D638 — 6317 psi Tensile elongation — ASTM D638 — 6.05 %
Diameter Range, inches	6 to 54 inches

Technology/Method	**Perma-Liner Point Repair System/Sectional CIPP**
Thickness Range, inches	Nominal liner thickness is 3 mm, but can be made in 4.5 mm or 6 mm depending on the design calculation from the engineers.
Pressure Capacity, psi	Not applicable
Temperature Range, ^{o}F	150º F
Renewal Length, feet	2- to 30-feet lengths
Other Notes	Not available
III. Technology Design, Installation, and QA/QC Information	
Product Standards	ASTM D5813-04
Design Standards	ASTM F1216-03
Design Life Range	50 years
Installation Standards	ASTM F1216-03
Installation Methodology	In situ resin impregnation (vacuum or rolled in). Liner air-pressure inversion, resin ambient temperature. The tube impregnated with the thermosetting two-part resin is loaded onto the carrier train, which is pulled or winched to the damaged area and positioned by CCTV camera guiding the installation. The installation follows the manufacturer's instructions for inflation curing and stripping out.
Qualification Testing	• Mechanical properties (HTS, Inc., Consultants, 06/2003) • Chemical resistance (HTS, Inc., Consultants, Houston, TX, 11/2003)
QA/QC	Certifications: • IAPMO Certificate C-4397 (IAMPO, 2008) • ANSI/NSF 14 Certificate 0D470-01 (NSF International, 2001) The post-installation CCTV inspection verifies the proper cure of the material and the integrity of seamless pipe.
IV. Operation and Maintenance Requirements	
O&M Needs	No special requirements
Repair Requirements for Rehabilitated Sections	No special requirements
V. Costs	
Key Cost Factors	• Preparation work required (removal of roots and soft deposits in the pipe, cleaning) • Cost of material
Case Study Costs	• Pricing is solely determined by the installers, but usually ranges from $1,500 to $3,500.
VI. Data Sources	
References	• www.perma-liner.com • IAMPO, 2008. C*ured-In-Place Thermosetting Resin Conduit Liner*, Certificate No. C-4397 issued to Perma-Liner Industries Inc, Apr 2008- Apr 2009, International Association of Plumbing and Mechanical Officials, Ontario, CA • NSF International, 2001. Certificate of Compliance with ANSI/NSF 14 Issued to Perma-Liner Industries, 0D470-01, Dec 10, 2001

Datasheet A-55. PerpetuWall® Composite CIP liner

Technology/Method	**PerpetuWall /Composite (epoxy-fiberglass) CIP liner**
I. Technology Background	
Status	Innovative
Date of Introduction	Not available
Utilization Rates	Not available
Vendor Name(s)	**Protective Liner Systems** Lithonia, GA Phone: (770) 482-5231 Email: JosephTrevino@ProtectiveLinerSystems.com Website: www.protectivelinersystems.com
Practitioner(s)	Not available
Description of Main Features	A composite cured-in-place liner made of fiberglass cloth (E-type glass) and modified epoxy resin system (the resin has fibers embedded for increased tear resistance of the liner). Intended for person-entry application.
Main Benefits Claimed	• Stops corrosion • Stops infiltration/exfiltration • Cures in dry or wet conditions • Trenchless technology with minimal disruptions to the community • No large equipment needed • Perfect for hard-to-reach locations • Reinforces structural strength
Main Limitations Cited	• Requires expertise • Flow bypass required
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other:____________________________
II. Technology Parameters	
Service Application	Wastewater, raw water, industrial, and power.
Service Connections	Depends on application
Structural Rating Claimed	Semi-structural
Materials of Composition	Reinforcing fabric (PLS-811) is an 11-oz. fiberglass bonded fabric of Type E glass, with stitch-bonded construction. Modified epoxy resin system (PerperuCoat Product Family) is bisphenol A epoxy resin, cross-linked with a modified polyamide curing agent. 100% solids, emitting no toxic odors. Mastic (PLS-614) will bond to concrete, brick, carbon steel, galvanized steel, aluminum, wood, and some plastics. The installed liner, PerpetuWall (PLS-650), has the following minimum physical properties (manufacturer's data):

Property	Test Method	Type I
Hardness	ASTM D2240	72 Shore D
Tensile strength	ASTM D638	29,200 psi
Compressive strength	ASTM D695	16,800 psi
Flexural strength	ASTM D790	343,000 psi
Ultimate elongation	ASTM D638	4.50%
Bond (concrete)	ASTM D4541	Substrate Failure
Flexural modulus	ASTM D790	1,590,000 psi
Shear strength	ASTM D2344	4,060 psi

Diameter Range, inches	4" to 108"
Thickness Range, inches	125 to 180 mils
Pressure Capacity, psi	Not available

Technology/Method	**PerpetuWall /Composite (epoxy-fiberglass) CIP liner**
Temperature Range, ^{o}F	Not available
Renewal Length, feet	1,000 ft to 3,000 ft
Other Notes	Not available
III. Technology Design, Installation, and QA/QC Information	
Product Standards	ASTM D1784 – rigid poly (vinyl chloride) (PVC) compound and chlorinated poly (vinyl chloride) (CPVC) compounds. ASTM D3350 – polyethylene plastic pipe and fitting materials.
Design Standards	ASTM F1216
Design Life Range	50 years, 5-year warranty
Installation Standards	ASTM F1216, Section 7, or ASTM F1743.
Installation Methodology	Mastic is first applied at an approximate thickness of 100 mils. The fiberglass fabric is cut into the required dimensions and pressed, using a putty knife, into the mastic to achieve full wetting of the fabric. With subsequent applications of the fabric, the edges are overlapped. Epoxy is applied between the overlapped edges to assure a monolithic construction. The fabric is top-coated with the mastic to ensure complete saturation and encapsulation of the fabric. The finish lining systems shall have a minimum thickness of 125.0 mils. The epoxy cures in 3 to 4 hours at 70°F to approximately 5% of its strength (at this time the structure may return to service) and to its full strength in 4 to 5 days. Higher temperatures reduce the cure time and lower temperatures increase it.
Qualification Testing	Not available
QA/QC	Test for adhesion before rehab: a 12 inches test square of PerpetuWall Protective Wall Covering is attached to the wall using the mastic adhesive, allowed to set for 24 hours, and pulled off. (If the adhesive has softened the paint, the wall must be stripped prior to installation.) CIPP samples are prepared for each installation and pipe physical properties tested in accordance with ASTM F1216 or ASTM F1743, Section 8 (flexural properties, wall thickness). Visual inspection of the CIPP in accordance with ASTM F1743, Section 8.6.
IV. Operation and Maintenance Requirements	
O&M Needs	No special requirements
Repair Requirements for Rehabilitated Sections	No special requirements
V. Costs	
Key Cost Factors	Not available
Case Study Costs	Not available
VI. Data Sources	
References	www.protectinginfrastructure.com

Datasheet A-56. Pipeliner (Ultraliner) PVC Alloy Fold-and-Form

Technology/Method	**Fold-and-Form/Thermoformed**
I. Technology Background	
Status	Conventional
Date of Introduction	1994
Utilization Rates	Over 4.5 million feet installed since 1994. Split fairly evenly between 4 to 16 inches and 18 to 30 inches pipeliner installations. As of 2008, PVC Alloy Pipeliner has been installed in 36 states, and 2 countries, with over $20 million 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™** Ultraliner, Inc. 201 Snow Street / PO Drawer 3630 Oxford, AL 36203 Phone: (256) 831-5515 Email: info@ultraliner.com Website: www.ultraliner.com
Practitioner(s)	Georgia Department of Transportation (GDOT) – District One Ken Reed, District Bridge Maintenance Manager 2505 Athens Hwy SE P.O. Box 1057 Gainesville, Georgia 30503-1057 City of Los Angeles, California Keith Hanks 650 S. Spring St., Room 1000 Los Angeles, CA 90014 Phone: (213) 847-8770 Jacksonville Naval Air Station [1] Bill Myer, the Navy's airfield facility manager for both NAS Jacksonville and the Outlying Field [OLF] of the White House Phone: (904) 542-3176 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 inches and less, are folded in the field prior to insertion, while large diameters, 15 inches and above, are deflected to a smaller profile (approximately 50%) at the manufacturing facility.
Main Benefits Claimed	• Conforms to size transitions, tight bends, offset joints and other irregularities. • Does not shift/shrink longitudinally or radially after installation (memory reset by heat and stretching to new dimensions); consistently achieves a tight fit. • Able to withstand significant shallow-impact loads. • Reliable flanged and gasketed end seals in pressure applications and hydrophilic gasket end seals in gravity applications. • The solid-wall PVC alloy cuts and polishes smoothly and quickly without jagged edges at lateral reconnections. • Very high abrasion resistance and ductility. • PVC alloys are chemically compatible with any sewerage application where a traditional direct burial PVC pipe would be appropriate. • Factory-controlled consistency of design properties, including modulus, wall thickness, and corrosion resistance, enhances long-term asset manageability [2], [3]. • Low mobilization, shipping, and set-up costs make for exceptional

Technology/Method	Fold-and-Form/Thermoformed
	competitiveness in rural, DOT, and smaller-scale projects. • Relatively small jobsite footprint. 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. • Limited long-term pressure test data to support independent use as a fully structural liner in pressure applications; available data supplemented by 10 years of practical field application. • Requires access at both ends of the pipe for installation. • Requires excavation for a pressure seal at branch connections. • All tight-fitting liners require additional technologies (grout packing, lateral lining, or other) to provide a seal at internal branch connections. • 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. • Construction network is small scale, which limits available economies of scale and influences potential competitiveness on larger-scale projects (particularly 30,000 lf+). • 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, stormwater, raw water, industrial, power
Service Connections	Laterals remotely reinstated with robots. Downtime 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 inches – F1504 only to 16 inches
Thickness Range, inches	4 inches – DR 32.5; 6, 8, 9 inches – DR 32.5 to 35; 10, 12, 15, 16 inches – DR 32.5 to 41; 18 inches – DR 35 to 50; 21, 24, 30 inches – generally designated by wall thickness up to 0.65 inches
Pressure Capacity, psi	Currently available for low pressure, under 80 psi (only available up to 15 inches - 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, feet	Up to 600 feet typical; 1,000 feet for 8 to 12 inches has been achieved, and up to 650 feet for 21 and 24 inches, up to 500 feet for 30 inches
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 F1871 Standard Specification for Folded/Formed Poly (Vinyl Chloride) Pipe Type A for Existing Sewer and Conduit Rehabilitation ASTM F1504 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.

Technology/Method	**Fold-and-Form/Thermoformed**
Design Life Range	100 years 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 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 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 and 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). • 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. • 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. • 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. • De-watering is not required for quality assurance, as water exposure cannot alter design property compliance of a solid-wall PVC Alloy Pipeliner, but it may be utilized for risk control, as appropriate, since excessive groundwater can narrow the window of installability. • The material cost is all-inclusive (and includes manufacturing QA/QC) with no additional onsite mixing of chemicals, nor "finishing" labor requirements prior to installation. • End seals, when specified, are routinely included in the unit price for the pipeliner. • Lateral reinstatements are generally a separate cost because the numbers of connections vary. • 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

Technology/Method	**Fold-and-Form/Thermoformed**
	and 40 to 80 feet 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 feet+) 8 inches PVC Alloy pipeliner projects can receive bids in the $22 per feet range, whereas smaller-scale 8 inches projects with significant mobilization requirements or especially challenging conditions can receive prices up into the $40 per feet range.
VI. Data Sources	
References	Ultraliner PVC Alloy Pipeliner™ brochure; Personal correspondence. (1) Whittle L. G. (2008). Takes Off at Naval Air Station in Jacksonville, Fla. Trenchless Technology Magazine, November, 2008. (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. (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. (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. (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.

Datasheet A-57. Polyspray Polyurea Spray-on Lining

Technology/Method	**PolySpray/PolyUrea Spray-on Lining**
I. Technology Background	
Status	Innovative
Date of Introduction	July 2006
Utilization Rates	Not available
Vendor Name(s)	**Hunting Specialized Products** 1210 Glendale-Milford Road Cincinnati, Ohio 45215 Phone: (513) 771-9319 Email: info@huntingsp.com Website: http://www.huntingsp.com/index.html
Practitioner(s)	Not available
Description of Main Features	PolySpray is a spray-applied structural lining system that has extraordinary toughness and flexibility. When applied to the interior of a deteriorated pipeline, PolySpray builds a new pipe inside the existing pipeline. PolySpray can be applied to large concrete or metal structures, sealing leaks and protecting the structure against corrosion. Primary advantages of polyurea include rapid cure, high film build, abrasion resistance, and high elongation.
Main Benefits Claimed	• Fully Structural Lining - Restores and enhances structural integrity of the system. • High Flexibility and Toughness - New lining is not brittle; resists fracture if subjected to impact or load. • Flexible and Waterproof - Provides a leak-tight seal. • Good Chemical Resistance - Resists most corrosive effluents. • Excellent Abrasion Resistance - Excellent wear resistance; extends life of lined pipe.
Main Limitations Cited	The extremely short time available for the material to be adequately mixed, passed through the application head, and sprayed onto pipe before it turns solid requires special installation procedures.
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other: Storm-water lines
II. Technology Parameters	
Service Application	Rehabilitation, Repair, and Replacement
Service Connections	When the machine is used, service connections need to be covered for big-diameter pipes; when a person is using a machine to spray the polyurea, it is easier to handle service connections.
Structural Rating Claimed	PolySpray has been independently tested for structural properties, such as flexural modulus, tensile modulus, and elongation so that the correct lining thickness can be recommended, depending upon pipe diameter and pipe depth underground. Flexural modulus and tensile strength exceed those required by ASTM F1216.
Materials of Composition	PolyUrea
Diameter Range, inches	≥ 6 inches
Thickness Range, inches	The liner is tough and flexible, has outstanding corrosion resistance, and can be applied in thicknesses from 0.002 up to 0.5 inch.
Pressure Capacity, psi	Not applicable
Temperature Range, °F	Recommended for use in cold-water installations.
Renewal Length, feet	Not available
Other Notes	Not available
III. Technology Design, Installation, and QA/QC Information	
Product Standards	No NSF 61 listing
Design Standards	PolySpray meets or exceeds the minimum requirements of ASTM F1216, Standard Practice for Rehabilitation of Pipelines by Inversion & Curing of Resin Impregnated Tube (CIPP).

Technology/Method	**PolySpray/PolyUrea Spray-on Lining**
Design Life Range	Not available
Installation Standards	Special equipment developed to install PolySpray is contained in a 36-foot trailer.
Installation Methodology	The material is mixed as it is applied from the application head by high-pressure impingement. The mixed material is injected into a rotating cone, which then centrifugally applies the lining, still in a liquid state at this stage, onto the pipe wall. Extremely fast, 2½ -second cure time. Computer-monitored for all the essential parameters, such as temperature, rate of material flow, spray head pressure, and lining speed. Once pipes have been prepared, the lining hoses will be pulled through the pipe for the required lining length. The application head then is connected, and the lining started with the hoses being pulled back through the pipe at a controlled rate to provide the specified lining thickness. As soon as the lining process has been completed, a further CCTV survey can be conducted to monitor lining quality; and the pipe can then be re-commissioned.
QA/QC	Not available
IV. Operation and Maintenance Requirements	
O&M Needs	Not available
Repair Requirements for Rehabilitated Sections	Not available
V. Costs	
Key Cost Factors	Not available
Case Study Costs	Not available
VI. Data Sources	
References	http://www.huntingsp.com/productsPolySpray.php NSF/ANSI 61 Website

Datasheet A-58. Poly-Triplex® Liner System

Technology/Method	**Poly-Triplex Liner System/Composite CIP Liner**
I. Technology Background	
Status	Innovative
Date of Introduction	Developed in U.S. in 1990. Also utilized in Canada.
Utilization Rates	Over 11,000 manholes rehabilitated, totaling over 100,000 vertical feet
Vendor Name(s)	**Poly-Triplex Technologies, Inc.** Bonifay, FL Phone: (850) 547-9999 Email: rputnam@poly-triplex.com Website: www.poly-triplex.com
Practitioner(s)	• Clark County Water Reclamation District, Las Vegas , NV, (7020 434-6600 (885 manholes, a total of 12,377 VF, rehabilitated since 1995) • Cincinnati Metropolitan Sewer District, OH, Mike Stevens, (513) 352-4941 (982 manholes/chimney guards, a total of 5,859 VF, rehabilitated since 1999) • Town of La Grange, NC, Dan Boone, *Wooten Company*, (919) 828-0531 (224 manholes and 6 pump stations relined in 2001) • City of Loveland, CO (a 72” pump station, 20 ft deep, relined in 2001) • City of Everett, WA, Don Hasselson, (425) 257-8853 (116-ft concrete pipe, 89” in diameter, lined in 1998). • Florida DOT (70-ft-long corrugated metal culvert, 30” in diameter, in Destin, FL, rehabilitated in 2003)
Description of Main Features	A composite CIP liner installed in manholes, catch basins, pump stations, wet wells, and/or culvert pipes. In manholes, installation can be completed without flow interruption or loss of customer services if inverts are not to be lined. Installations are typically completed within 2 to 3 hours.
Main Benefits Claimed	• Non porous inner membrane prevents infiltration/exfiltration and prevents sewer gases from contacting and deteriorating host structure. • 100-year life service
Main Limitations Cited	• Flow bypass may be required (if inverts are to be lined and lines can’t be plugged either due to pipe size or because flow must not be disrupted during installation)
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other: Culvert pipes, Pump Stations
II. Technology Parameters	
Service Application	Wastewater
Service Connections	In manhole relining, pipe openings are reopened with a reciprocal or offset grinder.
Structural Rating Claimed	Fully structural
Materials of Composition	Liner is typically a three-layer system: a non-porous inner membrane is sandwiched between two layers of structural fiberglass (fiberglass weight can be 12, 18, or 24 ounces per square yard, depending on requirements). The inner membrane itself contains three components: a non-porous PVC membrane mechanically bonded between, two layers of felt fibers. Felt fibers allow bonding of the inner membrane to the surrounding fiberglass layers with epoxy resin during installation. Resin used is epoxy. Four different systems are offered: Type / Depth / Non-Porous Membrane Type I / ≤ 8 feet / Two 12-oz. layers of woven roving fiberglass II / ≤ 13 feet / Two 18-oz. layers of woven roving fiberglass III / ≤ 24 feet / Two 24-oz. layers of woven roving fiberglass IV / > 24 feet / Four 24-oz. layers of woven roving fiberglass The installed liner has the following min physical properties (manufacturer’s data):

<table>
<tr><th>Technology/Method</th><th>Poly-Triplex Liner System/Composite CIP Liner</th></tr>
<tr><td></td><td>
<table>
<tr><th>Property</th><th>ASTM</th><th>Type I</th><th>Type II</th><th>Type III</th><th>Type IV</th></tr>
<tr><td>Flexural strength, psi</td><td>D790</td><td>20,000</td><td>30,000</td><td>35,000</td><td>40,000</td></tr>
<tr><td>Flexural modulus, psi</td><td>D790</td><td>600,000</td><td>750,000</td><td>800,000</td><td>1,000,000</td></tr>
<tr><td>Comp. strength, psi</td><td>D695</td><td>4,700</td><td>7,800</td><td>10,500</td><td>12,000</td></tr>
<tr><td>Comp. modulus, psi</td><td>D695</td><td>570,000</td><td>750,000</td><td>800,000</td><td>950,000</td></tr>
<tr><td>Tensile strength, psi</td><td>D638</td><td>10,000</td><td>18,000</td><td>25,000</td><td>35,000</td></tr>
<tr><td>Tensile % of elongation</td><td>D638</td><td>6.9</td><td>8.1</td><td>8.5</td><td>10.0</td></tr>
<tr><td>Hardness</td><td>D2240</td><td>No data</td><td>86.0</td><td>86.0</td><td>86.0</td></tr>
</table>
</td></tr>
<tr><td>Diameter Range, inches</td><td>Manholes: up to 120 inches (custom-made; larger diameters are possible)</td></tr>
<tr><td>Thickness Range, inches</td><td>116 mils; 137 mils; 151 mils; or 229 mils (Type I, II, III, or IV)</td></tr>
<tr><td>Pressure Capacity, psi</td><td>Not available</td></tr>
<tr><td>Temperature Range °F</td><td>33°F to 120°F</td></tr>
<tr><td>Renewal Length, feet</td><td>Manholes: up to 30 VF generally, pipes: up to 1,500 feet</td></tr>
<tr><td>Other Notes</td><td>Not available</td></tr>
<tr><td colspan="2">III. Technology Design, Installation, and QA/QC Information</td></tr>
<tr><td>Product Standards</td><td>ASTM D1784 – rigid poly (vinyl chloride) (PVC) compound and chlorinated poly (vinyl chloride) (CPVC) compounds.
ASTM D3350 – polyethylene plastic pipe and fitting materials.</td></tr>
<tr><td>Design Standards</td><td>ASTM F1216</td></tr>
<tr><td>Design Life Range</td><td>10 years</td></tr>
<tr><td>Installation Standards</td><td>CIPP installation in accordance with ASTM F1216, Section 7, or ASTM F1743.</td></tr>
<tr><td>Installation Methodology</td><td>**Manholes**. A sub-floor is built over the invert channel, allowing installation without disruption of service. The liner is resin-saturated at the site, and inserted into the manhole structure by crane or by hand. A canister is attached to the top of the liner, providing fittings for injecting steam and high-volume air. A disposable inflation bladder conforms the liner to the host structure, using a blower. The injected steam accelerates the curing process. After curing, the bladder is removed, and any incoming pipes are reopened using a reciprocal saw or offset grinder. The liner is trimmed at the invert channel and the sub-floor is removed. If the invert is to be lined, incoming and outgoing pipes are plugged, or bypass pumping is set up. No sub-floor will be built in this case.

Pipes. The liner is resin-saturated at the site and inserted into the pipe by winching. A disposable inflation bladder is conforms the liner to the host pipe. The injected steam accelerates the curing process. After curing, the bladder is removed.</td></tr>
<tr><td>Qualification Testing</td><td>• Mechanical Properties (HTS Consulting, Inc., 2005)
• Chemical Resistance (HTS Consulting, Inc., 2006)</td></tr>
<tr><td>QA/QC</td><td>CIPP samples prepared for each installation and physical properties tested (ASTM F1216 or ASTM F1743). The minimum wall thickness at any point must not be less than 87.5% of the minimum design wall thickness. Visual inspection of the CIPP (ASTM F1743, Section 8.6).</td></tr>
<tr><td colspan="2">IV. Operation and Maintenance Requirements</td></tr>
<tr><td>O&M Needs</td><td>No special requirements</td></tr>
<tr><td>Repair Requirements for Rehabilitated Sections</td><td>No special requirements</td></tr>
<tr><td colspan="2">V. Costs</td></tr>
<tr><td>Key Cost Factors</td><td>Labor and equipment cost (depending on part of country) versus number of liners installed per day (determined by the location of manholes; i.e. installation within the city limits vs. remote areas outside the city limits). Materials used (repaired diameter/length) influence the cost in smaller degree.</td></tr>
<tr><td>Case Study Costs</td><td>Not available</td></tr>
<tr><td colspan="2">VI. Data Sources</td></tr>
<tr><td>References</td><td>www.poly-triplex.com</td></tr>
</table>

Datasheet A-59. Powercrete PW Epoxy Spray Coating

Technology/Method	**Powercrete PW/Spray coating epoxy**
I. Technology Background	
Status	Conventional
Date of Introduction	Not available
Utilization Rates	Not available
Vendor Name(s)	**Powercrete PW** Berry Plastics, Coatings, Tapings Division 11010 Wallisville Road Houston, TX 77013 Phone: (713) 676-0085 Email: cpg@berryplastics.com Web: http://www.berrycpg.com/intro.asp
Practitioner(s)	Not available
Description of Main Features	Powercrete PW is an NSF 61 45ºC (113ºF)-approved liquid epoxy polymer coating designed for use as a pipe lining for potable and wastewater pipes and storage tanks. Powercrete PW is also very effective for slurries and abrasive applications. PW offers maximum protection from corrosion as it provides high adhesion to bare steel and ductile iron along with superior abrasion resistance.
Main Benefits Claimed	• 100% solids liquid epoxy • No VOCs and no isocyanates • Same formula can be hand- or spray-applied • Flexibility in difficult-to-coat field conditions • Excellent wetting properties to bare steel • Exceptional adhesion, cathodic disbondment, and soil stress resistance on bare steel
Main Limitations Cited	Not available
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other: Storage Tanks, Directional Drilling, Pipe Bends, Fittings, Valves & Odd Shapes, Any bare steel structure in need of protection
II. Technology Parameters	
Service Application	Rehabilitation
Service Connections	Need to be plugged or done in a second phase.
Structural Rating Claimed	ASTM D3289-03, ASTM C109, ASTM D2240
Materials of Composition	Epoxy
Diameter Range, inches	For pipes larger than 8 inches
Thickness Range, inches	2.5 to 4.0 mils
Pressure Capacity, psi	Not applicable
Temperature Range, ^{o}F	Max operating temperature is 131ºF
Renewal Length, feet	Not applicable
Other Notes	Not available
III. Technology Design, Installation, and QA/QC Information	
Product Standards	NSF 61 approved
Design Standards	ASTM D570, ASTM D149, ASTM C581, ASTM D4541, ASTM D4541, ASTM G14-88, NACE RP-0394, ASTM D4060-95, ASTM G95
Design Life Range	Not available
Installation Standards	If the surface to be coated is below 10ºC (50ºF), preheating of the substrate is recommended. Preheat temperatures should not exceed 82ºC (180ºF) prior to the application.
Installation Methodology	Colors: Black, tan Number of Coats: 1 Maximum Field Use Dry Film Thickness (in mils): 20 Final Cure Time and Temperature: 1 day at 72°F and 10 days at 104°F Special Comments: Mix ratio A:B is 100:5.5 by weight. Cure Schedule: 24 hours at 25°C and 10 days at 43°C +/- 3°C for drinking-water

Technology/Method	**Powercrete PW/Spray coating epoxy**
	pipe internal coating, after spray application, by NSF 61.
QA/QC	Not available
IV. Operation and Maintenance Requirements	
O&M Needs	Care must be taken so as not to damage coating
Repair Requirements for Rehabilitated Sections	No special requirements
V. Costs	
Key Cost Factors	Not available
Case Study Costs	Not available
VI. Data Sources	
References	http://www.berrycpg.com/index.asp?marca=004

Datasheet A-60. Prime Resins Polyurethane Grout Materials

Technology/Method	**Polyurethane grouts/Polyurethane grouts for leak repair**
I. Technology Background	
Status	Mature
Date of Introduction	1960s
Utilization Rates	Approximately millions of gallons industry-wide
Vendor Name(s)	**Prime Resins, Inc.** Conyers, GA Phone: (800) 321-7212 Email: jwest@primeresins.com Web: www.primeresins.com
Practitioner(s)	• Orange County, FL , Chris Bishop, christopher.bishop@ocfl.net, (407) 836-6854 (installer of Prime-Flex for leak repair) • Metropolitan Sewer District (MSD), St. Louis, Gene Stinnet, mestin@stlmsd.com, (314) 768-6364 (installs 180+ gallons per month) • City of Huntsville, AL, Shane Cook, shane.cook@hsvcity.com, (256) 883-3778 (end-user manhole and sewer-line repair)
Description of Main Features	Two major types of polyurethane grouts are offered: hydrophilic and hydrophobic. **Hydrophilic grouts** have a great affinity to water. Water is incorporated into the reaction to create a flexible foam or gel. Prime Flex 900 XLV is a low-viscosity hydrophilic foam that bonds to wet concrete and/or masonry structures. Hydrogel 970 is a hydrophilic gel that can react with up to 15 parts water and create a bond to wet concrete and/or masonry structures. These materials can be injected into hairline cracks or larger joints to create a permanent water stop. Hydrophilic grouts are also used to stop water/leaks through the voids around pipe penetrations. **Hydrophobic resins** repel water. Hydrophobics like the Prime Flex 920 are often used to stop gushing leaks and fill voids around below-grade structures. These materials are highly expansive and can be semi-rigid to rigid or semi-flexible. Water is used to initiate the reaction of hydrophobic grouts. Once that reaction begins, hydrophobic grouts repel or "push" water away from the injection point.
Main Benefits Claimed	• Trenchless application • Cost-effective for infiltration • Safe and inert materials • Permanent repairs • Instant results
Main Limitations Cited	• Education required
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other: Pipe Penetrations, Water Tanks, etc.
II. Technology Parameters	
Service Application	Manholes, Sewers, Pipes, Pipe Penetrations, Water/Holding Tanks, Laterals, Pump Stations, etc.
Service Connections	Not available
Structural Rating Claimed	Not available
Materials of Composition	Polyurethane resins
Diameter Range, inches	Unlimited
Thickness Range, inches	Unlimited
Pressure Capacity, psi	Variable upon application.
Temperature Range, °F	Up to 350°F
Renewal Length, feet	Not available
Other Notes	Suitable for contact with potable water.

Technology/Method	**Polyurethane grouts/Polyurethane grouts for leak repair**
III. Technology Design, Installation, and QA/QC Information	
Product Standards	ASTM D3574 and ASTM D1042
Design Standards	Variable
Design Life Range	Lifetime of the structure
Installation Standards	Various, depending on product application
Installation Methodology	Pressure injection
Qualification Testing	Various, depending on product application
QA/QC	Various, depending on product application
IV. Operation and Maintenance Requirements	
O&M Needs	None
Repair Requirements for Rehabilitated Sections	Presence of water or ability to introduce water into the defect.
V. Costs	
Key Cost Factors	• Size of voids and defects
Case Study Costs	• Various, depending on product application
VI. Data Sources	
References	www.primeresins.com

Datasheet A-61. Raven 405 Epoxy Lining

Technology/Method	**Raven 405/Sprayable epoxy coatings for manholes, pipes**
I. Technology Background	
Status	Conventional
Date of Introduction	1987
Utilization Rates	1.9 million square feet per year
Vendor Name(s)	**RLS Solutions Inc.** Broken Arrow, OK Phone: (918) 615-0020 Email: henkej@rlssolutions.com Website: www.rlssolutions.com
Practitioner(s)	• City of Dallas, TX, Jimmy Partain, (214) 671-9075, Jimmy.partain@dallascityhall.com (over 500 manholes rehabilitated since 2005). Note: Some manholes were new installations and sprayed with Raven 405 for protection. • City of Tulsa, OK, Matt Vaughn, (918) 596-9564, mvaughan@ci.tulsa.ok.us; Leonard Gardner, *L&L Construction*, (918) 299-2600, LGardner@landlconstruction.com (over 400 manholes rehabilitated since 2004) L & L Construction, Inc., (918) 299-2600 • City of Austin, TX, Leigh Cerda, GSWW, Inc., (512) 306-9266x71, (512) 626-4030, lcerda@gsw-inc.com • Mike Kennedy, Brown & Gay Engineers, Inc., (281) 558-8700, mkennedy@browngay.com
Description of Main Features	A solvent-free 100% solids, ultra-high-build epoxy coating spray-applied for structural or non-structural lining of manholes, pipelines, tanks and other deteriorated structures. Predominantly installed with manual spraying, although can be applied in small-diameter pipes using spin-casting equipment. The unique ultra-high-build ability allows it to be spray-applied on vertical and overhead surfaces.
Main Benefits Claimed	• Stops corrosion (broad range chemical resistance) • Prevents infiltration and exfiltration • Can be used to structurally rebuild severely deteriorated wastewater infrastructure (high physical strengths) • Superior bonding to concrete, steel, masonry, fiberglass, and other surfaces with proper surface preparation • Recommended for surfaces where an existing structure requires enhancement of the structural integrity and where exposure to concentrated acids and caustics may be expected.
Main Limitations Cited	• Dewatering required • Surface preparation is essential for successful applications. • Installation by trained and certified applicators only
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other:_Person entry_________________
II. Technology Parameters	
Service Application	Wastewater, stormwater, raw water, industrial
Service Connections	Not applicable
Structural Rating Claimed	Non-structural/structural
Materials of Composition	Raven 405 is a 100% solids epoxy with zero shrinkage. Part A: Resin, Part B: Hardener. 3:1 by volume The installed liner has the following properties (performance testing):

<table>
<tr><th>Technology/Method</th><th>Raven 405/Sprayable epoxy coatings for manholes, pipes</th></tr>
<tr><td></td><td><table>
<tr><th>Property</th><th>Test Method</th><th>Value</th></tr>
<tr><td>Tensile strength</td><td>ASTM D638</td><td>7,600 psi</td></tr>
<tr><td>Tensile ultimate elongation</td><td>ASTM D638</td><td>1.5%</td></tr>
<tr><td>Compressive strength</td><td>ASTM D695</td><td>18,000 psi</td></tr>
<tr><td>Flexural strength</td><td>ASTM D790</td><td>13,000 psi</td></tr>
<tr><td>Hardness, shore D</td><td>ASTM D2240</td><td>88</td></tr>
<tr><td>Taber abrasion, CS-17 wheel</td><td>ASTM D4060, 1 kg load/ 1,000 cycles</td><td><112 mg loss</td></tr>
<tr><td>Adhesion, concrete</td><td>ASTM D4541/7234</td><td>Substrate failure</td></tr>
</table></td></tr>
<tr><td>Diameter Range, inches</td><td>Any shape with dimensions accommodating man-entry; round pipes 3 to 36 inches (spin-casting)</td></tr>
<tr><td>Thickness Range, inches</td><td>60 to 250 mils per application layer. Recoating between 2 to 18 hrs of previous coat.</td></tr>
<tr><td>Pressure Capacity, psi</td><td>Design-dependent (pressure pipe)</td></tr>
<tr><td>Temperature Range, ^{o}F</td><td>150°F to 200°F</td></tr>
<tr><td>Renewal Length, feet</td><td>Up to 1,000 feet with man-entry (>1,000 ft with equipment entry);
up to 500 to 600 feet with spincasting application</td></tr>
<tr><td>Other Notes</td><td>Not available</td></tr>
<tr><td colspan="2">III. Technology Design, Installation, and QA/QC Information</td></tr>
<tr><td>Product Standards</td><td>Not available</td></tr>
<tr><td>Design Standards</td><td>• NACE RPO892, Standard Recommended Practice Coatings and Linings over Concrete for Chemical Immersion and Containment Service
• NACE RPO288, Standard Recommended Practice Inspection of Linings on Steel and Concrete
• 2008 Supplement to Greenbook, Section 500-2, Manhole and Structure Rehabilitation
• ASCE MOP92 (2008 Update) Manhole Inspection and Rehabilitation</td></tr>
<tr><td>Design Life Range</td><td>Up to 50 years</td></tr>
<tr><td>Installation Standards</td><td>• ICRI Technical Guideline No. 03732
• SSPC-SP 5/NACE No. 1, White Metal Blast Cleaning
• SSPC-SP 10/NACE No. 2, Near-White Blast Cleaning
• SSPC-SP 13/NACE No. 6, Surface Preparation of Concrete
• ASTM D7234 – 05, Standard Test Method for Pull-Off Adhesion Strength of Coatings on Concrete Using Portable Pull-Off Adhesion Testers
• ASTM D4541 – 02, Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers
• ASTM D4787 – 93, Standard Practice for Continuity Verification of Liquid or Sheet Linings Applied to Concrete Substrates</td></tr>
<tr><td>Installation Methodology</td><td>The two components’ 100% solids systems product is installed with a plural component spray application system (Raven), which pre-heats the product, mechanically ratios the two components, and mixes and delivers the homogeneously blended product to the spray gun (airless or air-assisted).
Initial set generally occurs within 6 hours at 70°F. Curing continues for several days.

When applying multiple coats, no more than 18 hours at 70°F should be permitted to pass between coats. For quality assurance, at least two coats are recommended.</td></tr>
<tr><td>Qualification Testing</td><td>• Chemical resistance (City of Los Angeles, CA, 2003)
• Chemical Resistance-Evaluation of Protective Coatings for Concrete (County Sanitation Districts of Los Angeles, 2004)
• (CIGMAT, University of Houston, Report No. 98-3)</td></tr>
<tr><td>QA/QC</td><td>• For quality assurance, at least two coats are recommended.
• NACE RPO188 Standard Recommended Practice Discontinuity (Holiday) Testing of New Protective Coatings on Conductive Substrates</td></tr>
</table>

Technology/Method	**Raven 405/Sprayable epoxy coatings for manholes, pipes**
IV. Operation and Maintenance Requirements	
O&M Needs	Damage to installed coating must be repaired to prevent system and substrate degradation.
Repair Requirements for Rehabilitated Sections	**Surface preparation:** The substrate must be a uniform, clean, sound, neutralized surface and free of oil, grease, rust, scale, or deposits. In general, coating performance is proportional to the degree of surface preparation. **Steel** surfaces may require "Solvent Cleaning" (SSPC-SP 1) to remove oil, grease, and other soluble contaminants. Chemical contaminants may be removed according to SSPCSP 12/NACE No. 5. Identification of the contaminants, along with their concentrations, may be obtained from laboratory and field tests as described in SSPC-TU 4 "Field Methods for Retrieval and Analysis of Soluble Salts on Substrates." Surfaces to be coated should then be prepared according to SSPC-SP 5/NACE No.1, "White Blast Cleaning" for immersion service or SSPC-SP 10/NACE No. 2, "Near White Blast Cleaning" for all other service. In certain situations, an alternate procedure may be to use high- (>5,000 psi) or ultrahigh- (>10,000 psi) pressure water cleaning, or water cleaning with sand injection and an approved rust inhibitor. The resulting anchor profile shall be 2.5 to 5.0 mils and be relative to the coating thickness specified. **Concrete and Masonry** surfaces must be sound and contaminant-free, with a surface profile equivalent to a CSP2 to CSP5 in accordance with ICRI Technical Guideline No. 03732. This can generally be achieved by abrasive blasting, shot blasting, high-pressure water cleaning, water jetting, or a combination of methods. Concrete exhibiting a moisture vapor emission rate greater than 3 lbs/1,000 ft^2/24 hours, when tested according to ASTM F1869, shall be primed with Raven 155 as recommended by RLS Solutions. **Repair and patching.** Areas with rebar exposed are repaired in accordance with the project engineer's recommendations. At a minimum, the areas are prepared via abrasive blasting according to SSPC-SP10 prior to coating. Repair products are used to fill voids, holes, and other surface defects. Resurfacing products are used to repair, smooth, or rebuild surfaces with rough profiles. Surfaces must be cleaned of oil, grease, rust, scale, deposits, and other contaminants.
V. Costs	
Key Cost Factors	Manhole/pipe cleaning and dewatering, repairs prior to applying the coating, and surface preparation; cost of materials.
Case Study Costs	• In Dallas, TX: Approximately $1,800/manhole for repair of 48" manholes that are 5 to 6 feet deep on average (the cost includes manhole cleaning, repairs with cement grout, and Raven 405). Approximately $100 to $140/VF (Raven 405 only) • In Tulsa, OK: approximately $13/SF (Raven 405 only)
VI. Data Sources	
References	• www.rlssolutions.com and product information

Datasheet A-62. Saertex-Liner® CIPP

Technology/Method	**Saertex-Liner® /CIPP**
I. Technology Background	
Status	Emerging
Date of Introduction	Europe in 1996/US since 2007
Utilization Rates	2008: about 100 miles
Vendor Name(s)	**Saertex multiCom® GmbH** Brochterbecker Damm 52 D-48365 Saerbeck Germany Phone +49 2574 902-400 Email: multicom@saertex.com Website: www.saertex-multicom.de **SAERTEX multiCom LP** 12249 Mead Way Littleton, CO 80125 Phone: (866) 921-5186 Email: multicom@saertex.com Website: www.saertex-multicom.de
Practitioner(s)	DIRINGER & SCHEIDEL Rohrsanierung GmbH & Co. KG Branch Oldenburg/Mr. Richard Mohr Donnerschweer Straße 82 26123 Oldenburg Phone: +49 441 2096410 C&L Water Solutions, Inc. Mr. Larry Larsson 12249 Mead Way Littleton, CO 80125 Phone: (303) 791-2521 Kleen GmbH Umwelt & Kanaltechnik Mr. Uwe Rieken Böttcherstraße 4 26506 Norden Phone: +49 4931 97207-0
Description of Main Features	The structural portion of the liner is made of several layers of Advantex® (ECR glass) glass-fiber reinforcement that is manufactured by SAERTEX multiCom. An inner film (styrene-tight) serves as an aid to installation and is removed immediately following the curing process. An external styrene tight film is outside the structural layer complex, followed by an opaque film that protects against UV exposure and damage during insertion. The liner is winched in after placement of a sliding film along the invert of the host pipe. Two types of resins can be used: a polyester resin or a vinylester resin for industrial sewage. The liner can be either UV-cured or steam-cured (catalyst is included for steam-curing option).
Main Benefits Claimed	• High tensile strength in both radial and axial directions due to glass fiber-reinforcement. Handle winching forces. • Excellent material data, like an e-modulus of 1.740 x 10^6 psi = static needs, are achieved with thin-wall thickness. • 1/10th the thermal shrinkage of an ordinary polyester felt-reinforced liner, resulting in annular gap normally less than 0.5%. • Higher long-term modulus than felt liners. • Cure with either UV or steam. • Liner can be placed into service directly after completion of curing process and re-opening of the laterals. • Circular, egg-shaped or box sections can be accommodated.

Technology/Method	**Saertex-Liner® /CIPP**
Main Limitations Cited	- More expensive than polyester felt material - Hose liners are produced in Germany and shipped to the U.S. warehouse of SAERTEX multiCom LP
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other: Storm Water Pipes
II. Technology Parameters	
Service Application	Gravity Sewer, Stormwater Pipes
Service Connections	Service connections reinstated same as conventional CIPP liners.
Structural Rating Claimed	Semi-structural to fully structural. The Saertex-S-Liner and Saertex-M-Liner have the following short-term flexural properties: Saertex-S Saertex-M Flexural strength, psi 36,250 29,000 Flexural modulus, psi 1.740 x 10^6 1.015 x 10^6 The S-Liner has a diminution factor of 1.35 for calculating the long-term flexural modulus.
Materials of Composition	Advantex® (ECR glass) glass fiber from Owens Corning. Polyester resin from DSM and Scott Bader. Vinylester resin from NRC.
Diameter Range, inches	6 inches to 48 inches (150 mm to 1200 mm)
Thickness Range, inches	0.118 to 0.472 inches (3 mm to 12 mm)
Pressure Capacity, psi	Not stated in literature.
Temperature Range, °F	Not stated in literature.
Renewal Length, feet	Hose liners up to 1,640 feet (500 meters).
Other Notes	Not available
III. Technology Design, Installation, and QA/QC Information	
Product Standards	EN 13566, Part 4
Design Standards	ATV-M 127, Part 2, NSF 14
Design Life Range	70 years based on 20,000-hour stress rupture testing
Installation Standards	DIN EN 1610
Installation Methodology	Sewer lines need to be cleaned and TV-inspected before start of work. A sliding film is inserted along invert to facilitate installation and packing heads are installed at the ends of the liner. The liner is drawn into the existing pipe and then inflated using compressed air. The liner is then cured with either UV light or steam, depending on resin type chosen. The curing process is computer-controlled. After curing, the packing heads are removed and the inner film removed. Tightness testing can be made at this point. Approximately 4 hours after curing, laterals or service connections can be reinstated, using conventional methods and the line returned to service.
QA/QC	Host pipe CCTV-inspected prior to lining. After lining, another CCTV inspection is necessary to confirm that there are no wrinkles, delamination, or foreign objects (defects) in the liner. Samples, per ASTM F1743, should be obtained and tested for wall-thickness, flexural, and tensile properties. Exfiltration tests for gravity pipes, with a maximum limit of 50 gal/in diameter/mile/day, and pressure testing to either twice the working pressure or working pressure plus 50 psi, whichever is less, is recommended in ASTM F1743. Allowable leakage for pressure test is 20 gal/in diameter/mile/day.
IV. Operation and Maintenance Requirements	
O&M Needs	Not available
Repair Requirements for Rehabilitated Sections	Not available

V. Costs	
Key Cost Factors	Not available
Case Study Costs	For example, for 8 inches = approximately $14/feeet material, chemicals, foil, glass fiber and approximately $12/feet installation, cleaning, mobilization
VI. Data Sources	
References	Trenchless Technology International, Pumper & Cleaner Magazine

Datasheet A-63. Sanipor™ Flood Grouting

Technology/Method	**Sanipor /Flood grouting of mainlines, laterals, and manholes**
I. Technology Background	
Status	In U.S., still innovative
Date of Introduction	Developed in Hungary in 1987. Offered in U.S. for a limited time in early 1990s and again since 2005. Also used in Canada, Europe, Australia, New Zealand.
Utilization Rates	By 2005, approximately 20,000 lf of mainline sewer rehabilitated in U.S. and over 700,000 lf in other countries, mostly in the UK and Germany.
Vendor Name(s)	**Sanipor, Ltd.** A- 2500 Baden bei Wien, Albrechtsgasse 5, Austria Phone: 011-43-2252-253062 Email: Sanipor@t-online.de office@sanipor.com Website: www.sanipor.com
Practitioner(s)	• Petrochemical plant in Corpus Christi, TX, Tom Gillette P.E., a *consultant for a petrochemical client*, (832) 407-0228, info@tegconsultants.com (approximately 600 LF of mainline, 13 laterals and 8 manholes sealed in 2008) • City of Mequon, WI (Milwaukee Sanitary Sewer District), Mark Lloyd, (262) 242-9655, mlloyd@ci.mequon.wi.us and Andy Lukas, Brown and Caldwell, (414) 203-2901, alukas@brwncald.com, a consultant for the City (approximately 3,600 LF of mainline, 26 laterals, and 14 manholes sealed in 2007) • City of Sarasota, FL, Dan Castorani, (941) 365-2200, ext 6250, dan_castorani@sarasotagov.com and Paul Lewis, a consultant for the City, Plewis@stantec.com (2006) • Lafayette Utilities System, LA, Steve Rainey (retired) and Janet Menard, 337-291-5887, jmenard@lus.org (a demo project sealing 1,400 feet of mainline, 1,750 feet of laterals, and 7 manholes in 2003) • City of St. Petersburg Beach, FL , Michael Lucas, Malcolm Pernie, Tampa, FL, (813) 248-6900 (3,286 LF of gravity mainline, 98 laterals, 16 manholes, 1 lift station sealed in 1992); re-inspection 2002 • Thames Water Plc, UK, Charlotte Howes, 44 (118) 923-6238, Charlotte.Howes@thameswater.co.uk and Dec Downey, Jason Consultants, 44 (148) 086-0899, dec.downey@jasonconsult.com (approximately 12,000 feet of mainline and 6,000 feet of laterals sealed in 1989) • City of Berlin, Germany, Fereste Sedehizade, 49-308-644-5538, Fereshte.Sedehizade@bwb.de (approximately 6,600 feet of mainlines and 3,000 feet of laterals sealed in 1994 and 1997)
Description of Main Features	A geotechnical method of sealing manholes, mainlines, and full length of laterals simultaneously in one setup utilizing hydrostatic pressure for the injection sealing process comparable to a hydro (water exfiltration) test. Two proprietary chemical solutions are consecutively applied to "flood" an isolated section of sewer and exfiltrate through defects in pipes and manholes into the soil, where they chemically react with each other. The cured grout with the soil aggregate creates a watertight sandstone-like silicate envelope around the leaks. The method eliminates infiltration and exfiltration and improves the embedding, but does not repair the structure of broken pipes.
Main Benefits Claimed	• Eliminates infiltration "everywhere" at the same time, while liquids under hydrostatic pressure find their way through all leaks. • Sanipor will seal any type of pipe, any material, any shape and sizes up to 22 inches in diameter. Suitable in situations where other repair methods might be impossible or unfeasible, e.g. branching service laterals; oily contaminated soil, saltwater infiltration, sand migration (infiltration). • Stops biogenic sulfur corrosion, reduces root growth. • Maintains full pipe capacity. • Creates a support base for the pipes and manholes due to the soil-stabilizing effect of the injections.

	• The chemicals used are environmentally friendly. • The chemicals are reusable and storable. • Sanipor appears to be much less costly than lining or replacing of complete conveyance systems while sealing all parts of an isolated length section in 1 day to 99%. • The disturbance to homeowners is minimal (most construction activity on the street during daytime). • Municipalities can train their in-house crews to apply flood grouting technology for maintenance of their sewers
Main Limitations Cited	• Does not structurally repair damaged pipes. Hence, not suitable for pipes that are broken, heavily cracked, distorted, and have missing parts. • Soil has to have aggregates and porosity; i.e., not for pipes in concrete bedding (walls, floor slabs) or in areas with (coral) caves. • Initial small "pilot projects" are not cost-effective because the volume of materials for flooding one section is bigger than the injected losses. Only larger installations (from 10 MH to MH segments or greater) will amortize the initial investment in flooding material in short time. (see also: Cost Factors) • Sewer service contractors in U.S. have been reluctant to commit to Sanipor because the technology needs a new and different kind of project planning, calculation, and (bid) specification. Education of future clients is indispensable. • Legal aspects of pipe ownership. • Municipal vs. private laterals
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other:____________________________
II. Technology Parameters	
Service Application	Gravity pipes, septic tanks, industrial sedimentation basins
Service Connections	Sealed at the same time
Structural Rating Claimed	No structural repair of pipe materials claimed. The method improves soil envelope around the pipes.
Materials of Composition	The S1 chemical is a sodium silicate (SiO_2*Na_2O) ("water glass") solution. The S2 chemical is a silicic acid solution.
Diameter Range, inches	Up to 22 inches (this limit comes from economical considerations, but is not an applicability restraint)
Thickness Range, inches	Not applicable
Pressure Capacity, psi	Not applicable
Temperature Range, ^{o}F	Solutions between 50^{o} and 90^{o}F
Renewal Length, feet	In practice, the maximum volume of each vacuum tank truck (i.e., their maximum street load limit) of 5,000 gal may limit the length of pipes.
Other Notes	Sanipor requires a holistic approach to eliminate infiltration from the entire conveyance system. Can be applied in combination with other structural rehabilitation methods.
III. Technology Design, Installation, and QA/QC Information	
Product Standards	DIBT (Deutsches Institut für Bautechnik) Z-42.3-11 WRc PT/256/0806 (Assessment of the Sanipor system)
Design Standards	None
Design Life Range	70 years and more (WRc 2004) Field testing since 1992 in Florida, re-inspection results in 2002. Pipes under permanent tide (and low) since 1992.
Installation Standards	See Product Standards

Installation Methodology	A section of sewer (e.g., one or two manholes, a mainline, and connecting laterals) is plugged. The flood grouting is performed in four steps: • Step 1—The section is completely filled with the solution S-1 though one manhole (the liquid level is brought up to the street level). This creates the necessary hydrostatic head for the injection of S-1 through the defects into the soil. While the level of S-1 is gradually sinking, the liquid is being refilled (once or several times) up to street level in order to maintain the hydrostatic head required for exfiltration. • Step 2—After a certain time, S-1 is pumped out completely and all pipes are flushed with water (the laterals with the help of buckets and the mainline with a quick interim flush of water with the jetting truck). • Step 3—Next, the section is completely filled with the solution S-2 from its tanker in the same manner as the solution S-1. In the soil, the two components react with each other and the soil particles, and an isolating watertight layer is created around the leaks. Thus, a soil stabilization takes place. • Step 4—After a certain time, S-2 is pumped out and all pipes are flushed with water.
Qualification Testing	• Chemical and mechanical properties (e.g., adhesion strength, water tightness, chemical stability, durability) (Hungarian Academy of Natural Sciences, 1987-1998) • Toxicology (Institute of Hygiene, Gelsenkirchen, 1992) • Environmental and technological approval (German Institute for Construction Technologies, 1992) • UK approval (WRc, 2006)
QA/QC	Hydrostatic (exfiltration) testing “before and after” installation (which is an integral part of technology application) confirms the water-tightness indicates the accomplished effectiveness of rehabilitation. Only trained and licensed installers are authorized to perform the rehabilitation
IV. Operation and Maintenance Requirements	
O&M Needs	Installation according to the training instructions and method statements described in Sanipor operations manual provided by licensor.
Repair Requirements for Rehabilitated Sections	Careful initial investigations (mapping, CCTV) and preparations (e.g., cleaning, root removal, cleanout installation) of all relevant parts of the pipe system needed. In case any structural repair of pipe is needed, it should be done prior to Sanipor sealing.
V. Costs	
Key Cost Factors	• Cost of chemicals (depends on quantities needed; i.e., condition of pipes and soil porosity) • Cost of labor (depends on who does the work, whether the equipment is rented or owned, etc.).
Case Study Costs	• $73,000 for 1,400 feet in mainlines, 1,750 feet of laterals, and 7 manholes, in Sarasota, FL (2003). Note: Pilot projects are usually more expensive than projects that follow because chemicals must be purchased in selling volumes and they end up with left-over quantities after the projects are completed. Established regional installers can charge only for the injected amounts of chemicals and keep the leftover volumes for future uses. • The ballpark for daily fixed costs (labor, equipment) is $4,000 daily and for chemicals between $8/feet (in 4” pipes) and $135/feet (in 48” manholes) (manufacturers’ quote).

VI. Data Sources	
References	• WERF, 2006. Methods for Cost-Effective Rehabilitation of Private Lateral Sewers, 02CTS5, Water Environment Research Foundation, Alexandria, VA, 436 p. • www.sanipor.com • WRc, 2006. Assessment of the Sanipor System - Schedule, PT/256/0806-AS, Aug 2006, WRc Plc, Blagrove, Swindon, UK, 4 p

Datasheet A-64. Sekisui Rib Loc Spiral-Wound Liners

Technology/Method	**SEKISUI Rib Loc Australia Pty Ltd Liners: ROTALOC , SPR™EX, SPR™PE, SPR™ST/Spiral Winding**
I. Technology Background	
Status	Innovative/Conventional
Date of Introduction	Developed in Australia and introduced to the market in the 1980s. Introduced in U.S. between 1983 (**SPR™EX**)and 2005 (**SPR™PE**) Used worldwide: Europe, Asia, Australia, New Zealand, and the Middle East.
Utilization Rates	Over 680 miles of pipeline rehabilitated worldwide over the years. ROTALOC : SPR™EX: SPR™PE: SPR™ST: 24 miles 625 miles 16 miles 23 miles
Vendor Name(s)	**SEKISUI Rib Loc Australia Pty Ltd (SRLA)** Gepps Cross, Australia Website: www.sekisuispr.com.au **CPT USA** Burbank, CA Phone: (818) 845-2394 Email: Jmjfrance@aol.com
Practitioner(s)	• City of Los Angeles, CA, Keith Hanks, (213) 485-1694 (a 260-ft-long box culvert, 156”×64” (W×H), in Hyperion Treatment Plant, was rehabilitated in 2004) • County Sanitation Districts of Los Angeles, CA, Anthony Howard, Whittier, CA, (562) 699-7411, ext. 1603 (approximately 5,000 feet of 114” semi-elliptical pipe and 518 feet of 78” semi-elliptical pipe were rehabilitated in 2005-06) • Northeast Ohio Regional Sewer District, OH, David Mast, NTH Consultants, Ltd, 216-344-4022 (1,300 feet of circular liner between 42” and 54” was installed inside a 60” pipe in 2006-07) • Harris County, TX, Glen Crawford, Troy Construction, (281) 437-8214, (362 feet of 42” liner was rehabilitated in 2007) • DeKalb County, GA, Nancy Smith, (404) 297-2568 (190 feet of 84” pipes and 50 feet of 72” pipe were rehabilitated in 2008)
Description of Main Features	Pipe liner fabricated inside a deteriorated pipe from a continuous thermoplastic strip by spiral winding. The systems consist of either PVC ribbed profile strip with interlocking edges or HDPE ribbed profile strip joined by an extruded HDPE weld. SPR™PE and SPR™ST are “fixed-diameter” liners that are wound with annular space between the host pipe and the liner, which is subsequently grouted with cementitious grout. SPR™EX is a “close-fit” liner made in two-step installation. The liner is first wound into the existing pipe at a diameter smaller than the existing pipe and is next progressively radially expanded by mechanical means to tightly fit the pipe. ROTALOC is also a “close-fit” liner spirally wound into the existing pipe by a patented winding machine that installs the pipe behind it as it traverses the pipeline.
Main Benefits Claimed	• No pipe storage onsite is required • Capable of accommodating large-radius bends • Bypass flow is typically not required • No excavation is required • Quick and quiet installation • Mechanical installation process without chemical processes, controlled site QA, environmentally safe (no Styrene, contaminated process waters to dispose of) ROTALOC SPR™EX SPR™PE SPR™ST

<table>
<tr><th>Technology/Method</th><th>SEKISUI Rib Loc Australia Pty Ltd Liners: ROTALOC , SPR™EX, SPR™PE, SPR™ST/Spiral Winding</th></tr>
<tr><td></td><td><table>
<tr><td>Structural liner</td><td>×</td><td>×</td><td>×</td><td>×</td></tr>
<tr><td>Corrosion resistance</td><td>×</td><td>×</td><td>×</td><td>×</td></tr>
<tr><td>Leak-tight</td><td>×</td><td>×</td><td>×</td><td>×</td></tr>
</table></td></tr>
<tr><td>Main Limitations Cited</td><td>• Reduction in flow area, but flow capacity recovered
• Ends of relined pipe require watertight sealing
• Grouting of annular space is required for “fixed-diameter” liners.
• Sharp changes of direction require bend fabrication or excavation.</td></tr>
<tr><td>Applicability
(Underline those that apply)</td><td>Force Main Gravity Sewer Laterals Manholes Appurtenances
Water Main Service Lines Other:___________________________</td></tr>
<tr><td colspan="2">II. Technology Parameters</td></tr>
<tr><td>Service Application</td><td>Wastewater, stormwater, raw water, industrial.</td></tr>
<tr><td>Service Connections</td><td>Ancillary operations, such as opening service connections and sealing the ends of the liner, are common with existing lining technologies</td></tr>
<tr><td>Structural Rating Claimed</td><td>Fully structural</td></tr>
<tr><td>Materials of Composition</td><td><table>
<tr><td>ROTALOC :</td><td>SPR™EX:</td><td>SPR™PE:</td><td>SPR™ST:</td></tr>
<tr><td>PVC strip</td><td>PVC strip</td><td>HDPE and steel</td><td>PVC and steel</td></tr>
</table>
The extruded profile strip has the following minimum physical properties:
<table>
<tr><th>Property</th><th>ROTALOC</th><th>SPR™EX</th><th>SPR™PE</th><th>SPR™ST</th></tr>
<tr><td>Tens. Strength, psi</td><td>7,000</td><td>7,000</td><td>2,600-<3,000</td><td>7,000</td></tr>
<tr><td>Tens. Modulus, psi</td><td>400,000</td><td>400,000</td><td>-</td><td>400,000</td></tr>
<tr><td>Flex. Strength, psi</td><td>7,000</td><td>7,000</td><td>-</td><td>7,000</td></tr>
<tr><td>Flex. Modulus, psi</td><td>400,000</td><td>400,000</td><td>80,000 -110,000</td><td>400,000</td></tr>
<tr><td>Cell Classification</td><td>13,454</td><td>13,454</td><td>334,320C or*</td><td>13,454</td></tr>
</table>
* as per ASTM D 3350</td></tr>
<tr><td>Diameter Range, inches</td><td><table>
<tr><td>ROTALOC :</td><td>SPR™EX:</td><td>SPR™PE:</td><td>SPR™ST:</td></tr>
<tr><td>32” to 72”</td><td>6” to 30”</td><td>36” to 120”</td><td>18” to 108”</td></tr>
</table></td></tr>
<tr><td>Thickness Range, inches</td><td><table>
<tr><td>ROTALOC :</td><td>SPR™EX:</td><td>SPR™PE:</td><td>SPR™ST:</td></tr>
<tr><td>0.826” to 1.46”</td><td>0.275” to 0.787”</td><td>0.787” to 1.57”</td><td>0.787” to 0.984”</td></tr>
</table></td></tr>
<tr><td>Pressure Capacity, psi</td><td>Not pressure-rated</td></tr>
<tr><td>Temperature Range, °F</td><td>HDPE and PVC profiles can become difficult to work with at lower temperatures. Therefore, the working temperature should be maintained in excess of 59°F (15°C), as higher temperatures will make the installation process easier (please consult manufacturer for further information).</td></tr>
<tr><td>Renewal Length, feet</td><td>The maximum length able to be wound is dependent on several variables and project specifics. The following lengths have to be achieved:
<table>
<tr><td>ROTALOC :</td><td>SPR™EX:</td><td>SPR™PE:</td><td>SPR™ST:</td></tr>
<tr><td>175 ft</td><td>430 ft</td><td>440 ft</td><td>212 ft</td></tr>
</table></td></tr>
<tr><td>Other Notes</td><td></td></tr>
<tr><td colspan="2">III. Technology Design, Installation, and QA/QC Information</td></tr>
<tr><td>Product Standards</td><td>ASTM F1697, Standard Specification for Poly (Vinyl Chloride) (PVC) Profile Strip for Machine Spirally-Wound Liner Pipe rehabilitation of Existing Sewers and Conduit.</td></tr>
<tr><td>Design Standards</td><td>ASTM F1741, Standard Practice for Installation of machine Spiral Wound Poly (Vinyl Chloride) (PVC) Liner Pipe for Rehabilitation of Existing Sewers and Conduits, Appendix X.1</td></tr>
<tr><td>Design Life Range</td><td>50 years</td></tr>
<tr><td>Installation Standards</td><td>ASTM F1741 Standard Practice for Installation of machine Spiral Wound Poly (Vinyl Chloride) (PVC) Liner Pipe for Rehabilitation of Existing Sewers and Conduits.</td></tr>
</table>

Technology/Method	**SEKISUI Rib Loc Australia Pty Ltd Liners: ROTALOC , SPR^{TM}EX, SPR^{TM}PE, SPR^{TM}ST/Spiral Winding**
Installation Methodology	Winding machine can be stationary (positioned in the manhole) or mobile (traversing through the pipe). ROTALOC . The machine rotates as it moves along the old pipeline, installing a continuous structural liner close fit against the old pipeline wall for the length required, depending on the supply of power and profile. Bends and offsets are negotiated by remote control. Ancillary operations, such as opening service connections and sealing the ends of the liner, are common with existing lining technologies. SPR^{TM}EX. The installation equipment positioned in the access point spirally winds out the pre-manufactured liner at a diameter small enough to pass through the old pipeline. When the liner reaches the next access point, the installer is radially expanded by mechanical means to contact the wall of the existing pipe, while maintaining a circular cross section (with up to 5% deflection). SPR^{TM}PE. The installation equipment positioned in the access point spirally winds SPR^{TM}PE as a fixed-diameter liner slightly smaller than the host pipe, with an annular space to be grouted after the lining process. SPR^{TM}ST. The installation equipment positioned in the access point spirally winds SPR^{TM}ST as a fixed-diameter liner slightly smaller than the host pipe, with an annular space to be grouted after the lining process.
Qualification Testing	• Joint leak tightness (Ramtech Laboratories, Paramount, CA, 1998; Rib Loc Australia Pty Ltd, 2000) • Abrasion resistance (MPA NRW Lab, Dortmund, Germany, 1988) • Long-term abrasion resistance (Duncan Tool & Gauge Pty Ltd, Australia, 1997) • Hydraulic roughness (University of South Australia, 1990) • Flow properties of annular space (Rib Loc Australia Pty Ltd, 2001) • Chem. resistance and tensile properties (City of Los Angeles, CA, 1995) • Long-term modulus of elasticity (Amdel Limited, Australia, 1998)
QA/QC	The processes SRLA uses to verify product quality and consistency are independently certified to ISO 9001 (pressure, vacuum, stiffness, mechanical property, and chemical-resistance testing)
IV. Operation and Maintenance Requirements	
O&M Needs	No special requirements
Repair Requirements for Rehabilitated Sections	No special requirements
V. Costs	
Key Cost Factors	Host pipe preparation; mobilization; site setup and access; winding time; grouting (when required)
Case Study Costs	Not available
VI. Data Sources	
References	www.ribloc.com

Datasheet A-65. Sekisui SPR™ Spiral-Wound Grout-in-Place Liner

Technology/Method	**SPR™ Spiral Wound/Spirally wound grout-in-place liner**
I. Technology Background	
Status	Innovative
Date of Introduction	Developed in Japan in mid-1980s; introduced in U.S. in 2004 Used worldwide.
Utilization Rates	Over 200 miles of pipeline rehabilitated worldwide over the past 20 years.
Vendor Name(s)	**SEKISUI Rib Loc Australia Pty Ltd (SRLA)** Gepps Cross, Australia Website: www.sekisuispr.com.au **CPT USA** Burbank, CA Phone: (818) 845-2394 Email: Jmjfrance@aol.com
Practitioner(s)	• City of Los Angeles, CA, Keith Hanks, (213) 485-1694 (a 260-ft-long box culvert, 156”×64” (W×H), in Hyperion Treatment Plant, was rehabilitated in 2004) • County Sanitation Districts of Los Angeles, CA, Anthony Howard, Whittier, CA, (562) 699-7411, ext. 1603 (approximately 5,000 ft of 114” semi-elliptical pipe, and 518 ft of 78” semi-elliptical pipe, were rehabilitated in 2005-06) • Northeast Ohio Regional Sewer District, OH, David Mast, NTH Consultants, Ltd, 216-344-4022 (1,300 ft of circular liner between 42” and 54” was installed inside a 60” pipe in 2006-07) • Harris County, TX, Glen Crawford, Troy Construction, (281) 437-8214 (362 ft of 42” was rehabilitated in 2007) • DeKalb County, GA, Nancy Smith, (404) 297-2568 (190 ft of 84” pipes and 50 ft of 72” pipe was rehabilitated in 2008)
Description of Main Features	A rigid PVC wall liner, spirally wound inside an existing pipe and grouted in place. A specially designed winding and locking machine operating inside the pipe is used for winding, and support jacks serve as a spacer to the inner surface of the host culvert pipe to create annular space filled with high-strength cementitious grout. The grout used is highly thixotropic (no dripping), has strong adhesion to existing pipe and liner, small drying shrinkage, and little segregation in water. The grout is the primary structural element.
Main Benefits Claimed	• Ideal for large-diameter circular and noncircular pipeline renewal projects • Can be installed in live-flow conditions (bypass flow is not required) • Negotiates bends (radius = diameter ×7) • Structural liner • Excellent abrasion resistance • Excellent corrosion resistance • Stops infiltration • Improved flow capacity • No pipe storage onsite is required • No excavating required • Small installation footprint • Quick and quiet installation
Main Limitations Cited	• Reduction in flow area, but flow capacity recovered • Ends of relined pipe require watertight sealing • Grouting of annular space • Man-entry
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other:____________________________
II. Technology Parameters	
Service Application	Wastewater, stormwater, raw water, industrial, power

<table>
<tr><th>Technology/Method</th><th>SPR™ Spiral Wound/Spirally wound grout-in-place liner</th></tr>
<tr><td>Service Connections</td><td>Ancillary operations such as opening service connections and sealing the ends of the liner, are common with existing lining technologies</td></tr>
<tr><td>Structural Rating Claimed</td><td>Fully structural</td></tr>
<tr><td>Materials of Composition</td><td>The profile strip is PVC.

Grout used is a thixotropic high strength compressive grout. The extruded profile strip and the grout have the following minimum physical properties :

<table>
<tr><th>Property</th><th>SPR^{TM}</th></tr>
<tr><td>Tensile strength, psi</td><td>6,000 psi</td></tr>
<tr><td>Tensile modulus, psi</td><td>360,000 psi</td></tr>
<tr><td>Flexural strength, psi</td><td>n/a -</td></tr>
<tr><td>Flexural modulus, psi</td><td>n/a</td></tr>
<tr><td>Cell classification</td><td>12,344 or higher</td></tr>
<tr><td>Property</td><td>Grout</td></tr>
<tr><td>Compression strength after 28 days</td><td>5,000 psi minimum</td></tr>
<tr><td>Strength after curing 7 days</td><td>2,800 psi</td></tr>
<tr><td>Strength after curing 21 days</td><td>4,900 psi</td></tr>
</table></td></tr>
<tr><td>Diameter Range, inches</td><td>32” to 197” (circular) and up to 12’×15’ or larger (non-circular shapes)</td></tr>
<tr><td>Thickness Range, inches</td><td>Ribbed profiles – rib height varies between 1/3 inch and 1.25 inches</td></tr>
<tr><td>Pressure Capacity, psi</td><td>Short-term testing of up to 80 psi done to date – projects considered on a case-by-case basis.</td></tr>
<tr><td>Temperature Range, °F</td><td>Deflection temperature under load 158º F (264 psi)</td></tr>
<tr><td>Renewal Length, feet</td><td>1,000 feet and longer</td></tr>
<tr><td>Other Notes</td><td>The composite design of SPR utilizes the steel reinforcement and the structural grout to produce a fully structural liner. As such, the flexural properties of the PVC material are not important in the design of the product. Tensile properties have been confirmed in order to determine the cell classification of the material for specification purposes.</td></tr>
<tr><td colspan="2">III. Technology Design, Installation, and QA/QC Information</td></tr>
<tr><td>Product Standards</td><td>ASTM F1697 - 09 Standard Specification for Poly(Vinyl Chloride) (PVC) Profile Strip for Machine Spiral-Wound Liner Pipe Rehabilitation of Existing Sewers and Conduit</td></tr>
<tr><td>Design Standards</td><td>Per ASTM F1741. Finite-element analysis design may be required per ASTM F1741 Clause X1.3.</td></tr>
<tr><td>Design Life Range</td><td>50 years</td></tr>
<tr><td>Installation Standards</td><td>ASTM F1741 - 08 Standard Practice for Installation of Machine Spiral Wound Poly (Vinyl Chloride) (PVC) Liner Pipe for Rehabilitation of Existing Sewers and Conduits.</td></tr>
<tr><td>Installation Methodology</td><td>A winding machine is first installed (a custom-form frame designed for interior dimensions of pipe is built inside the pipe), and the liner is wound (a roller system travels around the frame locking the SPR profile into place). Next, the winding machine is removed, internal bracing (support jacks) is installed, and bulkheads are constructed at the upstream and downstream sections. Grout is injected. The support jacks prevent the profile from floating and collapsing during injection of the grout. After grout has set, the jacks are removed.</td></tr>
<tr><td>Qualification Testing</td><td>ASTM F1697, Greenbook, Construction Engineering Evaluation Certification (Sewer Systems Technology) Report – Tokyo Metropolitan Sewage Service Corporation.</td></tr>
<tr><td>QA/QC</td><td>Pressure and vacuum testing</td></tr>
<tr><td colspan="2">IV. Operation and Maintenance Requirements</td></tr>
<tr><td>O&M Needs</td><td>Routine maintenance as required by agency</td></tr>
</table>

Technology/Method	**SPR™ Spiral Wound/Spirally wound grout-in-place liner**
Repair Requirements for Rehabilitated Sections	Obstructions and projecting points in the existing pipe are mitigated. Buildup of grease and other foreign matter is removed from walls, as well as all loose tiles and aggregate by hydro-blasting. Inverts of existing pipe are repaired, if necessary, for the winding machine to run smoothly.
V. Costs	
Key Cost Factors	Scope of work, design requirements, profile and grout/grout installation, including bracing, number of excavation pits, mobilization, pipe cleaning/dewatering, site restoration, flow bypassing, traffic control, lateral sealing.
Case Study Costs	• In Los Angeles, CA: approximately $500 to $600 for 114” SE • Typical installed cost range can be anywhere from $300 per foot installed to $900 per foot installed, based on diameter and site conditions and design requirements.
VI. Data Sources	
References	www.sekisuispr.com

Datasheet A-66. Sewer Shield Manhole Liner

<table>
<tr><th>Technology/Method</th><th>Sewer Shield Composite/Composite manhole inserts</th></tr>
<tr><td colspan="2">I. Technology Background</td></tr>
<tr><td>Status</td><td>Emerging</td></tr>
<tr><td>Date of Introduction</td><td>2001</td></tr>
<tr><td>Utilization Rates</td><td>Approximately 5,000 composite manhole inserts and manholes repaired or rehabilitated since 2001</td></tr>
<tr><td>Vendor Name(s)</td><td>Sewer Shield Composites, LLC
Mesa, AZ
Phone: (480) 986-1485
Email: pvanarkens@jpciservices.com
Website: www.sewershieldcomposites.com</td></tr>
<tr><td>Practitioner(s)</td><td>• City of Phoenix, AZ, Steve Fernandez, (602) 495-0724, steve.fernandez@phoenix.gov (approximately 2500 manholes repaired in the past 12 years)
• Denver Metro Wastewater Dist., Jeff Maier, (303) 286-3285, JMaier@mwrd.dst.co.us, 50+ manholes repaired in last 2 years</td></tr>
<tr><td>Description of Main Features</td><td>Composite manhole inserts made of Sewer Shield 100 epoxy resins are used to build free-standing manholes that are designed and engineered to replace/rehab manholes deteriorated due to corrosion. Inserts vary in length, as needed, providing maximum flexibility. Maximum weight for a 5-ft section is 600 lbs. The sections are easily assembled and aligned and walls may be cut to adjust the heights or allow for penetrations. Special hydrophobic grout is applied in the annular space, forming a watertight seal between the substrate and the exterior wall of the composite insert.</td></tr>
<tr><td>Main Benefits Claimed</td><td>• Maintenance-free solution to recurring manhole repairs/rehabs
• Manufacturer offers the only permanent lifetime corrosion-resistant warranty (98% acid-resistant), earthquake-resistant, water-tight seal between substrate and insert with Flex Grout®
• All repairs done at manhole in less than 8 hrs; no digging of critical and expensive cables (optic, gas, phone, etc.)</td></tr>
<tr><td>Main Limitations Cited</td><td>None</td></tr>
<tr><td>Applicability
(Underline those that apply)</td><td>Force Main Gravity Sewer Laterals <u>Manholes</u> Appurtenances
Water Main Service Lines Other:______________________</td></tr>
<tr><td colspan="2">II. Technology Parameters</td></tr>
<tr><td>Service Application</td><td>Municipal sewer manholes</td></tr>
<tr><td>Service Connections</td><td>Opening for mainlines made with power tools</td></tr>
<tr><td>Structural Rating Claimed</td><td>Fully structural</td></tr>
<tr><td>Materials of Composition</td><td>Composite material consists of epoxy resins with reinforced fiberglass. Annular space grout is filled with hydrophobic, closed-cell foam.

The installed insert has the following minimum physical properties (from manufacturer):

<table>
<tr><th>Property</th><th>Test Method</th><th>Value</th></tr>
<tr><td>Tensile modulus</td><td>ASTM D3753</td><td>1.57×10^6 psi</td></tr>
<tr><td>Shear modulus</td><td>ASTM D3753</td><td>0.357×10^6 psi</td></tr>
<tr><td>Poisson’s ratio</td><td>ASTM D3753</td><td>0.22</td></tr>
<tr><td>Tensile strength</td><td>ASTM D3753</td><td>18700 psi</td></tr>
<tr><td>Flexural strength</td><td>ASTM D3753</td><td>22000 psi</td></tr>
</table></td></tr>
<tr><td>Diameter Range, inches (mm)</td><td>42” (1067 mm), 54” (1372 mm), 60” (1524 mm)</td></tr>
<tr><td>Thickness Range, inches (mm)</td><td>3-layer thickness is 0.56 inches (12 mm)
5-layer thickness is 0.88 inches (23 mm)</td></tr>
<tr><td>Pressure Capacity, psi</td><td>Not available</td></tr>
<tr><td>Temperature Range, °F</td><td>120°F</td></tr>
</table>

Technology/Method	**Sewer Shield Composite/Composite manhole inserts**
Renewal Length, feet	5 to 40 feet (average range of manhole depths)
Other Notes	Not available
III. Technology Design, Installation, and QA/QC Information	
Product Standards	ASTM D3753
Design Standards	Not available
Design Life Range	Lifetime warranty (minimum 100 years)
Installation Standards	Not available
Installation Methodology	The top of the existing manhole is cut off and the interior is sand/hydroblasted to remove any loose materials and corrosion. The bench has already been repaired with C-120 cement and Sewer Shield 100 resin. The first barrel section is then lowered onto the now cured-in-place bench, which serves as the permanent foundation. Each subsequent section is lifted and placed inside the manhole space. After all barrel sections are in place to the bottom of the cone, Flex Grout (a hydrophobic grout) is then poured into the annular space between the insert and the existing manhole, creating a watertight seal between the substrate and the insert. As the sections are stacked, Sewer Shield 100 resin is applied to all joints to provide a monolithic seal between all of the sections; excess material is wiped from the inside seam to provide a smooth finish. Once the sections are fully assembled and the adjustment section has been trimmed to size, the composite Sewer Shield top manhole access section (flat or domed) is nested on top of the composite insert wall. The composite spacer ring and steel manhole cover are then set in place, the top is backfilled (if needed), the pavement is repaired, and the manhole is back in service, all in usually less than 8 hours.
Qualification Testing	• Corrosion resistance, Conlisk Engineering Mechanics Inc., 1/2005 • Mechanical properties, Western Technologies Inc., 6/2005
QA/QC	• Factory testing on-going for each section • Field testing (scaled-down model of insert is available for visual inspection purposes)
IV. Operation and Maintenance Requirements	
O&M Needs	None
Repair Requirements for Rehabilitated Sections	No special requirements
V. Costs	
Key Cost Factors	• Insert size (diameter/depth) and accessibility of manhole • Thickness of insert wall (3-layer vs. 5-layer) • Location from manufacturer's facilities
Case Study Costs	Not available
VI. Data Sources	
References	www.sewershield.com Personal communication

Datasheet A-67. Shotcrete Technologies Cementitious Spray Lining

Technology/Method	**Cementitious Lining/Spray concrete lining system**
I. Technology Background	
Status	Conventional
Date of Introduction	Shotcrete Technologies has been providing services to the industry since 1979. The use of robotic equipment to spray shotcrete within non-person-entry pipes and culverts has been carried out in recent years.
Utilization Rates	Not available
Vendor Name(s)	**Shotcrete Technologies, Inc.** Idaho Springs, CO Phone: (303) 567-4871 Email: kristian@shotcretetechnologies.com Website: www.shotcretetechnologies.com
Practitioner(s)	1. **Tunnel lining**. Ecuador, January 2002. By replacing traditional "form-and-pour" methods with high-production shotcrete, the massive Trasvases Manabi Water Project in Ecuador finished months ahead of schedule. Contractor Norberto Odebrecht, in conjunction with Shotcrete Technologies Inc., of Denver, Colorado, and Commercial Shotcrete Inc., of Phoenix, Arizona, placed over 6,000 cubic meters of shotcrete in less than half the time it would have taken by the specified method. The mix design strength was 24 MPA, and in-place testing produced 32 MPA on average. 2. **Pipe lining**. Colorado. Over 1,000 feet of 2-foot-diameter corrugated pipes were lined for the Colorado Department of Transportation. Over 2,500 feet of 42-inch pipe were lined for the Union Pacific Railroad in Hotchkiss, Colorado. Pumping through 550 ft of 1½-inch concrete hose, the pipe was lined at 400+ ft per day for 6 consecutive days. A severely misaligned 110-ft, 36-inch pipe in Grand Junction, Colorado, was relined for Mesa County in less than 2 hours.
Description of Main Features	Sprayed concrete (shotcrete) lining of tunnels, pipes, culverts, and structures. Both person-entry and robotic-spray operations are possible.
Main Benefits Claimed	Over 50 years of national and international experience. State-of-the-art technologies, including robotic spraying arms, silica fume, fiber-reinforced shotcrete, polymer shotcrete, NATM (New Austrian Tunneling Method), ground support systems, and material transport and handling.
Main Limitations Cited	May be subjected to concrete corrosion in sewer applications.
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other:____________________________
II. Technology Parameters	
Service Application	Wastewater mains, manholes, and appurtenance structures.
Service Connections	For thick layers and small services, may need to prevent plugging.
Structural Rating Claimed	Structural capability against external soil and water pressures.
Materials of Composition	Concrete, plus any additives used to enhance properties and/or ease application.
Diameter Range, inches	Not available
Thickness Range, inches	Not available
Pressure Capacity, psi	Not intended for internal pressure conditions.
Temperature Range, °F	Not available
Renewal Length, feet	Not available
Other Notes	Not available
III. Technology Design, Installation, and QA/QC Information	
Product Standards	ASTM C1116, Standard Specification for Fiber Reinforced Concrete and Shotcrete. ASTM C1140-03a, Standard Practice for Preparing and Testing Specimens from Shotcrete Test Panels ASTM C1141 / C1141M-08, Standard Specification for Admixtures for Shotcrete ASTM C1385/C1385M-98 (2004), Standard Practice for Sampling Materials for

Technology/Method	**Cementitious Lining/Spray concrete lining system**
	Shotcrete ASTM C1436-08, Standard Specification for Materials for Shotcrete ASTM C1604 /C1604M-05, Standard Test Method for Obtaining and Testing Drilled Cores of Shotcrete.
Design Standards	See American Shotcrete Institute, American Concrete Institute and International Tunneling and Underground Space Association
Design Life Range	Not available
Installation Standards	C1140, Standard Practice for Preparing and Testing Specimens from Shotcrete Test Panels.
Installation Methodology	Hand- or robot-spray application in person-entry-size structures. Spray-robot in small-diameter lines.
Qualification Testing	Not available
QA/QC	Mix design and control are critical to the success of a shotcrete product. The specified mix should reflect the desired "in situ" requirements for both initial and final support. When an emphasis is placed on mix design, material-handling equipment, and correct pre-testing prior to producing the shotcrete, problems should be minor. Shotcrete should run smoothly, as long as monitoring of the process by core sampling and test panels take place throughout the length of the job. Typically, mix contains a 30% cementitious material and 70% sand and aggregate. Both should be well-graded and screened because just one rock can clog a shotcrete hose and halt an entire operation. Slump should be as low as possible, depending on distance and pumpability. Plasticizers and water-reducing agents should also be used to modify slump, depending on working conditions. The mix will normally be pumped into a 2-inch shotcrete hose to be applied via a robotic arm or hand-held nozzling. A good pump easily performs 15 to 25 cubic yards per hour, and with proper setup, quality control, and maintenance, the shotcrete process can be continuous.
IV. Operation and Maintenance Requirements	
O&M Needs	No special requirements
Repair Requirements for Rehabilitated Sections	No special requirements
V. Costs	
Key Cost Factors	Not available
Case Study Costs	Not available
VI. Data Sources	
References	www.shotcretetechnologies.com

Datasheet A-68. Spectrashield Spray-Applied Resin Lining for Manholes

Technology/Method	**Spectrashield®/Spray-applied multi-layered polyresin**
I. Technology Background	
Status	Conventional
Date of Introduction	1993
Utilization Rates	2.0 million square feet over the years
Vendor Name(s)	**CCI Spectrum, Inc.** Jacksonville, FL Phone: (904) 268-4951 Email: jsrhyne@ccispectrum.com Website: www.spectrashield.com
Practitioner(s)	• JEA, Jacksonville, FL, Bill Clendenning, (904) 665-4723 • St. Louis MSD-Ron Moore, (314) 768-6388 • Metro Wastewater-Denver, CO, Jeff Maier, (303) 286-3285 • City of Hanover, IN, Scott Williams, (812) 492-2227 • City of Slidell, LA, Donna O'Dell, (985) 646-4270
Description of Main Features	A sprayed-on, multi-layer system for manhole rehabilitation consisting of: (1) silicone-modified polyurea coat (a moisture barrier and adhesion coat, (2) closed-cell polyurethane foam (fills all the voids, eroded areas, holes, and missing mortar joints and restores the surface to its original emplacement), and (3) silicone-modified polyurea (a corrosion barrier).
Main Benefits Claimed	• Restores manhole walls to their original surface levels • Imparts structural strength with its "stress skin panel" effect • Prevents corrosion • Stops groundwater infiltration • Cost-competitive with all coatings and liners on the market today • Can be installed in any shape or configuration
Main Limitations Cited	• Man-entry application • Cannot be applied under 36" in diameter
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other:____________________
II. Technology Parameters	
Service Application	Manholes, wetwells, headworks, grit chambers, clarifiers, aeration basins, chlorine contact chambers, large-diameter pipe
Service Connections	Not applicable
Structural Rating Claimed	Fully structural
Materials of Composition	Silicone-modified polyurea coat is 60 mils minimum thickness. Closed cell polyurethane foam is 400 mils minimum thickness. Typical physical properties of installed liner (based on manufacturer's specifications): Property — Test Method — Value Flexural strength — ASTM C273 — >5,000 psi Tensile strength — ASTM D412 — >3,600 psi Tear strength — ASTM D2240 — >5,450 psi Tensile elongation — ASTM D412 — >300%
Diameter Range, inches	Any
Thickness Range, inches	½" minimum
Pressure Capacity, psi	Not applicable
Temperature Range, °F	Not applied below 15°F
Renewal Length, feet	No limit (manhole depth)
Other Notes	Not available
III. Technology Design, Installation, and QA/QC Information	
Product Standards	ASTM D4541, D412, D2240, D1737, 4060

Technology/Method	**Spectrashield®/Spray-applied multi-layered polyresin**
Design Standards	ASTM D4541, D412, D2240, D1737, 4060
Design Life Range	100-year life design/10-year warranty
Installation Methodology	Existing manhole is first prepared by applying water blasting to remove soils and eroded surfaces. Layers are spray-applied using a spray gun.
Qualification Testing	Applications and performance of coatings on a concrete surface under hydrostatic pressure of 15 psi; chemical resistance and bonding (CIGMAT, University of Houston, TX, Dec 1996)
QA/QC	The applicator must be trained and certified by the manufacturer for the handling, mixing, application, and inspection of the liner system. All materials and installation are furnished by one applicator, who assumes full responsibility for the entire operation.
IV. Operation and Maintenance Requirements	
O&M Needs	No special requirements
Repair Requirements for Rehabilitated Sections	Repairs must be done by a licensed applicator to manufacturer's specifications.
V. Costs	
Key Cost Factors	Manhole size (diameter, depth); Manhole condition; Size and scope of project.
Case Study Costs	Not available
VI. Data Sources	
References	• http://www.spectrashield.com/ • Vipulanandan, C., H.P Ponnekanti and J. Liu, 1996. *Evaluating CCI Spectrum, Inc. Product for Coating Wastewater Concrete and Clay Brick Facilities in the City of Houston*, Report No. CIGMAT/UH 96-7, CIGMAT, University of Houston, TX, December 1996, 65 p.

Datasheet A-69. SprayShield Green #2® Spray-Applied Polyurethane Coating

Technology/Method	**SprayShield Green #2 /Spray-applied polyurethane coating**
I. Technology Background	
Status	Innovative
Date of Introduction	Developed in U.S. in 2009. Also utilized in Singapore and Australia
Utilization Rates	This product is not in use to rehabilitate a structure at this time
Vendor Name(s)	**Sprayroq, Inc.** Birmingham, AL Phone: (205) 957-0020 Email: jgordon@sprayroq.com Website: www.sprayroq.com
Practitioner(s)	None yet
Description of Main Features	Developed by Sprayroq, SprayShield Green #2® is a flexible, 1:1 ratio spray-applied 100% VOC-free polyurethane coating that provides **chemical resistance**, structural enhancement, and infiltration control against all elements that eat away at underground structures. Cure begins in less than 30 seconds. Moments later, the structure can be returned to service. SprayShield Green #2 may be applied in 250-mil lifts; additional lifts can be applied 15 minutes after the first and subsequent passes.
Main Benefits Claimed	• Fast and easy to install • Excellent chemical resistance • VOC-free • Quick cure time • Structural enhancement
Main Limitations Cited	• Structure must be man-accessible • Structure must be dry
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Service Lines Other: Lift Stations, Wet Wells, Tanks, Grit Chambers, Clarifiers, Digesters, Junction Boxes, Tunnels, Secondary Containment, Lagoons
II. Technology Parameters	
Service Application	Sewers, Manholes
	Needs to be plugged or bypassed if in pipe or structure being repaired or rehabilitated
Structural Rating Claimed	This product does not claim to be structural.
Materials of Composition	100% VOC-free polyurethane. SprayShield Green #2 is mixed in a 1:1 ratio proportioned by weight. There is 1 part "B" polyol to 1 part "A" isocyanate. The sprayed liner has the following minimum physical properties (manufacturer's data):

Property	Test Method	Value
Tear strength	ASTM D624	593 pli
Tensile strength	ASTM D638	2983 psi
Elongation	ASTM D638	43%
Water permeation	ASTM E96	1.49
Abrasion (Taber CS17)	ASTM D4060	52.6 mg loss
Hardness, shore D	ASTM D2240	67
Flex modulus	ASTM D790	75,750 psi
Density	ASTM D792	67.5 lbs/cf

Diameter Range, inches	42" and greater on pipes and unlimited on man-entry structures
Thickness Range, inches	Up to 1000 mils or greater in special applications
Pressure Capacity, psi	75,000 psi flex modulus (short-term)
Temperature Range, °F	Operating conditions up to 140°F/60°C
Renewal Length, feet	Unlimited sizes in man-entry, 720' on man-entry conduits (2 access points)

Technology/Method	**SprayShield Green #2 /Spray-applied polyurethane coating**
Other Notes	Complete capability to handle hydrostatic loading, if required. Solvent cleaning (SSPC-SP1) may be necessary for steel. Surfaces to be treated must be cleaned of all oil, grease, rust, scale, deposits, and other debris or contaminants. All resins, including SprayShield Green #2, require a clean and dry substrate for optimal technical performance of the product.
III. Technology Design, Installation, and QA/QC Information	
Product Standards	Not available
Design Standards	Not available
Design Life Range	50-year design life
Installation Standards	Per manufacturer's guidelines
Installation Methodology	The material is sprayed using a 1:1 ratio system through an airless spray gun. The A and B components are mixed within the spraygun's chambers and sprayed on the prepared surface by the Sprayroq Certified Applicator. SprayShield Green #2 begins to gel in about 8 seconds, with a tack-free condition after 1 minute. Within 30 to 60 minutes, the initial cure is completed and the structure is capable of accepting flow while the complete curing continues for the next 4 to 6 hours.
Qualification Testing	• Chemical resistance testing is performed at Sprayroq's Lab. • Texas Research International Company (TRI) conducts the following tests at their research facility: Water permeation–ASTM-E96 method (8/13/09) Tear strength–ASTM-D624 method (5/22/09) Tensile strength–ASTM-D638 method (5/22/09) Elongation–ASTM-D638 method (5/22/09) Abrasion (Taber CS17)–ASTM-D4060 method (5/22/09) • Sprayroq Labs conducts the following tests: Hardness, shore D–ASTM D2240 method (5/13/09) Density–ASTM method (5/13/09)
QA/QC	Licensed installers (Sprayroq Certified Partners, SCP's) are highly trained in proper substrate cleaning and preparation.
IV. Operation and Maintenance Requirements	
O&M Needs	Periodic pressure washes to maintain clean surface, if necessary.
Repair Requirements for Rehabilitated Sections	No special requirements
V. Costs	
Key Cost Factors	• Cost of material (resin, fabric); i.e., pipe length/diameter or manhole depth/diameter) • Labor • Part of country • Amount of surface preparation
Case Study Costs	Not available yet
VI. Data Sources	
References	www.sprayroq.net

Datasheet A-70. SprayWall® Spray-Applied Polyurethane Coating

Technology/Method	**SprayWall /Spray-applied polyurethane coating**
I. Technology Background	
Status	Conventional
Date of Introduction	Developed in U.S. in 1990. Also utilized in Singapore and Australia.
Utilization Rates Need #	Approximately 200,000 structures to date with over 5,000 feet of pipe rehabilitated (man-entry)
Vendor Name(s)	**Sprayroq, Inc.** Birmingham, AL Phone: (205) 957-0020 Email: jgordon@sprayroq.com Website: www.sprayroq.com
Practitioner(s) Need to add how many structures and dates.	• Wayne Schutz, Asst. Manager, Derry Township, PA, wschutz@dtma.com, (717) 566-3237, ext. 312, (717) 497-8026; • Rodney Jones, Construction Program Manager, County of Sarasota, FL, rjones@scgov.net, (941) 232-8295.
Description of Main Features	Developed by Sprayroq, SprayWall® is a durable, 2:1 ratio, spray-applied 100% VOC-free polyurethane coating that provides both structural reconstruction and chemical resistance against all elements that eat away at underground structures. Cure begins in less than 30 seconds. Moments later, the structure can be returned to service. Spraywall may be applied in 350-to 500-mil lifts (depending on substrate); additional lifts can be applied 15 minutes after the first and subsequent passes.
Main Benefits Claimed	• Fast and easy to install • Structural reconstruction • Excellent chemical resistance • VOC-free • NSF approval • Quick cure time
Main Limitations Cited	• Structure must be man-accessible • Structure must be dry
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other: Lift Stations, Wet Wells, Tanks, Grit Chambers, Clarifiers, Digesters, Junction Boxes, Tunnels, Secondary Containment, Lagoons, and Chlorine Contact Chambers.
II. Technology Parameters	
Service Application	Sewers, Manholes
Service Connections	Need to be plugged or bypassed if in pipe or structure being repaired or rehabilitated
Structural Rating Claimed	Tensile strength 7,450 psi; Compression strength 19,000 psi; Flexural modulus of elasticity (Short Term); 735,000 psi; (Long Term), 519,000 psi. Elongation < 4% at break.
Materials of Composition	100% VOC-free polyurethane. Spraywall is mixed in a 2:1 ratio proportioned by weight. There are 2 parts of "B" polyol to 1 part of "A" isocyanate. The sprayed liner has the following minimum physical properties (manufacturer's data): Property — Test Method — Value Flexural modulus — ASTM D790 — 735,000 psi Flexural strength — ASTM D790 — 14,000 psi Long term flex modulus of elasticity — ASTM D2990 — 529,000 psi Compressive strength — ASTM D695 — 19,000 psi Tensile strength — ASTM D638 — 7,450 psi Tensile modulus — ASTM D638 — 425,000 psi Elongation — ASTM D638 — <4% at break

Technology/Method	**SprayWall /Spray-applied polyurethane coating**
	Mannings “N” Factor .009 Abrasion (Taber CS17) ASTM D4060 17.7 mg loss Hardness, shore D ASTM D2240 90 Density 87 lbs./cf
Diameter Range, inches	42 inches and greater on pipes and unlimited on man-entry structures
Thickness Range, inches	Up to 1000 mils or greater in special applications
Pressure Capacity, psi	In unrestrained 3” opening, 250-mil sample tested to 400 psi.
Temperature Range, °F	Operating conditions up to 140°F/60°C
Renewal Length, feet	In man-entry applications, unlimited sizes (720 feet 2 access points in large conduit)
Other Notes	Complete capability to handle hydrostatic loading, if required. Solvent cleaning (SSPC-SP1) may be necessary for steel. Surfaces to be treated must be cleaned of all oil, grease, rust, scale, deposits, and other debris or contaminants. All resins, including SprayWall, require a clean and dry substrate for optimal technical performance of the product.
III. Technology Design, Installation, and QA/QC Information	
Product Standards	Including NSF 61 Listing (for potable water applications)
Design Standards	Thickness Design for Structural- F1216-07b Appdx X1
Design Life Range	50-year design life retaining 70% of flex modulus
Installation Standards	Per manufacturer’s guidelines
Installation Methodology	The material is sprayed using a 2:1 ratio system through an airless spray gun. The A and B components are mixed within the spray-gun chambers and sprayed on the prepared surface by the Sprayroq Certified Applicator. SprayWall begins to gel in about 8 seconds, with a tack-free condition after 1 minute. Within 30 to 60 minutes, the initial cure is completed and the structure is capable of accepting flow while the complete curing continues for the next 4 to 6 hours.
Qualification Testing	• Chemical/Resistance testing is performed at Sprayroq’s Lab. • Texas Research International Company (TRI) conducts the following tests at their research facility: Flexural modulus–ASTM D790 method (4/15/09) Flexural strength–ASTM D790 method (4/15/09) Long term flexural modulus of elasticity–ASTM D2990 method (4/17/05) Compressive strength–ASTM D695 method (3/9/09) Tensile strength–ASTM D638 method (4/5/05) Tensile modulus–ASTM D638 method (4/5/05) Elongation–ASTM D638 method (4/5/05) Mannings “N” Factor (8/30/08) Abrasion (Taber CS17)–ASTM D4060 method (4/25/05)
QA/QC	Licensed Installers (Sprayroq Certified Partners, SCP’s) trained in proper substrate cleaning and preparation.
IV. Operation and Maintenance Requirements	
O&M Needs	Periodic pressure washes to maintain clean surface, if necessary.
Repair Requirements for Rehabilitated Sections	Surface preparation per manufacturer’s guidelines. Surfaces to be treated must be cleaned of all oil, grease, rust, scale, deposits, and other debris or contaminants. All resins, including Spraywall, require a clean and dry substrate for optimal technical performance of the product.
V. Costs	
Key Cost Factors	Cost of material (resin, fabric), i.e., pipe length/diameter or manhole depth/diameter); labor; part of country; and amount of surface preparation.
Case Study Costs	On vertical structures, use the rate of $225 to $500 per VF based on substrate preparation. On large flat-wall structures, use the value of $15/sq. ft. to $35/sq. ft., which again is a function of substrate preparation.
VI. Data Sources	
References	www.sprayroq.net

Datasheet A-71. Sure Grip® Liner

Technology/Method	**Sure Grip liners/Grout-in-place relining**
I. Technology Background	
Status	Conventional
Date of Introduction	1988
Utilization Rates	Not available
Vendor Name(s)	**Agru America, Inc** Georgetown, SC Phone: (800) 373-2478 Email: salesmkg@agruamerica.com Website: www.agruamerica.com
Practitioner(s)	Not available
Description of Main Features	Thermoplastic liner tubes are installed with anchors (V-shaped studs) on the outside of the liner, which serve as a spacer to the inner surface of the host structure, thus creating annular space that is filled with high-strength cementitious grout. The grout is the primary structural element.
Main Benefits Claimed	Not available
Main Limitations Cited	Not available
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other:__________________
II. Technology Parameters	
Service Application	Wastewater, stormwater, raw water
Service Connections	Openings cut after relining
Structural Rating Claimed	Fully structural
Materials of Composition	HDPE and PP
Diameter Range, inches	30-144 inches
Thickness Range, inches	0.082 to 0.5 inches
Pressure Capacity, psi	Not applicable
Temperature Range, °F	Not available
Renewal Length, feet	Up to 3,000 feet
Other Notes	Not available
III. Technology Design, Installation, and QA/QC Information	
Product Standards	Not available
Design Standards	Not available
Design Life Range	Not available
Installation Standards	Not available
Installation Methodology	The liner is installed with the studded side toward the host structure or pipe. The liner is held in place against the host structure while a grout material is pumped into the annular space created by the liner studs. The V-shaped studs become anchored into the grout as it hardens, providing the ability of the liner to resist detachment from the grout.
Qualification Testing	Not available
QA/QC	Not available
IV. Operation and Maintenance Requirements	
O&M Needs	No special requirements
Repair Requirements for Rehabilitated Sections	No special requirements
V. Costs	
Key Cost Factors	Not available
Case Study Costs	Not available
VI. Data Sources	
References	http://www.agruamerica.com/

Datasheet A-72. Tenbusch Culvert Replacement Method

Technology/Method	**Tenbusch Culvert Replacement/Pipe replacement by tunneling**
I. Technology Background	
Status	Innovative
Date of Introduction	2008
Utilization Rates	Not available
Vendor Name(s)	**Tenbusch, Inc.** Lewisville, TX 75057 Phone: (972) 221-2304 Email: info@tenbusch.com Website: http://www.tenbusch.com
Practitioner(s)	Not available
Description of Main Features	An in-line pipe replacement method for man-entry pipes, in which a new pipe is jacked, segment by segment, in place of an existing deteriorated pipe, while simultaneously, within a protective shield, the existing pipe is manually removed in pieces. If pipe upsizing is involved, the face material is excavated as needed. After the new pipe segments are in place, the annular space is grouted.
Main Benefits Claimed	• Ideal for large-diameter circular and noncircular pipeline renewal projects • Replace substantial lengths of existing pipe in one step • Minimal disruption to traffic, buildings, and other utilities. • Avoids sizable surface damage and costly restoration required for trenching methods. • Installs a new pipe • Ability to increase pipe size • Substantial cost saving vs. traditional open-cut construction methods
Main Limitations Cited	• Man-entry • Requires entry and exit pits and excavations at each lateral location. • Reduction in flow area, but flow capacity recovered • Grouting of annular space
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other: Drainage culverts
II. Technology Parameters	
Service Application	Person-entry pipe segments suitable for jacked-pipe replacement
Service Connections	Not available
Structural Rating Claimed	Fully structural
Materials of Composition	Jacking pipe materials available for this method include vitrified clay, polymer concrete, reinforced concrete, and steel pipes. Liner plates are made of steel that can be as thick as 3/8 inch. The plates can be galvanized and coated with different coatings such as tar epoxy.
Diameter Range, inches	36 inches and up (circular) or any man-entry non-circular pipe
Thickness Range, inches	Depends on the selection of the new pipe to be installed.
Pressure Capacity, psi	Depends on the selection of the new pipe to be installed.
Temperature Range, ^{o}F	Depends on the selection of the new pipe to be installed.
Renewal Length, feet	Unlimited
Other Notes	Not available
III. Technology Design, Installation, and QA/QC Information	
Product Standards	Not available
Design Standards	Not available
Design Life Range	Depends on the selection of the new pipe to be installed -- usually 100 years
Installation Standards	Not available

Technology/Method	**Tenbusch Culvert Replacement/Pipe replacement by tunneling**
Installation Methodology	Replacement with jacking pipe: The new pipe is jacked, segment by segment, into place using hydraulic jacks that are located in a jacking pit. A tunnel shield is placed in front of the lead pipe segment. Replacement with liner plate: Liner plate rings, typically 16 inches long, are installed instead of a jacking pipe. Hydraulic cylinders located in the tunnel shield push against the most recently assembled liner plate ring, advancing the shield forward. As the shield advances itself, it creates the space for adding a new ring (a jacking unit is not required, nor a jacking pit). After the liner plate is in place, it can be sliplined with a new concrete pipe, or a wire-mesh-reinforced shotcrete lining can be applied.
Qualification Testing	Depends on the selection of the new pipe to be installed.
QA/QC	Pressure and vacuum testing
	IV. Operation and Maintenance Requirements
O&M Needs	No special requirements
Repair Requirements for Rehabilitated Sections	No special requirements
	V. Costs
Key Cost Factors	Not available
Case Study Costs	Not available
	VI. Data Sources
References	http://www.tenbusch.com

Datasheet A-73. Tenbusch Insertion Method (TIM™)

Technology/Method	**Tenbusch Insertion Method (TIM™)/Pipe replacement by pipe jacking**
I. Technology Background	
Status	Innovative
Date of Introduction	Developed in U.S. in 1998
Utilization Rates	Not available
Vendor Name(s)	**Tenbusch, Inc.** Lewisville, TX 75057 Phone: (972) 221-2304 Email: al@tenbusch.com Website: http://www.tenbusch.com
Practitioner(s)	Not available
Description of Main Features	A unique pipe replacement (pipe bursting) method that jacks (pushes) new pipe in place of the existing deteriorated pipe. The new pipe is jacked, segment by segment, into place using hydraulic jacks that are located in a jacking pit. The system utilizes the column strength of segmented jacking pipe for the newly installed line.
Main Benefits Claimed	• Burst and replace substantial lengths of existing pipe in one step • Minimal disruption to traffic, buildings, and other utilities. • Avoids sizable surface damage and costly restoration required for trenching methods. • Installs a new pipe • Ability to increase pipe size • Substantial cost saving vs. traditional open-cut construction methods
Main Limitations Cited	• Requires entry and exit pits and excavations at each lateral location. • Requires bypass pumping • Reduction in flow area, but flow capacity recovered
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other:___________________________
II. Technology Parameters	
Service Application	Wastewater, stormwater, raw water, industrial, power
Service Connections	Services need to be excavated before bursting and reconnected to the new pipe after bursting and then backfilled.
Structural Rating Claimed	Fully structural
Materials of Composition	Jacking pipe materials available for this method include vitrified clay, polymer concrete, reinforced concrete, and steel pipes.
Diameter Range, inches	4” and up
Thickness Range, inches	Depends on the selection of the new pipe to be installed.
Pressure Capacity, psi	Depends on the selection of the new pipe to be installed.
Temperature Range, ^{o}F	Depends on the selection of the new pipe to be installed.
Renewal Length, feet	Unlimited
Other Notes	Not available
III. Technology Design, Installation, and QA/QC Information	
Product Standards	Depends on the selection of the new pipe to be installed.
Design Standards	Depends on the selection of the new pipe to be installed.
Design Life Range	Depends on the selection of the new pipe to be installed – at least 100 years.
Installation Standards	Depends on the selection of the new pipe to be installed.
Installation Methodology	The new pipe is jacked, segment by segment, into place using hydraulic jacks that are located in a jacking pit. Lead equipment positioned ahead of the new pipe penetrates, fractures, and expands the old pipe. The lead equipment consists of (1) a heavy steel guide pipe, which maintains the alignment within the center of the old pipe, (2) cracker, which fractures the old pipe, (3) cone expander, which radially expands the fractured line into the surrounding soil, (4) front jack, which is a hydraulic

Technology/Method	**Tenbusch Insertion Method (TIM™)/Pipe replacement by pipe jacking**
	cylinder that provides axial thrust to the penetration and compaction pieces, and (5) pipe adapter, which provides a mating surface linking the new pipe to the front jack. The front jack advances the lead equipment into the old pipe, independent of the advance of the new pipe, by using the new pipe as a support column. New pipe segments are jacked behind the lead equipment, piece by piece, in the work pit. The primary jacking unit applies the required thrust to advance the new pipe column as the front jack is allowed to retract. Instrumentation and controls at the operator's control panel in the work pit allow the operator to "feel" the way through the existing pipe as the new pipe column and lead equipment are "inch-wormed" into the existing old line. Upon completion of the line replacement, the lead equipment is disassembled easily inside a typical 4-ft-diameter receiving manhole and the new pipe is jacked into its final position.
Qualification Testing	Depends on the selection of the new pipe to be installed.
QA/QC	Pressure and vacuum testing
	IV. Operation and Maintenance Requirements
O&M Needs	No special requirements
Repair Requirements for Rehabilitated Sections	No special requirements
	V. Costs
Key Cost Factors	Not available
Case Study Costs	Not available
	VI. Data Sources
References	http://www.tenbusch.com

Datasheet A-74. Terre Hill MultiPlexx™ CIP Manhole Liner

Technology/Method	**MultiPlexx™ PVCP/PVCP-F CIPM Liner/Composite CIP**
I. Technology Background	
Status	Innovative
Date of Introduction	Developed in 1998 in USA (first generation; more development and enhancements based on third-party testing and in-house R&D over time)
Utilization Rates	Not available
Vendor Name(s)	**Terre Hill Composites, Inc.** Ephrata, PA Phone: (717) 738-9164 Email: mailto:boberti@terrehill.comboberti@thcomposites.com Website: www.thcomposites.com
Practitioner(s)	• City of Wentzville, MO, Bill Rhoads, (314) 220-4174, (20 manholes rehabilitated from 2007 to 2009) • Township of Upper Saucon, PA, Dan Stahlnecker, (610) 694-8680 (88 manholes rehabilitated from 2006 to 2009) • City of Jersey Shore, PA, Keith Zerby, (570) 398-0104, jssewtrt@comcast.net (54 manholes rehabilitated in 2006) • City of Grand Rapids, MI, Ron Landis, (616) 336-4370, Ron.Landis@kentcounty.org (53 manholes from 2004 to 2009) • City of Napa, CA, Robin Gamble, (707) 258-6000, rgamble@NapaSan.com (5 manholes rehabilitated in 2005)
Description of Main Features	A composite CIP liner system for manhole rehabilitation comprising a PVC layer (as the exposed and therefore first layer of defense), felt, solids epoxies, and structural fiberglass. Each liner is custom-made for a specific structure. All epoxy-carrying fibers are saturated with the two-part epoxy system; the liner is inserted into the manhole, pressurized, and heat cured while pressed against the host structure's substrate with an inflation bladder. This pressurization forces the epoxy into the substrate, creating a deep and penetrating bond at cure.
Main Benefits Claimed	• Monolithic liner that is well-bonded to the host structure. • With the model PVCP-F (fused seam), the liner's innermost surface (the PVC) is completely monolithic when the liner is shipped from the production facility. This includes the floor of the liner. • The whole structure can be lined as one, from MH cover ledge to invert. Typical terminations are either at channel edge at bench or into channel up to invert, and pipe openings. • Stops infiltration/exfiltration • Arrests sewer-gas-induced corrosion of the host structure • Stops root intrusion • Stops ground wash and the typical sink-holes resulting from the root intrusion • Endures freeze-thaw cycles • Suitable for oddly shaped manholes • Suitable as a preventive measure for new structures.
Main Limitations Cited	• Surface preparation (good cleaning) is important, though unlike topical methodologies, a dry substrate is not necessary. • Flow bypass required in some cases. Often flow does not need to be stopped; as a matter of fact, the liner can be cured over active flow passing through in a channel below.
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other: Pump Stations, Wet Wells
II. Technology Parameters	
Service Application	Wastewater, raw water, industrial sewer.
Service Connections	Pipe openings are cut open using reciprocating saws and/or grinder wheels or special cutting bits. All liner terminations are protected with a proprietary two-part silica epoxy.

<table>
<tr><th>Technology/Method</th><th>MultiPlexx^{TM} PVCP/PVCP-F CIPM Liner/Composite CIP</th></tr>
<tr><td>Structural Rating Claimed</td><td>Fully structural (based on compressive strengths and can be specially designed for hydrostatic head pressure)</td></tr>
<tr><td>Materials of Composition</td><td>The installed liner is a complete laminate bonded to the surface, consisting of the following layers (from the surface bonded with the existing manhole to the inside of structure):

(1) Solids epoxy system (permeating through all fibers of the system – all but the outermost PVC)
(2) In some cases, additional felt layer(s)
(3) Fiberglass
(4) Polyester felt, which is embedded into the outer-most PVC layer
(5) PVC layer (Model PVCP is 0.020”; Model PVCP-F is 0.025”.

Layers (4) and (5) constitute a proprietary material called PVCP (Polyvinyl – Chloride-Polyester (felt). The felt is actually embedded into the PVC during manufacturing while it is still in its molten state. This creates a true laminate with no concern over potential delamination.

The installed liner has the following physical properties (based on manufacturer’s data):

<table>
<tr><th>Property</th><th>Test Method</th><th>Value</th></tr>
<tr><td>Flexural modulus</td><td>ASTM D 790</td><td>19,579 psi</td></tr>
<tr><td>Flexural strength</td><td>ASTM D 790</td><td>725,500 psi</td></tr>
<tr><td>Compressive strength</td><td>ASTM D 695</td><td>12,293 psi</td></tr>
<tr><td>Compressive modulus</td><td>ASTM D 695</td><td>1,365,000 psi</td></tr>
<tr><td>Tensile strength</td><td>ASTM D 638</td><td>12,397 psi</td></tr>
<tr><td>Tensile modulus</td><td>ASTM D 638</td><td>267,839 psi</td></tr>
<tr><td>Hardness (epoxy)</td><td>ASTM D 2240</td><td>Shore D 80</td></tr>
</table>
</td></tr>
<tr><td>Diameter Range, inches</td><td>24” to 19 ft
Note: Liner model and structure determine feasibility of size. As an example, a PVCP liner has been installed in a flat-walled wet-well structure, 15 ft ×15 ft (equivalent 19-ft-diameter), and 23 ft deep.</td></tr>
<tr><td>Thickness Range, inches</td><td>Thickness ranges from 0.093” to 0.264” for “off-the-shelf” models (custom-designed thicker liners possible). Thickness is typically a function of calculated compressive loading based on hydrostatic pressure and shape of structure. The compressive loading calculations are for round structures only.</td></tr>
<tr><td>Pressure Capacity, psi</td><td>Not applicable</td></tr>
<tr><td>Temperature Range, ^{o}F</td><td>Not available</td></tr>
<tr><td>Renewal Length, feet</td><td>Up to 100 ft (manhole depth)</td></tr>
<tr><td>Other Notes</td><td>Not available</td></tr>
<tr><td colspan="2">III. Technology Design, Installation, and QA/QC Information</td></tr>
<tr><td>Product Standards</td><td>See physical properties table for standards above.</td></tr>
<tr><td>Design Standards</td><td>See physical properties table for standards above. Any lining system for a structure greater than 8 feet in diameter or 25 feet deep should be designed in consultation with the manufacturer.</td></tr>
<tr><td>Design Life Range</td><td>50 years (PVC’s proven longevity in sewers); 100 years (life expectancy)</td></tr>
<tr><td>Installation Standards</td><td>As per manufacturer.</td></tr>
<tr><td>Installation Methodology</td><td>A liner prefabricated to manhole size is epoxy-coated onsite and lowered into the manhole interior. A bladder is placed inside the liner and inflated. Heat introduced within the pressurized system (180°F to 200°F typically) cures the epoxy, forming a protective barrier within the structure. The exposed surface of the lining system is white PVC.

Curing under pressure greatly enhances bonding with the structure (the resin penetrates the substrate forming epoxy anchors). Cure pressure is from ¼ psi to</td></tr>
</table>

Technology/Method	**MultiPlexx^{TM} PVCP/PVCP-F CIPM Liner/Composite CIP**
	maximum of 8 psi (3 to 5 psi typically). Once the liner is cured, it can handle any pressure against it as the host manhole would. Strength against outside-in pressure can be calculated for hydrostatic loading. Manholes and pump stations can be completely rehabilitated in 4 to 8 hours.
Qualification Testing	• Chemical resistance • Hydraulic capacity
QA/QC	Visual inspection of the CIPP explicit during manufacturing process; trained and licensed installers; installation guidelines; and manufacturer-recommended testing (spark).
IV. Operation and Maintenance Requirements	
O&M Needs	No special requirements
Repair Requirements for Rehabilitated Sections	No special requirements
V. Costs	
Key Cost Factors	Size (diameter/depth) of manhole, condition
Case Study Costs	Not available
VI. Data Sources	
References	www.thcomposites.com, Personal communication

Datasheet A-75. Top Hat® Lateral Connection Liner

Technology/Method	**Top Hat /Lateral CIP lining, short connection liners**
I. Technology Background	
Status	Emerging
Date of Introduction	In U.S. since 1999, in Austria since 1995
Utilization Rates	Approximately 22,000 installed in the US and over 100,000 worldwide
Vendor Name(s)	**Cosmic Sondermaschinenbau GmbH** Kasten, Austria Phone: (424) 558-9872 Email: tophatchris@gmail.com Website: http://www.cosmic.at
Practitioner(s)	• King County, Seattle, WA , Erica Jacobs, (206) 684-1138, erica.jacobs@metrokc.gov (226 Top Hat in 2003) • City of Pinetops, NC, Steve Vossmeyer, (310) 327-8717, COBRAMAN93@aol.com (200 Top Hat in 2003/04) • City of Nashville, TN, contractor: David Burton, Reynolds Inc, (812) 865-3232 (800 laterals) • City of San Diego, CA, Margaret Lagas, (858) 654-4494 mllagas@sandiego.gov (installed 2,613 Top Hat between 2002 and 2004) • City of Salem, OR, Chris Scarratt (contractor), Southwest Pipeline, Inc., (424) 558-9872, 10 Top Hat , in 2006
Description of Main Features	A CIP product for lateral connections installed from a manhole using a special applicator with inflatable bladder. The liner is air inverted and UV-cured. The final product is an ECR (E-glass corrosion resistant) fiberglass laminate. The product durability relies on bonding with the surface.
Main Benefits Claimed	• Seals off defective lateral connections that allow infiltration/exfiltration • Seals off the annular space (in the mainline) exposed after lateral reopening (as part of mainline relining) • Quick installation (30 to 45 min per connection; a lateral plugged in 30 min)
Main Limitations Cited	• In standard installations, reaches approximately 6 inches into the lateral, so the first joint up the lateral is not sealed. Optionally, the length of the product can be increased to reach 18 inches into the lateral. • Relatively high cost, considering short length of repair inside the lateral • Post-installation inspection is performed with CCTV, but no testing of installed product is doable for QA/QC • Durability of repair must be proven, in particular bonding with different surfaces (e.g., CIPP)
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other:____________________
II. Technology Parameters	
Service Application	Gravity wastewater
Service Connections	Not applicable
Structural Rating Claimed	Not applicable
Materials of Composition	• Fiberglass material is E-glass type. • Resin is unsaturated polyester glass fiber (UP-GF) or vinylester • Bonding agent is epoxy. The material (cured laminate) has the following minimum physical properties (Ingeneurburo for Kunststoftechnik, Hamburg, Germany, 1997): Property — Test Method — Value Flexural modulus — DIN EN 63 — 6,000 to 11,000 N/mm^2 Flexural strength — DIN EN 63 — 156 to 195 N/mm^2 Tensile strength — DIN EN 63 — 100 to 156 N/mm^2 Adhesive shear strength: - dry surface — DIN 53 455 — 6.8 (pipe failed) N/mm^2

Technology/Method	Top Hat /Lateral CIP lining, short connection liners
	- wet surface DIN 53 455 6.0 (pipe failed) N/mm^2 - wet/grease surface DIN 53 455 2.3 (bonds failed) N/mm^2 The installed liner has the following physical properties (HTS Inc Consultants, September 2002): Property / Test Method / Value Flexural modulus ASTM D 790 1,000,000 to 1,500,000 psi Tensile strength at break ASTM D 638 46,000 to 57,500 psi Tensile elongation at break ASTM D 638 11 to 13%
Diameter Range, inches	Laterals ID=4", 6", or 8" (mainline ID=4" to 20")
Thickness Range, inches	1.5 to 3.0 mm
Pressure Capacity, psi	Not applicable
Temperature Range, ^{o}F	Not determined
Renewal Length, feet	6" to 18"
Other Notes	Not available
III. Technology Design, Installation, and QA/QC Information	
Product Standards	Not available
Design Standards	ASTM D543, D578, D1600
Design Life Range	50 years minimum
Installation Standards	Manufacturer's Installation Process Manual
Installation Methodology	A resin-impregnated laminate is loaded on the applicator and attached to a robotic device; together with a CCTV camera, it is then driven through the mainline to the lateral opening, aligned with the opening, and inserted by air inversion (the bladder of the applicator is inflated). After insertion is completed, recommended pressure must be maintained on the impregnated SLC product for the duration of the UV-light-curing process (7 minutes). The bladder of the applicator is deflated and retrieved from the mainline.
Qualification Testing	• Mechanical properties (Ingeneurburo for Kunststoftechnik, Hamburg, Germany, 1997) • Mechanical properties and thickness of installed product (HTS, Inc., Consultants, 09/2002) • Greenbook chemical resistance (City of Los Angeles, May 2007)
QA/QC	• Cleaning (hydro water jetting) and removal of all roots, debris, and protruding service connections (if protruding more than ¼ inch) prior to rehabilitation, and CCTV inspection of the lateral connection to determine the overall structural condition of the connection • CCTV inspection is performed to verify the proper cure of the material, and the proper installation
IV. Operation and Maintenance Requirements	
O&M Needs	Process manual per manufacturer
Repair Requirements for Rehabilitated Sections	Heavy infiltration should be grouted before applying this product, while small leaks do not require any action.
V. Costs	
Key Cost Factors	• Density of laterals on the mainline between two manholes (i.e., the frequency of setting up the equipment) • Preparation work required (removal of roots and soft deposits for a distance of 2 feet up the lateral, rounding or removal of sharp or pointed cutout edges in lateral opening, removal of protruding lateral pipe materials down to within 1/8 inch of the mainline wall) • Cost of material $250 (manufacturer's quote)
Case Study Costs	• $1,250/lateral (with pre/post-CCTV, cleaning, root removal, traffic control, jetting and bypass, when needed) in Pinetops, NC, with a total of 200 Top Hats installed (2003/04) • $1,000 to $1,500 per lateral (manufacturer's quote)

Technology/Method	**Top Hat /Lateral CIP lining, short connection liners**
VI. Data Sources	
References	- WERF, 2006. Methods for Cost-Effective Rehabilitation of Private Lateral Sewers, 02CTS5, Water Environment Research Foundation, Alexandria, VA, 436 p. - www.cosmic.at

Datasheet A-76. TRIC™ Sewer Lateral Pipe Bursting

Technology/Method	**TRIC™ Sewer Lateral Zip™/Lateral pipe bursting**
I. Technology Background	
Status	Innovative
Date of Introduction	1996. Available in US, Canada, Australia, Russia, and Japan
Utilization Rates	Estimated 15,000,000 feet replaced in 8 years.
Vendor Name(s)	**TRIC Tools, Inc.** Alameda, CA Phone: (510) 865-8742 Email: michael.lien@trictrenchless.com Website: http://www.trictrenchless.com
Practitioner(s)	• City of Daly City, CA ,Tom Piccolotti, (650) 991-8200, tpiccolotti@DalyCity.org (replaced approximately 100 laterals in past 9 yrs) • City of Vallejo, CA, Andy Jannings, (707) 644-8949, ext. 271, aJannings@vsfcd.com • City of Sarasota, FL, Rick Wray, deceased; Dan Castorani, (941) 365-2200, ext 6250, dan_castorani@sarasotagov.com (replaced approx 300 "upper" laterals in 2001/02) • Stege Sanitary District, CA, Walter Lund, (510) 524-4668 • City of Pacifica, CA, Brian Martinez, (650) 738-4669
Description of Main Features	A method of lateral pipe replacement by pulling a bursting head through the existing lateral pipe using a cable or wire rope that breaks the pipe into fragments or slices the pipe-split open, while simultaneously pulling in a new replacement pipe. Also capable with larger systems to replace up to 14 inches mainline pipes.
Main Benefits Claimed	• New lateral pipe is installed ("permanent" repair). • Pipe can be upsized, if necessary, by several pipe sizes. • Relatively little excavation is required (significantly less compared to open-cut replacement). • The method is applicable in all pipe types, and is especially suitable in pipes that have lost structural stability (about to collapse). • Works in most different soil conditions. • Pipe cleaning/roots removal is not needed unless pulling the cable through the pipe is hindered (then only needed to a minimal extent). • Roots should not be an issue in the future because there are no joints in the HDPE pipe. • Minor sags can be eliminated during the process. • Short disruption of service to homeowners (up to 1 day). • No chemicals are used. • Equipment is lightweight and portable (components weighing no more than 75 lb). Larger mainline TRIC equipment is heavier than the lateral equipment and may require equipment to move it into place
Main Limitations Cited	• More excavation is required compared to other trenchless rehabilitation methods. Associated surface restoration work is required. • Access to private property is required and may be an issue. • Difficult in hard clays. • Difficult in pipes repaired with metal clamps in the past unless assisted with TRIC's Unified Force heads. • Not suitable for pipes with many sharp bends. Pipes with several sharp bends have to be replaced in separate bursts, with a pit excavated wherever such bend is located ("divide and conquer" approach). With more than three sharp bends in the pipe, CIP relining is usually better suited. • Significant sags cannot be removed. This is more of an issue in flatter than steeper pipes. • Risk of damaging nearby objects and surface objects when bursting at shallow depths.

Technology/Method	**TRIC™ Sewer Lateral Zip™/Lateral pipe bursting**
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other: Gas lines and utilities
II. Technology Parameters	
Service Application	Wastewater , water, gas, and utilities
Service Connections	Not applicable
Structural Rating Claimed	Fully structural
Materials of Composition	New pipe is installed, typically HDPE. Other pipe types are optional, e.g., cast iron, PVC
Diameter Range, inches	1 to 14 inches
Thickness Range, inches	Depends on the selection of the new pipe to be installed. HDPE pipe SDR 17 is typically selected; optionally, HDPE SDR 13.5 or 11.
Pressure Capacity, psi	Depends on the selection of the new pipe to be installed. Typically 100 to 160 psi.
Temperature Range, °F	Depends on the selection of the new pipe to be installed. Typically up to 140°F
Renewal Length, feet	1,400 feet longest on record. Usually the length of the cable determines the length of the pull. The longer the pull, the more cable stretching and pipe stretching become issues to consider, and the more pulling strength is required.
Other Notes	For replacing ductile pipes (e.g., lead, galvanized iron, cast iron), a pipe splitting head is used, which is a variation of the static pull head, with cutting blades that slice through the pipe and split the pipe open.
III. Technology Design, Installation, and QA/QC Information	
Product Standards	• ASTM F714-08, Standard Specification for Polyethylene (PE) Plastic Pipe (SDR-PR) Based on Outside Diameter • ASTM D3350-08, Standard Specification for Polyethylene Plastics Pipe and Fittings Materials (requirements for polyethylene compound used for extruding piping and bends)
Design Standards	None
Design Life Range	Depends on the selection of the new pipe to be installed. 100 years minimum for HDPE pipe
Installation Standards	ASTM D3261 – 03, Standard Specification for Butt Heat Fusion Polyethylene (PE) Plastic Fittings for Polyethylene (PE) Plastic Pipe and Tubing ASTM D2657 – 07, Standard Practice for Heat Fusion Joining of Polyolefin Pipe and Fittings IAPMO IS 26, Uniform Plumbing Code UPC – Installation Standard for the Trenchless Insertion of Polyethylene (PE) Pipe For Sewer Laterals **U.S. Patents** US Patent 6,305,880: Device and Method for Trenchless Replacement of Underground Pipe, Oct 23, 2001 US Patent 6,524,031: Device and Method for Trenchless Replacement of Underground Pipe US Patent 6,793,442: Device and Method for Trenchless Replacement of Underground pipe US Patent 6,799,923: Trenchless Water Pipe Device and Method Patent **Foreign Patents** Australia Patent 734068: Device for Trenchless Replacement of Underground Pipe Mexico Patent 217886: Device for Trenchless Replacement of Underground Pipe Brazil Patent PI 9807054-1: Device for Replacement of Underground Pipe Canadian Patent 2277202: Device for Replacement of Underground Pipe

Technology/Method	**TRIC™ Sewer Lateral Zip™/Lateral pipe bursting**
Installation Methodology	Two small pits are excavated (e.g., 2 ft × 4 ft). If HDPE pipe coming in 20- to 40-ft lengths is used as a replacement pipe, it is butt-fused to the required length. A winch (pulley) is placed inside the exit pit and braced with a vertical bearing plate to spread the load onto the soil. A pulling cable is run through the existing pipe and attached to the bursting head near the entry pit. The head is pulled through the lateral, pulling the replacement pipe with it. A little extra length of pipe is left to extend beyond the pit on both ends. The bursting tool is detached. After the new pipe stretched from the pull has relaxed (the pipe is either given time for relaxation or is bumped with a sledge hammer at the protruding end in the pits), the pipe is cut to the correct length. The new pipe is connected with the mainline and the house plumbing (first at the pulling pit and then at the entry pit). Flexible rubber couplings are usually used in combination with stainless-steel shear bands. The pits are closed and the surface restored.
Qualification Testing	Not available
QA/QC	Post-installation hydrostatic testing conducted in accordance with the manufacturer's recommended testing procedures, such as: • Low pressure air test procedure in accordance with ASTM F1417 – 92 (2005) Standard Test Method for Installation Acceptance of Plastic Gravity Sewer Lines Using Low-Pressure Air • CCTV video inspection performed after burst is complete
IV. Operation and Maintenance Requirements	
O&M Needs	No special requirements
Repair Requirements for Rehabilitated Sections	No special requirements
V. Costs	
Key Cost Factors	• Cost of pit excavation (depth of pipe), but not very much the length (cost of replacement pipe) • Density of laterals on the mainline between two manholes (i.e., the frequency of setting up the lateral equipment) • Region of the country (California, Northeast, Chicago area, etc., are more expensive than some other parts of country) • Who performs the work (a plumber/contractor replacing a single lateral or a utility contractor replacing laterals on large scale)
Case Study Costs	• $2,450/lateral in Sarasota, FL (2001/02) • $3,000 to $4,000 per 60-foot lateral on average (manufacturer's quote)
VI. Data Sources	
References	• WERF, 2006. Methods for Cost-Effective Rehabilitation of Private Lateral Sewers, 02CTS5, Water Environment Research Foundation, Alexandria, VA, 436 p. • http://www.trictrenchless.com

Datasheet A-77. Trolining Grout-in-place Lining

Technology/Method	**Trolining/Grout-in-place relining**
I. Technology Background	
Status	Conventional
Date of Introduction	Developed in Germany in 1992; available in US since 2000; used worldwide
Utilization Rates	Installed 1 million ft since 1992
Vendor Name(s)	**Ultraliner, Inc.** Oxford, AL Phone: (256) 831-5515 Email: grantwhittle@ultraliner.com Website: www.ultraliner.com
Practitioner(s)	• City of Bielefeld, Germany, rehabilitated egg-shaped sewers in 2006: approximately 1,000 ft of 47” × 71” and 700 ft of 55” × 83” (Kirste, 2007) • Near Losheim, Germany, two parallel pipes, 78” in diameter and 280 ft long, were rehabilitated in 2008 – Europe’s largest GIPP liner (Herrmann and Kirste, 2009) • Stone Mountain Memorial Association, GA, Mr. Cowhig, (770) 498-5714 (115’ length of 36’’, 140’ length of 48’’, and 73’ length of 60’’)
Description of Main Features	Thermoplastic liner tubes are installed with anchors (V-shaped studs) on the outside of the liner, which serve as a spacer to the inner surface of the host pipe, thus creating annular space that is filled with high-strength cementitious grout. The grout is the primary structural element. Grout-in-place liners can be installed as three different systems: • Basic system contains a single HDPE liner. The height of studs determines the thickness of annular space, which is typically between 10 mm and 19 mm (0.4 to 0.46 inches). • Preliner system also includes a smooth HDPE liner, which is usually required in areas near or below groundwater level to ensure dilution-free grouting. • Double system incorporates another HDPE liner to create a larger void space to the existing host pipe wall that will be filled with structural grout, thus increasing the structural capacity of the lining system. Double-liner systems are used in applications requiring additional structural load-bearing capacity and high-security containment.
Main Benefits Claimed	• Provides structural rehabilitation • Practically any pipe size and shape can be rehabilitated • Capable of accommodating large radius bends • No excavation is required. • Self-cleaning system (the textured surface causes micro-turbulences during periods of increased flow in the pipe, sweeping away any deposits from the liner surface) • Consistent wall thickness, consistent modulus, consistent corrosion, and abrasion resistance, lower risk exposure. • Cost-competitiveness with other methods, especially in large diameters and non-round geometries (lower mobilization costs and shipping costs, since no refrigeration of materials is required)
Main Limitations Cited	Access at both ends is necessary. Bypass pumping is normally required during installation.
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other:____________________________

<table>
<tr><th colspan="2">II. Technology Parameters</th></tr>
<tr><td>Service Application</td><td>Wastewater, stormwater, raw water, industrial, power</td></tr>
<tr><td>Service Connections</td><td>Cut out robotically (in small-diameter pipes) or manually (in man-entry pipes)</td></tr>
<tr><td>Structural Rating Claimed</td><td>Fully structural</td></tr>
<tr><td>Materials of Composition</td><td>A preliner is made from a smooth HDPE pipe. Studded liners (AGRU Sure Grip) are made from HDPE (the studs are integrally formed during the extrusion process). Grout used is high-strength grout.

The installed liner has the following physical properties:

<table>
<tr><th>Property</th><th>Test Method</th><th>Value</th></tr>
<tr><td>Flexural modulus</td><td>ASTM D790</td><td>N/A</td></tr>
<tr><td>Comp. strength</td><td>ASTM C109</td><td>>10,000 psi (28-day grout)</td></tr>
<tr><td>Tensile strength</td><td>ASTM D6693</td><td>4064 psi (HDPE Panel)</td></tr>
<tr><td>Tensile elongation</td><td>ASTM D6693</td><td>700% (HDPE Panel)</td></tr>
<tr><td>Identation Hardness</td><td>ASTM D2583</td><td>N/A</td></tr>
<tr><td>Ring Stiffness</td><td>ASTM D2412</td><td>110 (13-mm thickness, 500-mm diameter pipe)</td></tr>
</table></td></tr>
<tr><td>Diameter Range, inches</td><td>8” to 120” (or larger)</td></tr>
<tr><td>Thickness Range, inches</td><td>2 mm (panels) plus 10-mm, 13-mm or 19-mm (studs) for single-layer system. Thicker combinations are available for double system.</td></tr>
<tr><td>Pressure Capacity, psi</td><td>120 psi</td></tr>
<tr><td>Temperature Range, ^{o}F</td><td>120^{o}F</td></tr>
<tr><td>Renewal Length, feet</td><td>Depends on diameter (e.g., 600 feet for 36”)</td></tr>
<tr><td>Other Notes</td><td>Capable of handling gentle and sharp bends. Options such as self-cleaning invert, hydrocarbon barrier, monitorable dual containment, and embedded micro-cabling (fiber optic) system are available.</td></tr>
<tr><th colspan="2">III. Technology Design, Installation, and QA/QC Information</th></tr>
<tr><td>Product Standards</td><td>European standard, ASTM Standard is under development.</td></tr>
<tr><td>Design Standards</td><td>European standard, ASTM Standard is under development.</td></tr>
<tr><td>Design Life Range</td><td>50 to 150 years</td></tr>
<tr><td>Installation Standards</td><td>European standard, ASTM Standard is under development.</td></tr>
<tr><td>Installation Methodology</td><td>If used, a deformed preliner is winched through the existing pipeline, and after plugging its ends, air pressure is applied to form the preliner against the existing pipeline. The studded inliner is inserted using the same procedure. Next, the annular space between the liners is sealed at the ends, and grouting and air-release ports are installed (standard polyethylene extrusion welding equipment).

Each end is then plugged and braced, and the liner is pressurized to a minimum of 60 kPa (0.6 bar) using water or air pressure, depending on the pipe diameter (the applied internal pressure must exceed the grout pressure by a safety factor of 1.2). When the required pressure is attained, the annular void is filled with high-strength grout fed from the downstream end. Form work is generally applied to pipe larger than 80’’ in diameter or in irregular shape.</td></tr>
<tr><td>Qualification Testing</td><td>Not available</td></tr>
</table>

QA/QC	• The minimum thickness of the pipe liner is the height of the embedded anchors and is unalterable by field conditions or by construction crew decisions. • The grout is injected into the sealed annulus between the layers of the pipeliner using a gravity column, instead of pumping; this tends to preclude the creation of grout voids inside the pipeliner. • The required volume of grout necessary to achieve the structural wall thickness requirements is established and controlled by the fixed, sealed annulus between the layers of the pipeliner. • The application of the preliner prevents the grout from escaping, washing away, or losing strength due to dilution by groundwater. • The weld quality and the water-tightness of the HDPE GIPP are confirmed during the installation process.
IV. Operation and Maintenance Requirements	
O&M Needs	No special requirements
Repair Requirements for Rehabilitated Sections	The pipe section to be rehabilitated is plugged off at both ends, cleaned, and visually inspected. With translucent HDPE panels, an internal visual inspection, even by CCTV, can find grout voids. A "taping-test" can be used to find grout voids behind the opaque panels. Grout voids, if found, must be filled with grout through a hole drilled on the HDPE panel. The drilled hole is then patched.
V. Costs	
Key Cost Factors	Key drivers for the cost include: the condition of the existing pipe, the burial depth, the loading situation, and thickness requirement of the pipeliner. Contributors to the set-up cost: pipe cleaning, dewatering; normally no pit excavation is necessary; mobilization cost is minimum. Contributors to the material cost: HDPE panels, grout.
Case Study Costs	Depends on the case study project.
VI. Data Sources	
References	• www.ultraliner.com • Kirste, J., 2007. "Grouted-in-Place Pipe Method Used to Reline German Sewer Lines," *Trenchless Technology*, Sep 2007, pp. 48-50 • Herrmann, S. and J. Kirste, 2009. "Rehabilitation of a Combined Sewage Collector within a Groundwater Protection Area by Application of the GIPP Method," Project Report by Trolining GmbH, downloaded on 06/03/09 from http://www.trolining.de, 4 p.

Datasheet A-78. Warren Environmental Spray-on Epoxy Lining

Technology/Method	**Warren Environmental S301-14/Structural spray-on epoxy coating**
I. Technology Background	
Status	Emerging
Date of Introduction	Developed in U.S. in 1996. Also utilized in European Union, Australia, Canada, Tasmania.
Utilization Rates	Over 15,000 structures rehabilitated throughout the USA since 1996
Vendor Name(s)	**Warren Environmental, Inc.** Middleboro, MA Phone: (508) 947-8539 Email: jane@warrenenviro.com Website: www.warrenenviro.com
Practitioner(s)	• DeKalb County, GA, Ben Thornton, Sr., (678) 758-4992, bthorn@co.dekalb.ga.us (about 13,000 structures done since 1996) • Anheuser-Busch Co., Bill Kutosky, (618) 334-3358 (digesters and clarifiers at several breweries rehabilitated between 1997 and 2002) • City of Sarasota, FL, Dan Castorani, (941) 365-2200, Dan_Castorani@sarasotagov.com (4 pump stations in 1995) • Miami-Dade County, FL, John Hoffman, (954) 987-0066, jhoffman@hazenandsawyer.com (200 ft of 60" tunnel in low flow conditions, and 2 large underground siphon stations rehabilitated in 1997) • Washington Metropolitan Transit Authority, Ruth McCormick, (301) 618-7546, Rmccormick@wmata.com (relining of subway access shafts in 2005)
Description of Main Features	Structural spray-on epoxy is a fiber-reinforced polymer composite (FRPC). High-performance fibers are embedded in a polymer matrix, which provides continuity to the composite, distributes applied loads between fibers, supports the slender fibers against buckling, and protects the fibers from physical and environmental damage.
Main Benefits Claimed	• High strength-to-weight ratios • Good resistance to corrosion • Good bonding strength to a variety of substrates • High thixotropic index that allows for up to a ¼” build-up on vertical surfaces without sag • Lightweight (relatively easy to apply) • 100% solids • Solvent-free spray application • No VOCs
Main Limitations Cited	• Man-entry required (although can be applied with a spinner in smaller pipes) • Plugging and bypass pumping required
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Service Lines Other: Tunnels, Water Main, Aqueducts, Tanks, Digesters, Clarifiers, Lift Stations
II. Technology Parameters	
Service Application	Manholes, Sewers
Service Connections	Treatment depends on coating thickness compared to service diameter
Structural Rating Claimed	Fully structural

<table>
<tr><th>Technology/Method</th><th>Warren Environmental S301-14/Structural spray-on epoxy coating</th></tr>
<tr><td>Materials of Composition</td><td>100% solids epoxy

The installed liner (1/8 inch thickness) has the following physical properties (based on manufacturer’s data):

<table>
<tr><th>Property</th><th>Test Method</th><th>Value</th></tr>
<tr><td>Compressive strength</td><td>ASTM D695-85</td><td>12,000 psi</td></tr>
<tr><td>Flexural strength</td><td>ASTM D790-86</td><td>11,000 psi</td></tr>
<tr><td>Flexural modulus@ 0.100”</td><td>ASTM D790-86</td><td>500,000 psi</td></tr>
<tr><td>Tensile strength</td><td>ASTM D638-86</td><td>7,000 psi</td></tr>
<tr><td>Glass transition temperature</td><td>ASTM D3418-82</td><td>151°F</td></tr>
</table></td></tr>
<tr><td>Diameter Range, inches</td><td>Man-entry (pipes over 36 inches in diameter)
Can be applied with a spinner in smaller pipes</td></tr>
<tr><td>Thickness Range, inches</td><td>$^{1}/_{8}$ to ¾ inch in one coat (up to 1 inch total)</td></tr>
<tr><td>Pressure Capacity, psi</td><td>Not available</td></tr>
<tr><td>Temperature Range, ^{o}F</td><td>Not determined</td></tr>
<tr><td>Renewal Length, feet</td><td>Not available</td></tr>
<tr><td>Other Notes</td><td>Not available</td></tr>
<tr><td colspan="2">III. Technology Design, Installation, and QA/QC Information</td></tr>
<tr><td>Product Standards</td><td>Not available</td></tr>
<tr><td>Design Standards</td><td>Not available</td></tr>
<tr><td>Design Life Range</td><td>Not available</td></tr>
<tr><td>Installation Standards</td><td>Not available</td></tr>
<tr><td>Installation Methodology</td><td>The material is sprayed using a patented plural-component spray-on system. The epoxy component utilizes a two-part base to one-part activator mix ratio by volume. No thinners are utilized.

The coating is applied in thickness up to 750 mil, and multiple coats can be applied to a maximum thickness of 1,000 mils. The cure time is about 2 hours at 77°F. Additional coats are applied within 1 hour.</td></tr>
<tr><td>Qualification Testing</td><td>• Chemical Resistance-Evaluation of Protective Coatings for Concrete (County Sanitation Districts of Los Angeles, 2004)
• Chemical Resistance and Bond Strength under Hydrostatic Conditions (CIGMAT, University of Houston, 2004)
• Physical Characteristics of Deteriorated Concrete Pipe Repaired with Epoxy-Mechanical and Structural properties (University of South Carolina, 2002)</td></tr>
<tr><td>QA/QC</td><td>Not available</td></tr>
<tr><td colspan="2">IV. Operation and Maintenance Requirements</td></tr>
<tr><td>O&M Needs</td><td>No special requirements</td></tr>
<tr><td>Repair Requirements for Rehabilitated Sections</td><td>No special requirements</td></tr>
<tr><td colspan="2">V. Costs</td></tr>
<tr><td>Key Cost Factors</td><td>• Size and condition of structure
• Cost of labor, tools, equipment</td></tr>
<tr><td>Case Study Costs</td><td>• In DeKalb County, GA: approximately $300/VF in manhole rehabilitation (between 500 to 1,000 manholes rehabilitated over the last 10 years that were typically 4 feet in diameter and 9 to 10 feet deep, although some were 20 feet deep)</td></tr>
<tr><td colspan="2">VI. Data Sources</td></tr>
<tr><td>References</td><td>www.warrenenviro.com</td></tr>
</table>

Datasheet A-79. 3S Segment Panel System

Technology/Method	**3S Segment Panel Lining System**
I. Technology Background	
Status	Innovative in U.S.
Date of Introduction	Used for more than 10 years internationally. First U.S. installation in 2005.
Utilization Rates	Not available
Vendor Name(s)	**National Liner, LLC** 12707 North Freeway, Suite 490 Houston, TX 77060 Phone: (800) 547-1235
Practitioner(s)	2005 Orlando, FL (72 inches diameter)
Description of Main Features	Grout-in-place panel lining system for the structural rehabilitation and restoration of storm sewers, sanitary sewers, and culverts. Uses bolt-together, molded, translucent PVC panels that are grouted in place with a structural grout.
Main Benefits Claimed	• Can restore the structural strength of the original pipe • The see-through liner allows direct visual monitoring of the grouting process to ensure a quality installation every time.
Main Limitations Cited	• Requires person-entry • Flow depths must be less than 12 inches.
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Service Lines Other:
II. Technology Parameters	
Service Application	Person-entry sewers, manholes and appurtenances
Service Connections	Handled in situ since person-entry is required.
Structural Rating Claimed	Fully structural
Materials of Composition	• Molded, translucent PVC panels and structural grout • The 3S segment paneling system is manufactured in Japan by Shonan Plastic Mfg. Co. Ltd.
Diameter Range, inches	• Circular pipe diameters: 40" to 160" • Culvert diameters: 40" x 40" to 200" x 200" • Customization possible (arches, horseshoes, semi-circular, etc.)
Thickness Range, inches	Not available
Pressure Capacity, psi	Not applicable
Temperature Range, °F	Not available
Renewal Length, feet	Unlimited
Other Notes	Not available

III. Technology Design, Installation, and QA/QC Information	
Product Standards	Not available
Design Standards	• UK WRc approved as Type 1 sewer rehabilitation technique • Can safely span joint separations up to 6 inches
Design Life Range	Not available
Installation Standards	• The 3S Segment Panel System can follow curving sewers with a centerline radius as small as 26' 3" • Can handle inflection angles up to 3° • Adjusts to joint offsets up to 2% of the host pipe I.D. • The 3S Segment Panel System can be installed with as much as 12 inches of water flow in the pipeline
Installation Methodology	Each panel is slightly curved and is approximately 8 in. wide by 3 ft long (sizes will vary and are based on the dimensions of the host pipe or culvert). The lightweight (3-lb) panels are handed down through an existing manhole, and then assembled into a series of rings. The rings are then joined, using uni-chrome steel screw rods, to form the new pipe to any desired length. Once in place, a structural grout, formulated to project specifications, is injected into the annular space between the old pipe and the new 3S Segment Panel Pipe. Since the 3S Segment Panels are translucent, the contractor is able to monitor the grouting procedure to ensure complete and consistent coverage. For a faster installation, the 3S Segment Panel construction can be initiated at the central point between the upstream and downstream manholes and installed outward, in both directions, simultaneously.
Qualification Testing	• Testing has been carried out in Europe, Asia, and the U.S. • Classified as grout-in-place liner (GIPL) • Independent testing reported to confirm that the 3S Segment Panel PVC materials are equal to or greater than typical PVC wastewater piping in abrasion, tensile, stress, and compression strength • Reported that the liner has passed the Greenbook "pickle jar" chemical resistance test
QA/QC	• See-through 3S Segment Panels allow for constant visual monitoring of the grouting process
IV. Operation and Maintenance Requirements	
O&M Needs	No special requirements
Repair Requirements for Rehabilitated Sections	No special requirements
V. Costs	
Key Cost Factors	• Size and condition of structure • Accessibility of structure and flow conditions
Case Study Costs	Not available
VI. Data Sources	
References	http://www.nationalliner.com/; *Underground Construction*, April 2009

APPENDIX B

APPLICABLE ASTM STANDARDS

Standard	Description
ASTM A-240	Standard Specification for Chromium and Chromium-Nickel Stainless Steel Plate, Sheet, and Strip for Pressure Vessels and for General Applications
ASTM A-760	Standard Specification for Corrugated Steel Pipe, Metallic-Coated for Sewers and Drains
ASTM A-762	Standard Specification for Corrugated Steel Pipe, Polymer Precoated for Sewers and Drains
ASTM A-862	Standard Practice for Application of Asphalt Coatings to Corrugated Steel Sewer and Drainage Pipe
ASTM A-926	Standard Test Method for Comparing the Abrasion Resistance of Coating Materials for Corrugated Metal Pipe
ASTM A-978	Standard Specification for Composite Ribbed Steel Pipe, Precoated and Polyethylene Lined for Gravity Flow Sanitary Sewers, Storm Sewers, and Other Special Applications
ASTM C-39	Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens
ASTM C-94	Standard Specification for Ready-Mixed Concrete
ASTM C-109	Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens)
ASTM C-143	Standard Test Method for Slump of Hydraulic-Cement Concrete
ASTM C-267	Standard Test Methods for Chemical Resistance of Mortars, Grouts, and Monolithic Surfacings and Polymer Concretes
ASTM C-273	Standard Test Method for Shear Properties of Sandwich Core Materials
ASTM C-293	ASTM C293 - 08 Standard Test Method for Flexural Strength of Concrete (Using Simple Beam With Center-Point Loading)
ASTM C-469	Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression
ASTM C-496	Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens
ASTM C-541	Standard Specification for Linings for Asbestos-Cement Pipe
ASTM C-580	Standard Test Method for Flexural Strength and Modulus of Elasticity of Chemical-Resistant Mortars, Grouts, Monolithic Surfacings, and Polymer Concretes
ASTM C-581	Standard Practice for Determining Chemical Resistance of Thermosetting Resins Used in Glass-Fiber-Reinforced Structures Intended for Liquid Service
ASTM C-882	Standard Test Method for Bond Strength of Epoxy-Resin Systems Used With Concrete By Slant Shear
ASTM C-900	Standard Test Method for Pullout Strength of Hardened Concrete
ASTM C-905	Standard Test Methods for Apparent Density of Chemical-Resistant Mortars, Grouts, Monolithic Surfacings, and Polymer Concretes
ASTM C-923	Standard Specification for Resilient Connectors Between Reinforced Concrete Manhole Structures, Pipes, and Laterals
ASTM C-1131	Standard Practice for Least Cost (Life Cycle) Analysis of Concrete Culvert, Storm Sewer, and Sanitary Sewer Systems
ASTM C-1202	Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration
ASTM C 1244-93 (Historical standard)	Standard Test Method for Concrete Sewer Manholes by the Negative Air Pressure (Vacuum) Test Prior to Backfill
ASTM C1385 / C1385M – 98 (2004)	Standard Practice for Sampling Materials for Shotcrete
ASTM C1141 / C1141M - 08	Standard Specification for Admixtures for Shotcrete
ASTM C1436 - 08	Standard Specification for Materials for Shotcrete
ASTM C1604 / C1604M - 05	Standard Test Method for Obtaining and Testing Drilled Cores of Shotcrete
ASTM C1140 - 03a	Standard Practice for Preparing and Testing Specimens from Shotcrete Test Panels

ASTM D-149	Standard Test Method for Dielectric Breakdown Voltage and Dielectric Strength of Solid Electrical Insulating Materials at Commercial Power Frequencies
ASTM D-412	Standard Test Methods for Vulcanized Rubber and Thermoplastic Elastomers—Tension
ASTM D-543	Standard Practices for Evaluating the Resistance of Plastics to Chemical Reagents
ASTM D-570	Standard Test Method for Water Absorption of Plastics
ASTM D-578	Standard Specification for Glass Fiber Strands
ASTM D-581	Standard Specification for Glass Fiber Greige Braided Tubular Sleeving
ASTM D-624	Standard Test Method for Tear Strength of Conventional Vulcanized Rubber and Thermoplastic Elastomers
ASTM D-638	Standard Test Method for Tensile Properties of Plastics
ASTM D-648	Standard Test Method for Deflection Temperature of Plastics Under Flexural Load in the Edgewise Position
ASTM D-695	Standard Test Method for Compressive Properties of Rigid Plastics
ASTM D714	Standard Test Method for Evaluating Degree of Blistering of Paints
ASTM D-790	Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials
ASTM D-792	Standard Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement
ASTM D-1042	Standard Test Method for Linear Dimensional Changes of Plastics Under Accelerated Service Conditions
ASTM D-1248	Standard Specification for Polyethylene Plastics Extrusion Materials for Wire and Cable
ASTM D-1598	Standard Test Method for Time-to-Failure of Plastic Pipe Under Constant Internal Pressure
ASTM D-1600	Standard Terminology for Abbreviated Terms Relating to Plastics
ASTM D-1784	Standard Specification for Rigid Poly(Vinyl Chloride) (PVC) Compounds and Chlorinated Poly(Vinyl Chloride) (CPVC) Compounds
ASTM D-1785	Standard Specification for Poly(Vinyl Chloride) (PVC) Plastic Pipe, Schedules 40, 80, and 120
ASTM D-2239	Standard Specification for Polyethylene (PE) Plastic Pipe (SIDR-PR) Based on Controlled Inside Diameter
ASTM D-2240	Standard Test Method for Rubber Property—Durometer Hardness
ASTM D-2241	Standard Specification for Poly(Vinyl Chloride) (PVC) Pressure-Rated Pipe (SDR Series)
ASTM D-2290	Standard Test Method for Apparent Hoop Tensile Strength of Plastic or Reinforced Plastic Pipe by Split Disk Method
ASTM D-2344	Standard Test Method for Short-Beam Strength of Polymer Matrix Composite Materials and Their Laminates
ASTM D-2412	Standard Test Method for Determination of External Loading Characteristics of Plastic Pipe by Parallel-Plate Loading
ASTM D-2561	Standard Test Method for Environmental Stress-Crack Resistance of Blow-Molded Polyethylene Containers
ASTM D-2583	Standard Test Method for Indentation Hardness of Rigid Plastics by Means of a Barcol Impressor
ASTM D-2584	Standard Test Method for Ignition Loss of Cured Reinforced Resins
ASTM D-2657	Standard Practice for Heat Fusion Joining of Polyolefin Pipe and Fittings
ASTM D-2837	Standard Test Method for Obtaining Hydrostatic Design Basis for Thermoplastic Pipe Materials or Pressure Design Basis for Thermoplastic Pipe Products
ASTM D-2990	Standard Test Methods for Tensile, Compressive, and Flexural Creep and Creep-Rupture of Plastics
ASTM D-3034	Standard Specification for Type PSM Poly(Vinyl Chloride) (PVC) Sewer Pipe and Fittings
ASTM D-3035	Standard Specification for Polyethylene (PE) Plastic Pipe (DR-PR) Based on Controlled Outside Diameter
ASTM D-3039	Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

ASTM D-3212	Standard Specification for Joints for Drain and Sewer Plastic Pipes Using Flexible Elastomeric Seals
ASTM D-3261	Standard Specification for Butt Heat Fusion Polyethylene (PE) Plastic Fittings for Polyethylene (PE) Plastic Pipe and Tubing
ASTM D-3262	Standard Specification for “Fiberglass” (Glass-Fiber-Reinforced Thermosetting-Resin) Sewer Pipe
ASTM D-3289	Standard Test Method for Density of Semi-Solid and Solid Bituminous Materials (Nickel Crucible Method)
ASTM D-3350	Standard Specification for Polyethylene Plastics Pipe and Fittings Materials
ASTM D-3418	Standard Test Method for Transition Temperatures and Enthalpies of Fusion and Crystallization of Polymers by Differential Scanning Calorimetry
ASTM D-3517	Standard Specification for “Fiberglass” (Glass-Fiber-Reinforced Thermosetting-Resin) Pressure Pipe
ASTM D-3550	Standard Practice for Thick Wall, Ring-Lined, Split Barrel, Drive Sampling of Soils
ASTM D-3574	Standard Test Methods for Flexible Cellular Materials—Slab, Bonded, and Molded Urethane Foams
ASTM D-3681	Standard Test Method for Chemical Resistance of “Fiberglass” (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe in a Deflected Condition
ASTM D-3753	Standard Specification for Glass-Fiber-Reinforced Polyester Manholes and Wetwells
ASTM D-3754	Standard Specification for “Fiberglass” (Glass-Fiber-Reinforced Thermosetting-Resin) Sewer and Industrial Pressure Pipe
ASTM D-3829	Standard Test Method for Predicting the Borderline Pumping Temperature of Engine Oil
ASTM D-4060	Standard Test Method for Abrasion Resistance of Organic Coatings by the Taber Abraser
ASTM D-4161	Standard Specification for “Fiberglass” (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe Joints Using Flexible Elastomeric Seals
ASTM D-4541	Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers
ASTM D-4783	Standard Test Methods for Resistance of Adhesive Preparations in Container to Attack by Bacteria, Yeast, and Fungi
ASTM D-4787	Standard Practice for Continuity Verification of Liquid or Sheet Linings Applied to Concrete Substrates
ASTM D-5813	Standard Specification for Cured-In-Place Thermosetting Resin Sewer Piping Systems
ASTM D-6693	Standard Test Method for Determining Tensile Properties of Nonreinforced Polyethylene and Nonreinforced Flexible Polypropylene Geomembranes
ASTM D-7234	Standard Test Method for Pull-Off Adhesion Strength of Coatings on Concrete Using Portable Pull-Off Adhesion Testers
ASTM D-7274	Standard Test Method for Mineral Stabilizer Content of Prefabricated Bituminous Geomembranes (BGM)
ASTM E-96	Standard Test Methods for Water Vapor Transmission of Materials
ASTM E-797	Standard Practice for Measuring Thickness by Manual Ultrasonic Pulse-Echo Contact Method
ASTM E-2135	Standard Terminology for Property and Asset Management
ASTM F-477	Standard Specification for Elastomeric Seals (Gaskets) for Joining Plastic Pipe
ASTM F-585	Standard Practice for Insertion of Flexible Polyethylene Pipe Into Existing Sewers
ASTM F-679	Standard Specification for Poly(Vinyl Chloride) (PVC) Large-Diameter Plastic Gravity Sewer Pipe and Fittings
ASTM F-714	Standard Specification for Polyethylene (PE) Plastic Pipe (SDR-PR) Based on Outside Diameter
ASTM F-1216	Standard Practice for Rehabilitation of Existing Pipelines and Conduits by the Inversion and Curing of a Resin-Impregnated Tube
ASTM F-1417	Standard Test Method for Installation Acceptance of Plastic Gravity Sewer Lines Using Low-Pressure Air

ASTM F-1504	Standard Specification for Folded Poly(Vinyl Chloride) (PVC) Pipe for Existing Sewer and Conduit Rehabilitation
ASTM F-1533	Standard Specification for Deformed Polyethylene (PE) Liner
ASTM F-1606 (withdrawn)	ASTM F1606 - 95 Standard Practice for Rehabilitation of Existing Sewers and Conduits with Deformed Polyethylene (PE) Liner (Withdrawn 2004)
ASTM F-1697	Standard Specification for Poly(Vinyl Chloride) (PVC) Profile Strip for Machine Spiral-Wound Liner Pipe Rehabilitation of Existing Sewers and Conduit
ASTM F-1698	Standard Practice for Installation of Poly(Vinyl Chloride)(PVC) Profile Strip Liner and Cementitious Grout for Rehabilitation of Existing Man-Entry Sewers and Conduits
ASTM F-1735	Standard Specification for Poly (Vinyl Chloride)(PVC) Profile Strip for PVC Liners for Rehabilitation of Existing Man-Entry Sewers and Conduits
ASTM F-1741	Standard Practice for Installation of Machine Spiral Wound Poly (Vinyl Chloride) (PVC) Liner Pipe for Rehabilitation of Existing Sewers and Conduits
ASTM F-1743	Standard Practice for Rehabilitation of Existing Pipelines and Conduits by Pulled-in-Place Installation of Cured-in-Place Thermosetting Resin Pipe (CIPP)
ASTM F-1867	Standard Practice for Installation of Folded/Formed Poly (Vinyl Chloride) (PVC) Pipe Type A for Existing Sewer and Conduit Rehabilitation
ASTM F-1869	Standard Test Method for Measuring Moisture Vapor Emission Rate of Concrete Subfloor Using Anhydrous Calcium Chloride
ASTM F-1871	Standard Specification for Folded/Formed Poly (Vinyl Chloride) Pipe Type A for Existing Sewer and Conduit Rehabilitation
ASTM F-1947	Standard Practice for Installation of Folded Poly (Vinyl Chloride) (PVC) Pipe into Existing Sewers and Conduits
ASTM F-2019	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 (CIPP)
ASTM F-2207	Standard Specification for Cured-in-Place Pipe Lining System for Rehabilitation of Metallic Gas Pipe
ASTM F-2233	Standard Guide for Safety, Access Rights, Construction, Liability, and Risk Management for Optical Fiber Networks in Existing Sewers
ASTM F-2303	Standard Practice for Selection of Gravity Sewers Suitable for Installation of Optical Fiber Cable and Conduits
ASTM F-2304	Standard Practice for Rehabilitation of Sewers Using Chemical Grouting
ASTM F-2414	Standard Practice for Sealing Sewer Manholes Using Chemical Grouting
ASTM F-2454	Standard Practice for Sealing Lateral Connections and Lines from the Mainline Sewer Systems by the Lateral Packer Method, Using Chemical Grouting
ASTM F-2550	Standard Practice for Locating Leaks in Sewer Pipes Using Electro-Scan–the Variation of Electric Current Flow Through the Pipe Wall
ASTM F-2551	Standard Practice for Installing a Protective Cementitious Liner System in Sanitary Sewer Manholes
ASTM F-2561	Standard Practice for Rehabilitation of a Sewer Service Lateral and Its Connection to the Main Using a One Piece Main and Lateral Cured-in-Place Liner
ASTM F-2599	Standard Practice for The Sectional Repair of Damaged Pipe by Means of an Inverted Cured-in-Place Liner
ASTM F-2718	Standard Specification for Polyethylene (PE) and Cement Materials for an Encapsulated Cement Mortar Formed in Place Liner System (FIPLS) for the Rehabilitation of Water Pipelines
ASTM F-2719	Standard Practice for Installation of Polyethylene (PE) and Encapsulated Cement Mortar Formed in Place Lining System (FIPLS) for the Rehabilitation of Water Pipelines
ASTM G-95	Standard Test Method for Cathodic Disbondment Test of Pipeline Coatings (Attached Cell Method)
ASTM WK10959 (under development)	Standard Specification for High Density Polyethylene (HDPE) and Encapsulated High Strength Grout Formed In Place Lining System (FIPLS) for the Rehabilitation of Conduits and Sewers

ASTM WK10960 (under development)	Standard Practice for Installation of High Density Polyethylene (HDPE) and Encapsulated High Strength Grout Formed In Place Lining System (FIPLS) for the Rehabilitation of Conduits and Sewers
ASTM WK23937 (under development)	WK23937 New Guide for Structural Spray Pipe Renewal Technology
ASTM WK24074 (under development)	WK24074 New Practice for Installation of Machine Spiral Wound High Density Polyethylene (HDPE) Liner Pipe for Rehabilitation of Existing Sewers and Conduits
ASTM W24075 (under development)	WK24075 New Specification for High Density Polyethylene (HDPE) Profile Strip for Machine Spiral Wound Liner Pipe Rehabilitation of Existing Sewers and Conduit
ASTM WK24231 (under development)	WK24231 New Practice for Internal Nonstructural Pipe Epoxy Barrier Coating Material Used In Pressurized Piping Systems

APPENDIX C

REFERENCED STANDARDS AND STANDARDS/ GUIDELINES ORGANIZATIONS OTHER THAN ASTM

The following table lists the non-ASTM standards, guidelines, and manual of practice listed in this report. Contact information is provided for the organization with the specific standards referenced in the report and the datasheets indicated.

AASHTO (American Society of State Highway and Transportation Officials) • AASHTO H-20 truck-loading configuration	http://www.transportation.org/
ACI (American Concrete Institute) • ACI 440 Committee: Fiber-reinforced polymer reinforcement	http://www.concrete.org/
ASCE (American Society of Civil Engineers) • Standard Construction Guidelines for Microtunneling (CI / ASCE 36-01) • MOP92 (2008 Update) Manhole Inspection and Rehabilitation	http://asce.org/
ANSI (American National Standards Institute) • ANSI/AWWA C900-07, AWWA Standard for Polyvinyl Chloride (PVC) Pressure Pipe and Fabricated Fittings, 4 In. Through 12 In. (100 mm Through 300 mm), for Water Transmission and Distribution • ANSI/AWWA C901-08, AWWA Standard for Polyethylene (PE) Pressure Pipe and Tubing, ½ In. (13 mm) through 3 In. (76 mm), for Water Service • ANSI/AWWA C905-10, AWWA Standard for Polyvinyl Chloride (PVC) Pressure Pipe and Fabricated Fittings, 14 In. Through 48 In. (350 mm Through 1,200 mm) • ANSI/AWWA C906-07, AWWA Standard for Polyethylene (PE) Pressure Pipe and Fittings, 4 In. (100 mm) Through 63 In. (1,600 mm), for Water Distribution and Transmission • ANSI/NSF 14 Certificate 0D470-01	http://www.ansi.org/
ATV (German Water Association) • ATV-M 127-2 Structural Analysis for Rehabilitation of Sewers and Pipelines by Lining and Reassembling Methods, Worksheet, Jan 2000	http://dwa.de/portale/dwahome/dwahome.nsf/home?readform
AWWA (American Water Works Association) AWWARF (American Water Works Association Research Foundation) – Now Water Research Foundation (WRF) • AWWA C900, C901, C905, C906 (see ANSI/AWWA) • AWWA M45 Fiberglass Pipe Design Manual, 2nd Edition	http://www.awwa.org/ http://www.waterresearchfoundation.org/
Barcol Harness • See ASTM 2583	www.astm.org
British Standards Institute • BS 5480:1990 Specification for glass-reinforced plastics (GRP) pipes, joints. and fittings for use for water supply or sewerage • BS 8010-2.5 - Code of practice for pipelines - Pipelines on land: design, construction, and installation – Glass-reinforced thermosetting plastics	http://www.standardsuk.com/shop/

CIGMAT (Center for Innovative Grouting and Materials – University of Houston) • Chemical Resistance and Bond Strength under Hydrostatic Conditions 2004	http://cigmat.cive.uh.edu/
CSA (Canadian Standards Association) • CSA B137.3 "Rigid Polyvinyl Chloride (PVC) Pipe for Pressure Applications"	http://www.csa.ca/cm/ca/en/home
CMOM (Capacity, Management, Operations, and Maintenance) • CMOM Regulations Formulated by the US EPA	http://yosemite.epa.gov/water/ http://www.cmom.net/
Darmstad Rocker Test Method • See DIN 19565	
DIBT (Deutsches Institut für Bautechnik) • DIBT Z-42.3-11 Approval. Purpose: SANIPOR process for temporary rehabilitation of sewer pipes with nominal sizes DN 100 to DN 500	http://www.dibt.de/index_eng.html
DIN (Deutsches Institut für Normung e.V.) • Wide range of applicable standards (standards referenced in this report are): o DIN 53 o DIN EN 63 o DIN 455 o DIN EN 1610	http://www.normas.com/DIN/pages/Translations.html
EN Standards (CEN - European Committee for Standardization) • BS EN 13566-4:2002 Plastics piping systems for renovation of underground non-pressure drainage and sewerage networks. Lining with cured-in-place pipes	http://www.standardsdirect.org/standards/
ETV (Environmental Technology Verification) Program - US EPA and NSF International	http://www.epa.gov/etv/pubs/600s07012.pdf
Government Accounting Standards Board (GASB) • GASB Statement 34	http://www.gasb.org/repmodel/index.html
Green Book (Standard Plans for Public Works Construction, and the Special Provisions Guide for Use with the Standard Specifications for Public Works Construction) • 2008 Supplement to Greenbook; Section 500-2 Manhole and Structure Rehabilitation	http://www.greenbookspecs.org/
IPBA (International Pipe Bursting Association) • Guideline Specification for the Replacement of Mainline Sewer Pipes by Pipe Bursting (IPBA, NASSCO)	http://www.nassco.org/about_nassco/an_div_ipba.html
IAMPO (International Association of Plumbing and Mechanical Officials) • IAPMO IS 26 – Uniform Plumbing Code UPC – Installation Standard for the Trenchless Insertion of Polyethylene (PE) Pipe For Sewer Laterals • IAPMO Certificate C-4397 (IAMPO, 2008)	http://www.iapmo.org/
ICRI (International Concrete Repair Institute) • ICRI Technical Guideline No. 03732	http://www.icri.org/
ISO (International Standards Organization) • ISO/TR 10465-1 - Underground installation of	www.iso.org/

flexible glass-reinforced thermosetting resin (GRP) pipes; part 1: installation procedures • ISO/TR 10465-2 - Underground installation of flexible glass-reinforced thermosetting resin (GRP) pipes - Part 2: Comparison of static calculation methods • ISO 9001-2000 Certified Quality Control	
ISTT (International Society for Trenchless Technology) • Trenchless Technology Guidelines	www.istt.com
NACE International (formerly National Association of Corrosion Engineers) • NACE RPO188 Standard Recommended Practice Discontinuity (Holiday) Testing of New Protective Coatings on Conductive Substrates NACE • NACE RPO288 Standard Recommended Practice Inspection of Linings on Steel and Concrete • NACE RP0394-2002. Standard Recommended Practice - Application, Performance, and Quality Control of Plant-Applied, Fusion-Bonded Epoxy External Pipe Coating • RPO892 Standard Recommended Practice Coatings and Linings over Concrete for Chemical Immersion and Containment Service • SSPC-SP 5/NACE No. 1 White Metal Blast Cleaning • SSPC-SP 10/NACE No. 2 Near-White Blast Cleaning • SSPC-SP 13/NACE No. 6 Surface Preparation of Concrete	www.nace.org
NASSCO (National Association of Sewer Service Companies) • Guideline Specification for the Replacement of Mainline Sewer Pipes by Pipe Bursting - 2004 • MACP (Manhole Assessment and Certification Program) • NASSCO Specification Guidelines • PACP (Pipeline Assessment and Certification Program) • Performance Specification Guideline for the Installation of Cured-in-Place Pipe (CIPP) - 05.18.09 • Performance Specification Guideline for the Installation of Folded (Thermoplastic) Pipe (FP), (HDPE, PVC and PVC Type A) - 8.30.06 • Performance Specification Guideline for the Renovation of Manhole Structures - 10.23.07	http://www.nassco.org/

NASTT (North American Society for Trenchless Technology) • Horizontal Directional Drilling Good Practices Guidelines – 2008 (3rd Edition) • Pipe Bursting Good Practices HDD	www.nastt.org
NSF International (formerly National Sanitation Foundation) • NSF/ANSI 61-2008 Drinking Water System Components - Health Effects Edition: 27th NSF International / 19-Dec-2008 / • ANSI/NSF 14 Certificate 0D470-01 (NSF International, 2001)	www.nsf.org
NUCA (National Utility Contractors Association) • Guide to Pipe Jacking and Microtunneling Design • HDD Installation Guidelines - CD ROM • Trenchless Assessment Guide CD ROM	www.nuca.com
PPI (Plastics Pipe Institute) • PE 3408 designation • PE 2406 designation	http://plasticpipe.org/index.html
RERAU (French National Project RERAU - Rehabilitation of Urban Sanitation). • RERAU report R4A2-18	http://pagesperso-orange.fr/irex-web/rerau.htm
"Six Sigma" Standard	http://en.wikipedia.org/wiki/Six_Sigma
SN Stiffness Class for Pipes • See EN Standard prEN 1225	
TTC (Trenchless Technology Center) • Guidelines for Impact Moling • Guidelines for Pipe Bursting • Guidelines for Pipe Ramming	www.ttc.latech.edu www.ttc.latech.edu/publications/
WERF (Water Environment Research Foundation) • Wide range of guidelines and technical reports	www.werf.org
WIS (Water Industry Specification) • WIS 4-32-01 Guidance Note • See also WRc	
WRc (Water Research Center UK) • WRc SRM (Sewer Rehabilitation Manual) • WRc Type I (composite) design • WRc Type II (stand alone) design • WRc Type-III (corrosion barrier) design • WRc PT/256/0806 (Assessment of the Sanipor system)	http://www.wrcplc.co.uk/