A recent study from the Uni-Bell PVC Pipe Association, conducted by Sustainable Solutions Corp., presents the first comprehensive environmental review of underground PVC pipes for drinking water, sanitary sewer, and storm sewer piping systems in North America based on a 100-year life cycle assessment (LCA) methodology.

The study evaluates underground pipe infrastructure in the context of providing sustainable water and sewer service over a 100-year period: (1) with minimal risk of degrading water quality; (2) while reducing the costs of operations, maintenance and repair; and (3) by taking into consideration the variables which can influence pipe performance and service-level expectations. The report also provides relevant data which can assist utility officials with their asset management plans and life cycle cost assessments for different pipe materials.

The study, “Life Cycle Assessment of PVC Water and Sewer Pipe and Comparative Sustainability Analysis of Pipe Materials,” combines two major components of sustainability analysis. First, the study documents the cumulative embodied energy of PVC pipe for each of its life cycle stages from cradle-to-grave. This creates a common platform to both discuss and compare aspects of the product’s carbon footprint and its environmental impacts in scientific terms.

The second component takes into consideration the elements which can influence pipe performance and service level expectations. While manufacturers suggest a pipe life expectancy based on testing and manufacturing processes, utilities typically select a different service life in the installed environment. Service life is determined by design features, operational conditions, environmental conditions both inside and outside the pipe, and intended use. This study recognizes this fact and develops a performance-based service life for each pipe material. This performance-based service life in the installed environment focuses on the pipe’s ability to deliver a sustained level of high water quality in a cost-effective manner. In order to accomplish this, the major pipe materials and environmental and sustainability variables were considered. This includes an in-depth review of the two most common water pipe materials – PVC and ductile iron – as well as the specific attributes of other pipe materials. Sustainability, in terms of consistent water quality and delivery through underground pipe infrastructure, includes the variables of corrosion risk, climate impacts and energy costs. When determining a pipe material’s service life, a 100-year system design life is used. When all of these elements are combined, monetized costs can be applied to better compare the results. The following provides some highlights of key findings of the overall study.

Comprehensive & Transparent

This study provides a comprehensive and transparent life cycle assessment and sustainability review to the North American water and sewer industry. The PVC pipe LCA contains the required cradle-to-grave life cycle stages which include:

- Extraction and processing of raw materials;
- Manufacturing;
- Transportation and distribution;
- Installation, use and maintenance; and
- Recycling and final disposal

By including the impacts throughout the product life cycle, the LCA provides a comprehensive view of the environmental aspects of the product and an accurate picture of the environmental tradeoffs in product selection. Pipe life cycle assessments are based on a minimum 100-year design life benchmark due to the very long asset life of pipe infrastructure.

LCA is a more comprehensive and transparent analysis of the environmental impacts of a product throughout its life and is a much better indicator of environmental performance than single attribute claims like recycled content. Some materials, like metal, require large amounts of energy to recycle; and in the process, emit additional toxic emissions compared to nonrecycled primary metal production.

The Institute for Market Transformation to Sustainability’s SMaRT certification for ductile iron and vitrified clay pipes (VCP) does not provide complete transparency for environmental certification. No life cycle environmental information about the products is disclosed, preventing comparability with other pipe materials. Without transparent disclosure of environmental impact data, it is not clear if ductile iron pipe corrosion mitigation treatments such as cement lining and other additives to reduce corrosion are included in the analysis or certification of the pipe. SMaRT certification requires that dioxins are not produced during manufacturing; however, the manufacturing of ductile iron pipe produces dioxins.

When evaluating the sustainability of piping products for life cycle design, it is important to understand and evaluate the life cycle impacts of all materials used in the piping system.

This PVC pipe LCA study supports the efforts of asset management best practices and concepts that strive to reduce the life cycle costs of underground water, sewer and storm sewer assets while maintaining performance and reliable service levels, protecting water quality and minimizing water main breaks, water loss, infiltration and pavement repairs.

Pipe manufacturers market various pipe materials with an estimated life. This “estimated” life does not represent the point at which pipe performance may begin to fail to meet intended service levels. The PVC pipe LCA study considers the various literature and manufacturers’ estimated pipe life, but it also incorporates the practical evidence of industry pipe failure trends and dig-up studies to attribute a real-life pipe performance age to be used in the 100-year evaluation period.
This study provides some examples of 50-, 75- and 100-year service lives to assist utility operators in understanding the modeling assumptions used in this study.

PVC pipe is assigned a 100-year service life based on 60 years of experience, extensive industry studies, dig-up field samples and historical data demonstrating low failure and water main break rates. A study of exhumed PVC sewer pipe estimated its service life between 100 and 300 years.

PVC water pipe break rates reduce with time, whereas failures in corrosion-prone iron and concrete pipes increase over time, resulting in higher operating and maintenance costs.

Based on data from existing literature and industry pipe failure trends, ductile iron (DI) and high-density polyethylene (HDPE) pipes with thinner walls are not expected to last for 100 years due to internal/external corrosion and oxidation/strain creep, respectively.

Ductile iron, like PVC, has been used for water and wastewater infrastructure for about 60 years. For this study, ductile iron pipe is assigned a 50-year service life based on failure data of DI pipes and the fact that new ductile iron pipes have much thinner walls than older iron pipes and lack independent dig-up and pipe material testing studies. Metallic pipe systems require extensive condition assessment, corrosion surveys, corrosion protection systems and water quality testing. Since there is very little data on the actual longevity and performance of newer HDPE pipe with thinner walls, a 50-year service life was assumed due to the potential for oxidation, strain creep and reduced Safety Factor.

Long-Term Water Quality

Consistent long-term water quality is a critical sustainability requirement during the life of a pipe. Some of the primary water quality benefits of PVC include:

- PVC pipe does not corrode from bacteria and biofilm and PVC pipe does not serve as a nutrient source for bacterial growth;
- PVC pipe will not degrade, corrode or leach when exposed to corrosive water, wastewater, sewer gases or disinfectants;
- PVC pipe does not require chemical additives to prevent internal corrosion;
- PVC pipe does not have oxidation-induced premature failures;
- PVC pipe does not contain plasticizers such as DEHP or other phthalates;
- PVC pipe does not contain lead;
- PVC pipe does not contain BPA; and
- PVC pipe does not leach vinyl chloride monomer.

Cast iron pipes have used molten lead as a pipe joint since the late 1800s. Any iron pipe water distribution systems older than 60 years most likely used lead to seal pipe joints. These iron pipes face severe corrosion issues, high water loss and can be a source of lead contamination to drinking water supplies.

Metallic and concrete pipes are always at risk and subject to internal and external corrosion. They require chemical additives (phosphates) in the drinking water to help reduce pipe wall corrosion. Phosphates increase the chances of biogrowth (such as algae blooms in extreme cases) in drinking water sources, lakes and rivers.

Corroded iron pipes cause rusty water events with an increase of iron ions. This can cause a water disinfectant to become ineffective, creating an increased risk of contamination. The inside area of a ductile iron pipe from the beginning of the bell to the gasket is not coated with lining material so that portion of each joint of installed DI pipe has potable water exposed to a surface not certified to NSF/ANSI 61.

Studies demonstrate that cement-mortar linings used in ductile iron pipes may fail or degrade between 10 and 30 years due to structural issues and chemical leaching. This leaves potable water exposed to a pipe wall not certified to NSF/ANSI 61.

Manufacturing

PVC pipe manufacturing is a very efficient process. It requires low inputs of energy and water, and scrap and rework materials (regrind) can be returned directly into the manufacturing process. This results in virtually no manufacturing waste.

Only a small amount of energy is required for the extrusion of PVC pipe, so manufacturing is a small contributor to cradle-to-grave impacts. The use of closed-loop water conservation technology has significantly reduced water consumption for the manufacturing of PVC pipe, demonstrating the industry’s commitment to continuous improvement and efficiency.

Many pipe material production processes emit dioxins, such as manufacturing of ductile iron pipe, cast iron pipe for plumbing, concrete pipe and PVC resin. U.S. EPA data on dioxin emissions from PVC resin manufacturing show that dioxin levels are extremely low for PVC resin production and are continually being reduced.

EPA data show that dioxin emissions released from a ductile iron foundry were almost six times as high as a facility producing PVC resin. PVC pipe manufacturing facilities do not emit dioxins.

Ductile iron pipe manufacturing, which uses recycled metals, can release a host of additional chemicals such as lead, mercury, manganese, zinc, chromium compounds, trimethylamine, xylene, methanol and phenol in the process.

Greenhouse gas (GHG) emissions are far higher for concrete than for PVC pipe. This clearly illustrates the need to evaluate all life cycle aspects when selecting piping materials. The cement industry is ranked as the third-largest GHG emitter in the world, releasing more than 5 percent of the world’s carbon dioxide emissions.

The production of PVC pipe using virgin material is less energy intensive than ductile iron pipe production using recycled materials, resulting in fewer environmental impacts for water infrastructure projects.
Transportation and Installation

PVC pipe has a lower transportation carbon footprint per installed foot than ductile, concrete and clay pipes. PVC pipe is 25 percent of ductile iron’s weight per foot, which means PVC pipe can be transported with a lower carbon footprint compared to equivalent lengths of ductile iron pipe. PVC pipe manufacturing facilities are also found throughout the United States and Canada which reduces transportation costs and environmental impacts.

The light weight and durability of PVC pipe can reduce installation costs and environmental impacts as well as greenhouse gas emissions. Lighter-duty equipment and smaller crew sizes can be used with PVC pipe installation compared to other pipe materials. PVC pipe eliminates traffic costs, related construction and environmental impacts as well as other lost revenue associated with pipe replacements over a 100-year design life. PVC pipes can be installed with a 30 percent installation time savings over concrete pipes.

Pumping Energy Comparisons Over a 100-year Life Cycle

Water distribution systems require significant amounts of pumping energy to overcome frictional forces between the walls of the pipe and the flowing water. The energy required to pump water through PVC pipe remains constant over the life of the pipe, unlike metallic and concrete pipes. This generates overall life cycle cost savings and a lower carbon footprint compared to materials that require more pumping energy over time due to the roughening of their interior surfaces from corrosion and internal degradation.

PVC pipe is not subject to corrosion, unlike iron and concrete pipes, or chemical oxidation which affects HDPE. Corrosion and chemical oxidation increase the risk of pipe failure and water loss and reduce the sustainability benefits for water utilities.

Corrosion affects 75 percent of water utilities. Durability and corrosion resistance of a pipe greatly affect the life cycle environmental impacts. Ductile iron pipe may last as little as 11-14 years in moderately corrosive soils requiring it to be replaced many times over a 100-year period. This increases the embodied environmental impacts of iron pipe by up to nine times compared to PVC pipe.

The pumping energy represents between 24 and 75 percent of the total 100-year embodied energy depending on the size and pipe material. The smooth, inner wall of PVC pipe helps minimize that impact. The fact that PVC does not corrode means that PVC pipe has, over the piping system’s design life, reduced pumping energy and reduced operational costs compared to corrosion-prone pipe materials. In addition, PVC pipe does not experience the increase in pipe friction and pumping energy over time that is characteristic of cement-lined pipes.

More utilities and local governments are implementing strategies to reduce greenhouse gas emissions as part of their long-term goals. Municipal water treatment and delivery systems require a significant amount of energy for moving water. Water and wastewater utilities often consume as much as 40 percent of a municipality’s total energy consumption. Choosing PVC pipe provides low embodied impacts and consistently smooth, non-corroding walls which help utilities and local governments minimize the energy (and GHGs) required in their water systems.

Loss of carrying capacity and higher pumping costs are due much more to the effects of iron pipe corrosion, leaks and tuberculation rather than minor internal diameter differences between iron and PVC pipes. HDPE pipe, on the other hand, has a much smaller internal diameter than either DI or PVC pipe, significantly impacting its pumping energy requirements over time.

The smooth walls, large diameters and lack of deterioration of the friction factor for PVC pipe results in more sustainable processes than just life cycle pumping energy. Pumping facilities are designed for the long-term pipeline capacity of the system that will be supplied by their discharge.

Materials such as DI and PCCP may have a larger internal diameter and a respectable friction factor when new, but pumping facilities are not designed based on the capacity of new pipes. DI and PCCP may experience at least a 30 percent decrease in friction factor over their pipe lives. This can result in a 100 percent increase in the pump power required for the same flow as new pipe as for older pipelines.

This article is an excerpt of the study, “Life Cycle Assessment of PVC Water and Sewer Pipe and Comparative Sustainability Analysis of Pipe Materials.” The Uni-Bell PVC Pipe Association commissioned an LCA on seven PVC pipe products in three market segments (potable water pressure pipe, sanitary sewer gravity pipe and storm drainage gravity pipe). Gravity piping included both solid-wall and profile-wall products. The LCA was conducted by Sustainable Solutions Corp., a firm specializing in life cycle assessment and sustainable product design and analysis. To view the full report, click here. For more information, visit uni-bell.org.