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SHARING PIPELINES, TUNNELS, MULTIPURPOSE STRUCTURES, AND RIGHTS OF WAY AMONG CABLES, GASLINES, SEWERS, HEATING DUCTS, AND WATERLINES

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ABSTRACT

Our citizens are fed up with utilities- each one doing their own thing creating disruption to their lives, multiple times. We need refreshing ways to serve our citizens better. This paper presents innovative construction ideas of how structures could be designed, constructed, and shared among multiple utilities to save enormous amount of time and money in the most environmental friendly manner.

KEYWORDS

Multiuse structures, shared rights of way, cables

INTRODUCTION

The very governmental, commercial, and residential end users who are craving for true broadband coming into their premises already have sanitary sewers, storm drains, waterlines, and natural gas lines reaching their premises to meet their needs. The fat pipe to carry infinite voice/video/data from multiple providers could be housed in these utilities by forming creative business partnerships among optical fiber owners, service providers, utility pipe owners, and vendors. By municipalities taking the initiatives for building the last mile or FTTH fiber, they could meet the needs of FTTH, renovation of their aging pipeline infrastructure, and improved sensing, surveillance, and security of vital lifelines and treatment plants. None of the old and established rules for making money in the cable market would work. First of all, the causes of the current fiber glut need to be understood; new rules need to be written with a whole new set of business partners and new financial incentives ought to be considered in the rewriting of the business plan. The very governmental, commercial, and residential end users who are craving for infinite bandwidth through optical fiber networks coming into their premises already have sanitary sewers, storm drains, waterlines, hot water pipes, heating ducts, electrical conduits, and natural gas lines reaching their premises for providing essential services to meet their needs. These underground pipes start in the vicinity of the current POPs of optical fiber in the metro loops or backbones and finish inside of the very buildings where the last mile or FTTH fiber needs to end to provide the on and off ramps for these information highways made of optical fiber. It makes all the sense in the world to locate the last mile or FTTH fiber in these existing rights of way on sewers, water mains, and gas pipes to deploy last mile or FTTH fiber quicker and at a cheaper cost, particularly when some of these pipes are renovated.

WORLD IS HUNGRY FOR BANDWIDTH

More than 110 million North Americans are expected to telecommute to work by 2010. This will increase our productivity and quality of life significantly. The rest of the world also would have similar unprecedented numbers of people working from these home offices. The world needs more bandwidth to meet its demands for better homeland security, better classrooms, better government, better medicine, better science and technology, better entertainment, better quality of life, and better job opportunities.

CHALLENGES WITHIN THE LAST MILE

There are numerous challenges for anyone other than local utilities or ILECS to build the last mile or FTTH fiber. Local municipalities control access of much needed rights of way. They charge franchise fees, make the permit process really difficult, and pass numerous ordinances to discourage open cut construction of fiber and even impose network build moratoriums. Some even demand free fiber, where the network provider will lose even their existing revenue from the very municipalities, while requiring that the network builder pass on to them a portion of the gross revenue from the remaining fiber. Often, the areas where municipalities are willing to let fiber construction proceed are not where demand is and even in these, municipalities enforce strict time limits. The ILECS already have infrastructure in place in most locations and only fiber laterals are left to bridge the last mile or FTTH. Even regulatory environment has not given the CLECS the legal teeth they needed to compete more aggressively in the marketplace against the ILECS. The result is a mere 10% penetration by CLECS in the local access market even after 6 years of operating in the aftermath of the Telecom Act of 1996. Most significantly, the last mile or FTTH fiber carrying conduit design and installation has been in the hands of mostly telecom personnel with little or no input from civil engineers, resulting mostly in expensive and laborious implementation adding further to the problems surrounding the last mile or FTTH. If adequate civil engineering talent were involved in approaching the municipalities for access for rights of way on behalf of fiber installers, given the very municipality public works departments are managed by civil engineers, matters would have preceded a lot quicker.

SECURITY OF PIPES, PLANTS, AND PUMPS

If the optical fiber technology could be rolled out at a faster pace, with less hurdles in rights of way acquisition, and at a lower cost, then end-to-end optical fiber connectivity could win this race in the coming years in the last mile or FTTH. For this to happen, we need to turn to existing underground infrastructure to build our communication networks, so that we can avoid additional congestion underground. North America already has invested many trillions of dollars in the past century building an extensive underground pipe network. These underground utilities were carefully engineered, constructed, operated, and maintained with mostly public funds. These have been stable well-protected structures deep in the ground forming a vast network as shown in Table 1. Other countries have similar underground pipe networks. These have served their intended functions meeting our needs for over 100 years. Using them for the un-intrusive housing of broadband fat pipe would speed up significantly the deployment of fiber in the most challenging last mile or FTTH. These would afford us an opportunity to monitor the security of these underground lifelines. These would also provide us an opportunity to operate treatment plants, compressors, pumps, and other equipment unmanned from remote unknown locations toward better homeland security measures.

Table 1. Underground utilities in america

Sanitary sewers, 1,280,000 km
Storm drains, 720,000 km
Combined sewers, 160,000 km
Potable waterlines, 1,360,000 km
Natural gas lines, 1,800,000 km
Petroleum pipelines, 480,000 km
Irrigation pipelines, 320,000 km
Industrial waste lines, 880,000 km

Total 7,000,000 km

There are a number of cities around the world that have used existing utility pipes for building their broadband networks while serving their originally intended functions and Table 2 provides a partial list. It appears the needs of FTTH, renovation of aging pipeline infrastructure, and improved sensing and surveillance could all be accomplished by municipalities taking the lead to build the last mile or FTTH networks with suitable partners in existing pipeline infrastructure.

THIS IDEA HAS BEEN AROUND SINCE 1983

Using existing conduits for multiple uses is not a new concept. Early attempts were in Paris more than 100 years ago but poor results led to abandonment of the concept of installing multiple utilities in the same underground tunnels. There also were a number of projects in America about 80 years ago where telephone companies were permitted to lay their cables inside of drinking waterlines. The innovative idea of using existing fluid conduits for additional functions not originally intended, emerged again in 1983 when Jeyapalan et al. designed 2 high pressure hydropower penstocks of size 2144 mm (84 inch) in diameter to hang from the roofs of 6.4m (21 ft) diameter outlet tunnels at Jennings Randolph and Gathright dams in West Virginia and Virginia. These large penstocks were designed in 304L stainless steel to survive the acidic water with a pH of 3 or less flowing through the outlet tunnels. Therefore the technical issues in the current situation of using existing pipelines for housing optical cables are rather minor compared to what we coped with in 1983 and we have progressed in our civil engineering know-how in many fronts in the past 20 years.

Table 2. Broadband networks in underground utilities

City	How Long?
Tokyo	850 km in sewers
Vienna	400 km in sewers
Taipei	400 km in gas lines
Hamburg	100 km in sewers
Berlin	50 km in sewers
Yokohama	42 km in sewers
Kawasaki	37 km in sewers
Ogaki	24 km in sewers
Sapporo	21 km in sewers
Nagoya	18 km in sewers
Kyoto	18 km in sewers
Minami	13 km in sewers
Yodogawa	11 km in sewers
Albuquerque	9 km in sewers
Osaka	6 km in sewers
Toronto	5 km in sewers
Hmeji	5 km in sewers
Akashi	5 km in sewers
Indianapolis	5 km in sewers
Hanau	5 km in sewers
Tokushima	4 km in sewers
Dublin	3 km in sewers
Munich	3 km in sewers
Amsterdam	2 km in sewers
Copenhagen	2 km in sewers
Madrid	1 km in sewers
Boston	1 km in sewers

OPTICAL FIBER IN JAPANESE SEWERS

Shortly thereafter, the first invention for using existing sewers for installing communication cables was developed by a group of engineers from the Water Research Center (WRc) in UK. A patent was issued by the UK patent office on 16 May 1984. Subsequently, the US patent No: 4,647,251 was secured on March 3, 1987 and the assignee was Cabletime Installations Limited operating out of Washington, DC. For reasons unknown even to the current employees of WRc, this patent was allowed to expire due to nonpayment of annual dues after WRc attempting to commercialize this invention for some years. Japanese assembled a robot in 1987, following an art somewhat similar to that disclosed in the UK invention, to install optical fibers initially in Tokyo sewers, and the Japanese applied for European, Japanese, Korean, and US patents. The US patent No: 4,822,211 was issued on April 18, 1989 with Nippon Hume, Tokyo Metro Government, and Tokyo Metro Sewer Service Corporation as co-assignees to protect the robot.

The primary reason for the Japanese engineers to install optical fiber in their sewers in Tokyo in 1987 was to control sewage treatment plants remote without having to employ human power at each of these locations. Tokyo Metro Government and Tokyo Metro Sewer Service Corporation promoted this concept as their SOFT plan widely. JSOFTA was also instrumental in changing the Japanese public law in 1996 for the sewer owners to permit materials other than sewage in their sewer system paving the way for a wider deployment of fiber in the sewer. Tokyo Metro alone has more than 850 km of fiber in the sewer, with about 140 km installed by these robots, more than any other city in the world. According to Nippon Hume, the original robots had options to either be self-driven or operated by winches. Given most of the sewers in Japan were made of centrifugally cast reinforced concrete pipe, drilling into the pipe wall required significant amount of power through the umbilical cable supplying water, air, electricity, and communication circuits. According to Nippon Hume, when the Tokyo Metro discovered that it was better to conserve power, self-driven robots were not the preferred option. Nippon Hume began to promote this robot system for sewer sizes 200 to 1200 mm widely. Recently, the Japanese Ministry of Construction has also published a goal of building 100,000 km of optical fiber networks in existing sewers all over Japan by year 2010 toward promoting the Multi-Media Society. In America, the Technology Network has called on the federal government to adopt a goal of 100 megabits per second to 100 million homes and small businesses by 2010.

BERLIN USING NIPPON HUME ROBOTS

BerliKomm owned by Berlin Water had an ambitious plan in 1997, in that it would provide each customer in Berlin with a broadband connection within 30 days of asking. Berlin water turned to 3 Japanese robots sold by Nippon Hume initially by setting up a new company named Robotic Cabling GmbH Kabelverlegung (RCC) owned with Marubeni and Nippon Hume and installed about 1500 m of optical fibers in its own combined sewers in Berlin in the winter of 1998. The Japanese robot was steered by a control unit but was pulled using winches through the manholes. A special drill was used to cut a hole 6 mm dia. 15 mm deep for the J-hook anchor of the cable with its 2 part resin system that hardens in the hole after activating the plunger pin once deployed after placing the optical fiber cable in the J-hook. A change from the version of the Japanese robots Berlin used is that the 3 units assembled in Berlin could propel it once inside the sewers, in a way no different from the robots Japanese had in their first generation for Tokyo Metro, installing the cable at high speeds under optimal conditions. The Berlin drill and dowel anchor robot has eliminated the use of the 2-part resin bonding the Japanese system uses.

MAN-ENTRY TECHNOLOGY

Man-entry sewers are those with a diameter larger than 700 mm. The sewer lengths in North America of sizes not larger than 700 mm exceed 90%. Even the sewers of sizes larger than 700 mm forming less than 10% of route lengths lie in the outer skirts of a major city, where the demand for last mile or FTTH fiber is not there yet. This implies that the market for man-entry technology is rather small in North America at this time. Many methods could be used for putting fiber once human could enter the sewers. For fixing the expansion anchor, a hole must be drilled into the sewer wall, which would pose no major structural problems as long as there is adequate wall thickness in sewers with an 800mm dia. and above. The cables can be added in the future as demand for the fiber count increases. This technology has been in use for some years. In Tokyo alone, there is over 700 km of such fiber installations in man-entry sized sewers for the longest duration, more than any other city in the world. And in Vienna, there is over 400 km of man-entry fiber using CableRunner.

MORE WAYS FOR CABLES IN SEWERS

CableRunner uses a drill and dowel system in sewers of 250 to 700 mm in size. DTI-CableCat uses either a back-reamed anchor or an adhesive bed system in sewers of sizes 200 to 1200 mm, while Nippon-Hume and RCC use drill and dowel systems for the same sized sewers. In addition, there are liner systems vying to do some of this as part of routine sewer maintenance programs. There is a good chance that these liner companies will succeed if they are able to offer value-added relining systems for an attractive incremental fee to the city sewer agencies over the standard lining systems without cutting too much into the current functions of the sewers. The author is also aware of a number of other new technologies for building optical fiber networks in sewers. For example, see US patent No: 6,301,414 issued on October 9, 2001 to a group of optical fiber experts from Alcatel. Nippon Hume, Consec, TMG, and TMSSC have jointly applied for new patents to protect their new C and W anchors and new modular robots, shown in Figure 1.

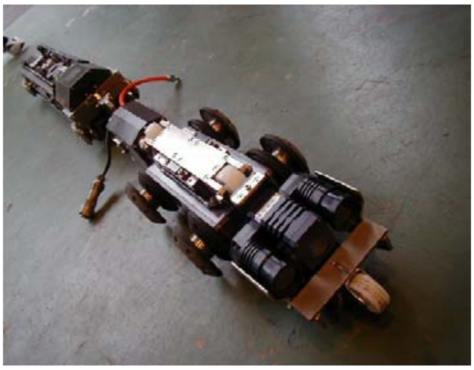

Figure 1: New Nippon Hume Robot

TMG, Corning Cable Systems MCS-Drain, shown in Figure 2, and Ashimori Industries' offering to use tensioning devices to span the cables manhole to manhole to anchor them on the walls of the manhole are quite similar. A typical technology to build cables as part of relining a sewer is shown in Figure 3.

OPTICAL FIBER IN NATURAL GAS PIPES

Sempra Fiber Links, Alcatel, and Gastec are three companies offering new technologies to install optical fiber cables in natural gas pipes. Tokyo Gas and Osaka Gas also have installed cables in gas mains. In Sempra's technology, special fittings are attached after tapping the gas main at two locations to form the entry and exit points for the optical fiber. The gas mains could be even as small as 25 mm in size and the fiber conduit will take up to no more than 10% of gas flow area. In the event a particular gas line cannot handle even a 10% reduction in capacity, additional pipe capacity will be added according to Sempra. In this author's opinion, if the additional pipe capacity is needed then this approach offers little advantage over the traditional dedicated conduit for placing the optical cable. A small HDPE conduit is threaded through the entrance fitting until it reaches the exit fitting. A special tool is used to grab hold of the threaded conduit and pull it out through the exit fitting. Once this housing conduit is placed in the gas main, the optical fiber cable is pushed through this conduit from one fitting to the next. The fittings and seals are designed to meet all gas pipeline safety requirements of the U.S. DOT, CFR 49, section 192 and any local regulations such as California PUC General Order 112-E. Sempra reports that a crew of 5 to 7 workers can install up to 600 m per day.

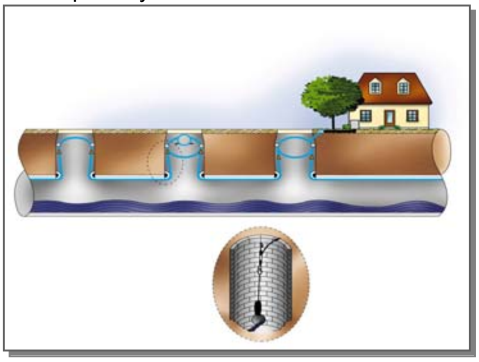

Figure 2: Cables in Sewers

Figure 3: Building Cables in Liners

In the Alcatel system, a balloon device is used to pull a specially designed optical fiber cable through the Inlet port clear through the Outlet port shown using a gas pressure differential. The cable itself has a special metallic barrier, to prevent hydrogen gas migration to cause the optical fiber strands going blind. Again, the seals and the ports are designed to meet various safety regulations. Gastec offers a solution where a specially designed shuttle pulls a cord from an inlet attached to the gas main all the way to the exit port using a gas pressure differential. This is done by creating an overpressure of about 150 mbar at the inlet side while a negative pressure is created by flaring off gas through a venting safety valve at the outlet side. An added benefit of fiber in gas deployment is that a few strands of the fiber could be used as a leak detection system by collecting spatial resolution data. The fiber in gas solution as introduced by Alcatel is shown in Figure 4.

CABLES IN DRINKING WATER PIPES

Drinking water pipelines also enter most buildings. All fiber cable materials must meet EPA regulations on drinking water. In typical metropolitan regions, numerous valves exist in the drinking water pipeline and are bypassed with the cable. Ideally, each of these bypasses forms a fiber POP. A cable entry point consists of a water pipe flange and a sealed cable inlet. The flange is installed on the water conduit under normal operating conditions and the water flow is

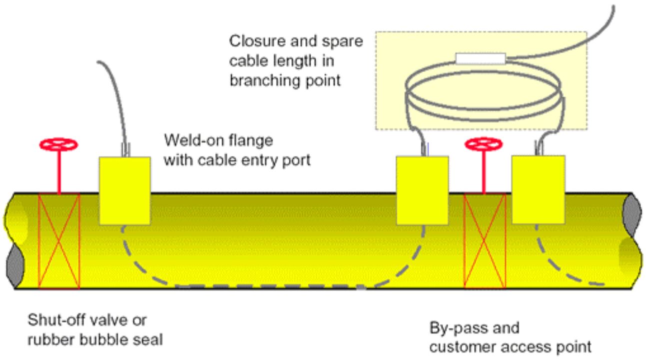

Figure 4: Cables in Natural Gas Mains

interrupted only for the actual cable insertion. The cable is installed by means of a rope, which is fed into a flange and floated to the next flange as shown in Figure 5. The cable is then attached to the rope and pulled manually into the pipe. Cables in drinking water pipes is also inexpensive and every valve is a potential customer connection point. There have been many installations of communication networks in active or abandoned drinking water pipes going as far back as 100 years.

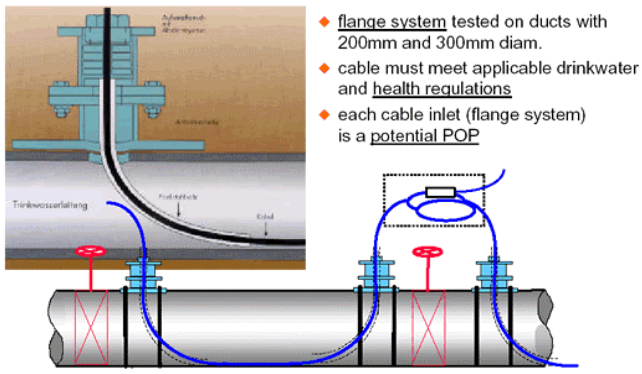

Figure 5: Cables in Drinking Water Pipes

OTHER METHODS OF CABLE INSTALLATION

There are numerous other ways to build FTTH or the last mile using micro-cuts in pavements and ducts that are either new or occupied with other cables. Corning, Alcatel, Draka, Erickson, Strangeways, and others are able to deploy by making micro-cuts in pavements. Sewerlink by Brugge provides an attractive option for laying cables on the bottom of the pipe for low installation cost and at high production rates. Pipe bursting method could be used to install cables with pipes for other functions. Microduct blowing of fiber is done by Alcatel, Sumitomo, Neptco, ABF, NextGen, Draka, and others. Cables of fiber could be blown by Plumettaz, Lancier, Condux, Neptco, and others. Horizontal directional drilling also can be used for cable installation. Many different forms of rehabilitation liners are also available for fiber cable inclusion during pipe renovation.

ASTM, CIGRE', ICEA AND IEEE

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Over 200 stakeholders from 20 countries have joined together to form new ASTM Committee F36 on Technology and Underground Utilities. This group has been at work developing standards for the deployment of fiber-optic cables in underground utilities, pipeline rehabilitation methods, and seismic risk assessment procedures. Participants in the new committee include municipal authorities, building owners, robot- manufacturers, pipe manufacturers, optical-fiber cable manufacturers, telcos, and construction, architectural and engineering consultants, to name just a few. This committee usually meets in January and June. Although attendance of members is always preferred because of its value in networking, participation is still encouraged via web forums, teleconferences, emails, and regular correspondence. The standards in print to date are:

1. F2233-03 Standard Guide for Safety, Access Rights, Construction, Liability, and Risk Management for Optical Fiber Networks in Existing Sewers
2. F2303-03 Standard Practice for Selection of Gravity Sewers Suitable for Installation of Optical Fiber Cable and Conduits
3. F2462-05 Standard Practice for Operation and Maintenance of Sewers with Optical Fiber Systems
4. F2304-03 Standard Practice for Rehabilitation of Sewers Using Chemical Grouting
5. F2414-04 Standard Practice for Sealing Sewer Manholes Using Chemical Grouting
6. F2454-05 Standard Practice for Sealing Lateral Connections and lines from the mainline Sewer Systems by the Lateral Packer Method, Using Chemical Grouting
7. F2550-06 Standard Practice for Locating Leaks in Sewer Pipes Using Electro-Scan--the Variation of Electric Current Flow Through the Pipe Wall
8. F2349-04 Standard Practice for Operation and Maintenance of Integrated Natural Gas Pipelines and Optical Fiber Systems
9. F2350-04 Standard Practice for Selection of Natural Gas Pipelines Suitable for Installation of Optical Fiber Systems

In 2004, IEEE founded a new working group within PES/ICC named C27-Installing and Operating Power Cables in Pipelines and Rights of Way. The goals of this group are: To study and report feasibility, design, construction, testing, quality assurance, risk management, operation, and maintenance issues associated with locating underground power distribution cables in existing rights of way and pipelines performing other functions. This work has also included a review of existing regulations prohibiting such installations and addressing technical issues to pursue this approach toward many benefits to those parties with such interest. This group has been meeting twice each year and will continue its work toward fruition in the form of a series of deliverables. We are trying to develop answers to the following questions:

1. How did this work for the communication cables?
2. What problems we foresee if we attempt to use the same techniques for power cables?
3. What specs or barriers need to be overcome when we attempt to apply this approach within certain jurisdictions around the world?
4. How do we address the safety and regulatory issues?

Cigre' formed working group WG-B1-08 in August 2004 during its biannual meeting in Paris, has been meeting thrice each year, and is developing an engineering guide on Cable Systems in Multipurpose or Shared Structures. The scope of this working group has been:

- To establish the appropriate terminology.
- To collect and summarize the worldwide information and experience for multipurpose tunnel or shared structure through a questionnaire built by the WG. Questionnaire shall not be limited to technical aspects (type of cables, type of structure design, kind of infrastructure installed in the same structure, construction, installation, mutual impacts, maintenance, operation constraints …). Questionnaire also deals with
    - Economical aspects,
    - Safety aspects,
    - Administrative aspects,
    - Legal aspects and
    - Decision making aspects.
- To review the issues that needs to be taken into consideration when installing underground cable in multipurpose or shared structures.
- To recommend guidelines for practical application of installed cables in multipurpose or shared structures.

The global survey of such structures in existence has been completed and 25 tunnels and bridges have been documented as those that have cables with other utilities. The pros and pros have been documented by Cigre' working group B1-08 as follows:

Pros:

- Lower capital cost to all parties concerned.
- Less impact on surroundings and the environment.
- Avoidance of multiple excavations and disruption to traffic.
- Shorter design, construction, and commissioning.
- Less risk on utility conflicts.
- Better government oversight to get many utilities to cooperate.
- Better protection against natural hazards.

Cons:

- Longer planning time.
- Higher degree of coordination among multiple parties.
- Higher upfront costs.
- Higher reliance on others for better security.
- Increased access issues.
- Constraints on O&M.
- Higher risk on employees.
- Risk of damage by others in the consortium.
- Better worker training needs.
- Mutual impact of one utility on another.

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- Ongoing cost of leasing and increased level of maintenance.
- Increased reliance on others.

The past meetings of WG-B1-08 have been in Paris, Sydney, Stockholm, and Tokyo. The upcoming meetings are in Paris, and possibly in Singapore, London, and Tokyo. The August 2006 meeting in Paris will focus on developing the draft for the guidance document considering the following issues:

- Management
- Ownership
- Compatibility
- Safety
- Segregation
- Design life
- Services
- Security
- Legal
- Risk Management
- Technical
- Construction Techniques
- Environmental
- Financial Incentives
- Worker training

In addition, the Insulated Cable Engineers Association (ICEA) has been writing a new standard on special cables for installation in sewers. There are a number of FTTH projects underway nationwide and additional communities have undertaken feasibility studies on FTTH deployments. Many of the techniques reported in this paper could be used to lower the overall cost of FTTH deployments while cutting the construction time by a substantial percentage. It should be borne in mind that the inclusion of additional conduits to carry cables either inside or outside of utility pipes planned in new construction projects would add minimal cost to the overall design and construction of conduits in the ground.

CONCLUSIONS

1. U.S. EPA rules have required most cities to upgrade their sewers and waterlines in the coming years. It appears that a viable partnership could be arranged among telcos, pipe owners, service providers, and vendors, where each party has something to gain by cost sharing.
2. The installation of cables inside of sewers, waterlines, hot water pipes, electrical conduits, heating ducts, and gas pipes is a major break through in sharing the underground pipes. However, telecommunication and power companies need to address all the concerns associated with using existing pipes, before wide spread cable deployment could proceed.
3. Working in the sewer, water, or gas pipe will affect the health, safety, and welfare of the people we serve and any shortsighted approach to selecting the suitable sewers or gas pipes for installing and operating cables, would expose all those in this new industry to an enormous liability. Developing sound engineering standards to guide this new industry falls well within this obligation.
4. The factors which will continue to provide momentum for the market are:
   - Aging underground infrastructure
   - Doing more work with less funds
   - Protecting the environment
   - Increasing congestion
   - Faster rate of technology transfer
   - Privatization of utility companies
5. Not all sewers, waterlines, hot water pipes, heating ducts, electrical conduits, and gas pipes are amenable for installing cables and companies which support strong engineering talent on their staff will focus their attention to those lines which would satisfy proper engineering criteria.
6. The deployment of cables in existing pipelines and rights of way offers a win-win situation for all parties involved if proper standard of care is afforded. However, working in these pipes requires sound pipeline engineering input and anything less than that would be shortsighted. If telecommunication and power companies did not follow proper engineering know-how, it would only be a matter of time before we will face major problems and the cost to return these sewers, waterlines, and gas lines to normal working order would be far greater than the lease revenue cable installers are offering at the present time.