GeoSpray™

Geopolymer Mortar

GeoSpray™ geopolymer mortar system for structural rehabilitation of sewer and storm water infrastructure

EXECUTIVE SUMMARY

Asset owners throughout the United States and the world are in search of cost-effective and environmentally-friendly solutions to severe infrastructure degradation problems such as aging pipes. GeoSpray™ is a revolutionary geopolymer mortar system that is an environmentally-preferred solution for trenchless storm and sewer water pipe repair. GeoSpray allows a contractor to perform an on-site reconstruction of new structural storm or sewer pipe using a patented spray technology resulting in improved strength and flow characteristics within the old pipe. GeoSpray is a styrene-free, easy-to-install pipe within a pipe. It fits within the old pipe regardless of the original pipe condition. The GeoSpray system offers a cost advantaged solution to both contractors and asset owners.

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The world currently faces enormous challenges in how to address it's decaying infrastructure. Whether roads, bridges, tunnels, or buildings on which our everyday livelihood and quality of life depend, these systems are all in a serious state of disrepair; many are on the verge of outright failure. While some of these systems are clearly visible to the public, there are vast underground networks hidden from the naked eye that must provide clean drinking water and removal of waste water for processing. In fact, the American Society of Civil Engineers (ASCE) 2013 report on America's infrastructure gives a D^- score to the waste water category. Specifically, the report states:

> "Capital investment needs for the nation's wastewater and storm water systems are estimated to total $298 billion over the next twenty years. Pipes represent the largest capital need, comprising three quarters of total needs. Fixing and expanding the pipes will address sanitary sewer overflows, combined sewer overflows, and other pipe-related issues. In recent years, capital needs for the treatment plants comprise about 15%-20% of total needs but will likely increase due to new regulatory requirements. Storm water needs, while growing, are still small compared with sanitary pipes and treatment plants. Since 2007, the federal government has required cities to invest more than $15 billion in new pipes, plants, and equipment to eliminate combined sewer overflows[1]."

Almost daily, local and national news sources report the massive safety and quality issues facing the United States with respect to our water systems. This is not just an issue for the United States. It is a problem facing almost every developed nation in the world. In addition to the high economic costs of insuring that the nation's water supply is safe and functional, there are a series of environmental costs that have to be addressed. First, when thinking of the public safety concerns related to failing or degrading sewer or storm water pipelines, toxins or contaminants can leak from these pipes into the neighboring soil and water, creating a myriad of issues. A series of recent articles[2-4] explain, in great detail, the extent of this problem - a problem which is well known to the EPA's water division[5]. Second, simply digging up and replacing the decaying infrastructure has its own environmental issues including: (1) disruption of local environments above and around the piping, (2) possible additional contamination of soil and ground water from the disruption of the existing piping and (3) enormous expense to the tax payer in by-passing these systems while new systems are installed. Finally, many of the current technologies used to address the problem, including the "trenchless" or "no-dig" concepts, have their own significant environmental issues. Cure-in-place-pipe (CIPP) uses styrene-containing resin systems to create a new pipe inside the old pipe, but these systems have the potential to leach contaminates into the water systems.

Standard concrete or cement techniques using high levels of Portland cement create large quantities of greenhouse gases both in their production and use. In addition to these environmental concerns, each of these systems has technical drawbacks that make long term solutions tenuous.

ClockSpring|NRI has developed a revolutionary geopolymer mortar material – *GeoSpray™* – for use as a trenchless technology that addresses cost and environmental concerns. GeoSpray is a styrene- free, easy-to-install pipe within the old pipe. The technology can be employed regardless of the condition of the original pipe. GeoSpray allows a contractor to reconstruct a new structural storm or sewer pipe on-site using a patented spray technology[6]. The "new-pipe-within-a-damaged-pipe" technology results in improved strength and flow characteristics as compared the preexisting structure. The GeoSpray system offers a cost advantageous solution to contractors and asset owners alike. The environmental benefits of the GeoSpray system include: (1) use of industrial waste materials that would otherwise be landfilled, (2) substantial reduction in environmental disruption from the use of a trenchless technology, (3) significantly reduced CO_2 emissions when compared to standard cement materials, and (4) replacement of styrene-based resin alternative CIPP solutions. To date, the GeoSpray technology has been applied to over 150 individual structures. This constitutes more than 30,000 linear feet and 10 million pounds of GeoSpray that has been installed to repair decaying infrastructure.

Geopolymers

Geopolymer is a term originally coined by French researcher Joseph Davidovits to describe a class of "cement" formed from aluminosilicates. While traditional Portland cement relies on the hydration of calcium silicates, geopolymers form by the condensation of aluminosilicates. The kinetics and thermodynamics of geopolymer networks are driven by covalent bond formation between tetravalent silicon and trivalent aluminum. The molar ratio of these key components along with sodium, potassium, and calcium have been shown to affect set-time, compressive strength, bond strength, shrinkage, and other desired properties. In various parts of the world, this type of material is also industrially known as "alkali-activated cement" or "inorganic polymer concrete".[7] Geopolymers are known to provide comparable or better performance to traditional cementitious binders but with the added advantages of significantly reduced greenhouse emissions, increased fire and chemical resistance, and reduced water utilization. The use of geopolymers in modern industrial applications is becoming increasingly popular based on both their intrinsic environmental and performance benefits. Historically, trial applications of

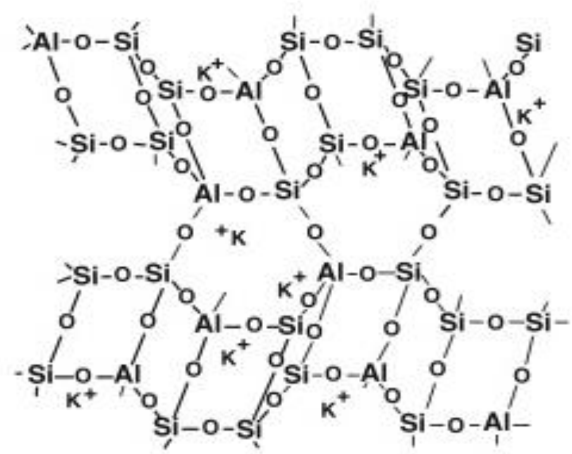

Figure 1: Example Aluminosilicate Geopolymer Structure[7]

geopolymers were first used in some concrete applications by Glukhovsky and co-workers in the Soviet Union post WWII; the geopolymer was then known as “soil cements”[7]. Figure 1 shows a typical aluminosilicate structure that is common among many geopolymer materials.

GeoSpray™

GeoSpray™ is a proprietary geopolymer mortar specially formulated to meet all the physical and chemical requirements of sewer and storm water structures. The material is designed for ease of use. Water is added to GeoSpray at the job site where it can be easily centrifugally sprayed inside an existing structure. The exact formulation of GeoSpray is a trade secret, but generally speaking, it contains a mixture of the standard materials that are used in the production of calcium-aluminosilicates. Other components include, but are not limited to, blast furnace slag, reactive silicas, metal oxides, mine tailings, coal fly ash, metakaolin, calcinated shale, natural pozzolans and natural/processed zeolites. Additional bio-based admixtures are included in the formulation in order to allow the composite material to set-up quickly and easily hydrate with a single addition of water. A summary of the physical properties of GeoSpray as compared to conventional concrete pipes is included in Table 1.

GeoSpray™ has been specially formulated to provide several key benefits to the contractor and asset owner. First, GeoSpray, unlike traditional geopolymers, is a "just add water" job site solution. Traditional geopolymer formulations require the alumino-silcates to be combined with a solution of sodium or potassium silicates that have been dissolved in water. With GeoSpray, the entire system is contained within original powder formulation, allowing a single step addition. Second, the proper selection of proprietary aggregates allows the GeoSpray to maintain easy pumpability up to 500ft within a pipe and still be centrifugally cast without clogging or damaging nozzle performance. To achieve this standard of performance, traditional cement or geopolymer formulations would require much higher water ratios which would degrade their ultimate strength and require a much thicker final product during the installation to meet the flexural strength requirements of the rehabilitation.

Table 1: Physical Properties of GeoSpray™

Test Method	Duration	GeoSpray	Conventional Repair Mortar
Compressive Strength ASTM C-39/C-39M-09a/C-109	1 Day 28 Days	Min. 2,500 psi / 17 MPa Min. 8,000 psi / 55 MPa	5000 psi / 34 MPa
Flexural Strength ASTM C-78	7 Day 28 Days	1200 psi / 8.3 MPa (C-78) 1300 psi / 9 MPa (C-78)	500 psi / 3.4 MPa
Modulus of Elasticity ASTM C-469 – 02	1 Day 28 Days	3,000,000 psi / 20700 MPa 6,500,000 psi / 46500 MPa	3,000,000 psi / 20700 MPa
Bond Strength to Concrete ASTM C-882/C-882M-05	1 Day 28 Days	Min 1,300 psi / 9 MPa Min. 2,500psi / 11 MPa	N/A
Set Time ASTM C-807 – 08 Initial Cure Time	Initial Set Final Set	60 - 75 Minutes 90 - 110 Minutes	120 Minutes 300 minutes
Freeze Thaw Durability ASTM C-666	300 Cycles	100% Zero loss	80% to 90% 10% to 20% degradation
Sulfate Resistance (% expansion) ASTM C-1012-04	6 Weeks	0.011 % Expansion	0.038% to 0.044% Expansion
Shrinkage ASTM C-1090	28 Days	0.07%	0.35% to 0.50%
Tensile Strength ASTM C-496	28 Days	Min. 750 psi / 5.2 MPa	400 psi / 2.7 MPa
Abrasion Resistance ASTM C-1138	6 Cycles @ 28 Day Maturity	0.67% Loss	5.60% Loss
Chloride Ion Penetration by Ponding ASTM C-1543	90 days ponding	0.014 % wt Cl at 55-65 mm	N/A

GeoSpray™ in Action:

To apply GeoSpray™ in the field, the damaged pipe is cleaned in place, typically with high pressure water blasting of 2,500 psi or more. In order to insure adhesion of the GeoSpray to the damaged substrate, it is sometimes necessary to perform an additional cleaning with an environmentally friendly detergent to remove excess oil and grease from the existing pipe walls. If there are large leaking holes, the pipe can be simply plugged with a thin application of the GeoSpray material or another plugging compounded. Finally, the geopolymer mortar is centrifugally cast from atop a sled, which is slowly removed from the pipe to provide a uniform application. Typical application thicknesses range between 1.5 – 3 inches, depending on the type of pipe, local soil and water conditions, current condition of the existing pipe, and the design life requirements of the particular pipe in question. Figure 2 shows a series of images in the repair of a storm water culvert made of corrugated metal from the original deteriorated pipe to the completely restored system.

GeoSpray™ has been installed for both private and public asset owners in the following states: California, Florida, Georgia, Louisiana, Michigan, North Carolina, Ohio, South Carolina, Tennessee, Texas, and Washington[11].

Alternative Technologies:

Currently, there are multiple alternative technologies to solve the crisis in storm and sanitary infrastructure. The first and most costly alternative is dig and replace. This obviously involves the complete replacement of a pipe by digging up the old piping system which is often impractical inside major cities due to the disruption of everyday life. A second set of alternative technologies are what is referred to as "trenchless." Trenchless technologies include CIPP, concrete spray or lining, and slip lining. Environmental benefits of GeoSpray will be directly compared to the competitive technologies.

Figure 2: From left to right (a) Leaking storm water culvert (b) Centrifugal application of GeoSpray™ (c) Completed Repair[11]

Environmental Benefits:

A. Trenchless Technologies: Trenchless technologies, by their nature, have the environmental benefit of creating minimal disruption to the surrounding infrastructure. They use the already existing infrastructure and avoid clearing land, digging, and destruction of plant life. These advantages are of significant importance when the degraded pipes or culverts are in environmentally sensitive natural habitats. In contrast, the traditional open trench replacement method creates significant obstacles. The EPA has long recognized the benefit of trenchless technologies and has commissioned several studies documenting their improved environmental impact.[8]

B. Use of Recycled Industrial Waste: All of the alternative technologies rely mainly on the use of virgin raw materials. Whether it is a new pipe, CIPP made of non-woven textiles with styrene-based resins, or the use of Portland cement, all require new raw materials to provide adequate quality control of the final physical properties of the new or repaired infrastructure. Geopolymers have long been recognized as a safe and effective method for permanently binding inorganic waste streams. The GeoSpray™ geopolymer mortar contains over 60% post-industrial waste as the starting raw materials; a much greater percentage than can be incorporated in any of the other technologies. These industrial waste stream materials are covalently bonded into the materials as the geopolymer undergoes condensation. In addition, the metals and other minerals contained in these waste streams are permanently sequestered by the material and have been shown to not leach into the environment.[7]

C. Styrene-Free Chemistry: Styrene is a volatile compound that quickly mixes with air and water streams. The EPA has defined styrene as a priority pollutant. The use of styrene-based resins in CIPP technologies is particularly hazardous due to both the confined spaces involved and cure conditions. The Virginia Transportation Research Council has shown that an accidental release of uncured resin leads to higher than permissible levels of styrene in the environment. The higher levels have been directly related to fish kills as shown in Figure 3. It has been recommended that the Virginia DOT stop using CIPP processes until such time as it can be shown to be safe to the water supply.[9] GeoSpray is an entirely styrene-free system, using traditional inorganic chemistry.

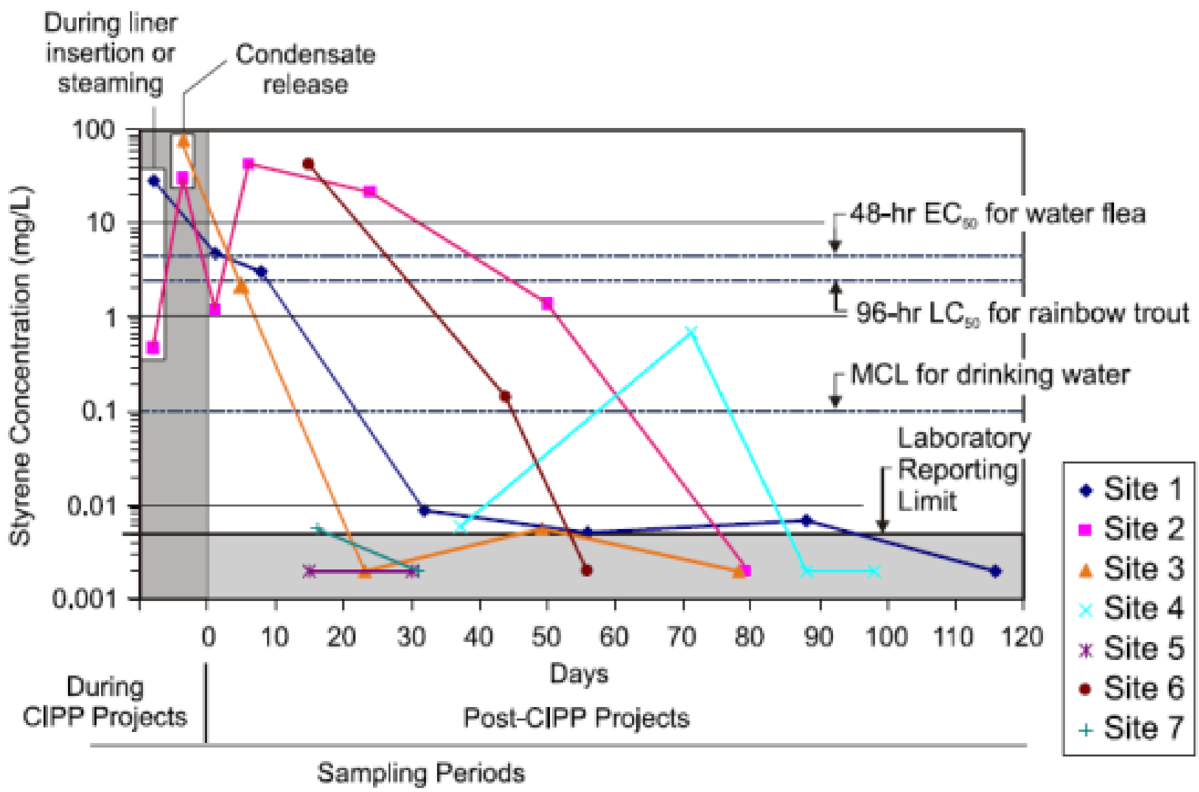

Figure 3: Styrene concentrations in water samples during and after CIPP installations at various sites as part of a VDOT study[9]

D. Reduction in CO_2 Emissions: A great amount of CO_2 is emitted during the production of Portland cement, which is one of the main reasons often cited for global warming. Life cycle analysis studies have shown that for every ton of Portland cement made anywhere in the world, approximately one ton of carbon dioxide is released into the atmosphere. In contrast, GeoSpray™ does not require extremely high-temperature treatment of the limestone but instead relies on a low-temperature processing of naturally occurring or direct man-made alumino-silicates (kaoline or fly ash). It was reported by Davidovits[7] that about 60% less energy is required to produce a standard geopolymer as compared to Portland cement, and 80-90% less CO_2 is emitted.

In addition to the more environmentally friendly product, the process benefits of trenchless technologies from a CO_2 emission standpoint have been quantified by the North American Society of Trenchless Technology (NASTT) in a 2007 report. The authors consider the CO_2 emissions from (a) increased fuel consumption due to traffic delays (b) increased travel distances for detours around open cut repairs (c) fuel consumption of construction machinery and equipment involved in excavation, compaction, backfilling and repaving operations, (d) fuel consumption used to haul materials to and from work sites, and (e) specific manufacturing material such as pipes, asphalt, concrete, back fill materials and other chemicals. As shown in Figure 4, their report found the greenhouse gas emission using a trenchless solution can be reduced by approximately 90% depending on specific conditions based on estimated annual average daily traffic (AADT).[10]

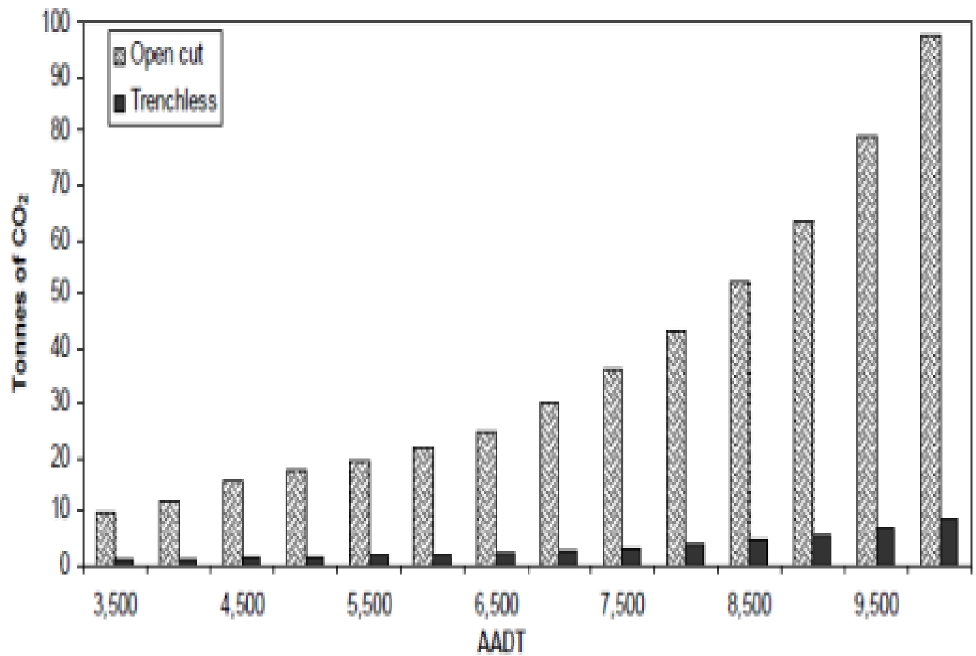

Figure 4: Comparison CO_2 Emissions of traditional open cut versus trenchless pipe repair[10]

Cost Benefits of GeoSpray™:

It has been well established that the cost of trenchless technologies, where a pipe can be repaired instead of replaced, are significantly lower than dig and replace options. Estimates suggest trenchless technologies of any kind have a 50 to 70% advantage over the cost of open trench solutions. A simulation based on raw material cost and labor rates is shown in Figure 5. Among trenchless technologies, GeoSpray™ is the most cost effect method for waste water and storm water pipe repair for pipes of greater than 36 inches in diameter. As the pipe diameter increases, the cost of repairs begin to dramatically increase due to the cost of materials and labor required to clean, prepare, and repair the pipe. GeoSpray™ and its patented method of installation keeps the costs 20 to 50% lower in comparison to CIPP, the market's leading solution. Finally, from the asset owner position, the lifetime of the infrastructure can be extended by more than 50 years based on standard design life calculations.[11]

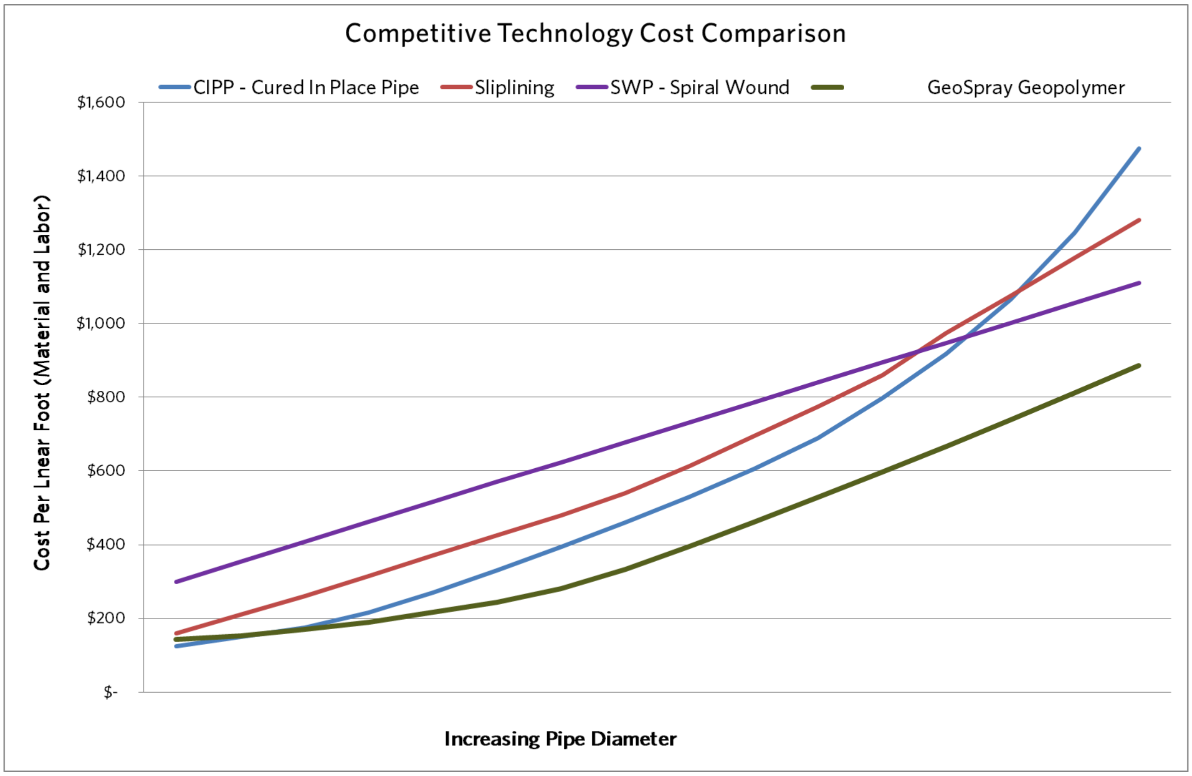

Figure 5: Cost comparison of competitive trenchless technologies

Conclusion:

Asset owners throughout the world are in search for cost-effective, economic, and environmentally-friendly solutions to severe infrastructure degradation. GeoSpray™, a revolutionary geopolymer mortar system, is the environmentally preferred solution for trenchless storm and sewer water repair. The mix of a proprietary geopolymer formulation has significant environmental advantages over existing trenchless technologies. These advantages include preservation of current sensitive environments, use of over 80% post-industrial waste, reduced water usage, and 80-90% less CO_2 emissions, all with a styrene-free chemistry. Finally, GeoSpray and its patented installation method reduces costs by up to 50% compared to the leading existing technology and extends the lifetime of the infrastructure by more than 50 years. GeoSpray has been installed by private and public asset owners in over 10 states, and the number of applications is growing every day.

References:

1. 2013 Report Card for American Infrastructure, http://www.infrastructurereportcard.org
2. Ashely Halsey III and Dana A. Hedgpeth, "Billions Required for Infrastructure," *The Washington Post*, October 15, 2011, p.B1
3. Bruce Hollands, "Procurement Practices that Impede Rehabilitation of Underground Water Infrastructure," *Mayors Water Council*, Summer/Fall 2010, p.4
4. Nassco, Inc, "Guideline for the use and handling of styrenated resins in cured-in-place-pipe" September 2008
5. EPA-832-F-99-032
6. US Patent Applications US20120199062A1; US20120199668A1; US20120199669A1.
7. Davidovits, Joseph, "Geopolymer Chemistry and Applications" 3rd Edition, *Geopolymer Institute*, 2011.
8. water.epa.gov; EPA-832-F-99-032
9. http://www.virginiadot.org/vtrc/main/online_reports/pdf/08-r16.pdf
10. Rashid Rehan and Mark Knight, "Do Trenchless Pipeline construction methods reduce greenhouse gas emissions?", NASTT, Sept. 2007
11. http://www.teamipr.com