NATIONAL CLAY PIPE INSTITUTE
The VCP Authority Since 1917

# Vitrified Clay Pipe
## Environmental Product Declaration
per ISO 14025

## About the National Clay Pipe Institute

The National Clay Pipe Institute (NCPI) is a not-for-profit organization dedicated to research, education, and leadership in the Vitrified Clay Pipe (VCP) sanitary sewer industry. NCPI member companies include clay pipe manufacturers Gladding McBean, Logan Clay Products, Building Products Company, and Mission Clay Products.

VCP is used for gravity sanitary sewer systems for many reasons. When vitrified, individual clay and shale particles fuse into a ceramic state, creating an inert, strong, impermeable material. The vitrified clay, together with flexible compression joints installed during manufacturing, create a water-tight product that resists groundwater infiltration and contamination, as well as root penetration. VCP is produced and available in sizes ranging from 4-inch to 42-inch internal diameters.

NCPI promotes VCP as "THE Sustainable Sewer Pipe." The environmental claims of VCP were validated in 2011 by a third party, ISO 140001 compliant audit of cradle-to-grave impacts (SMaRT Certification). This certification included a Life Cycle Assessment (LCA) generated using the Building for Environmental and Economic Sustainability (BEES) online software from the National Institute of Standards and Technology.

## About this EPD

This is a Type III Environmental Product Declaration (EPD) for Vitrified Clay Pipe as produced by Gladding McBean, Logan Clay Products, Building Products Company, Mission Clay Products, and Superior Clay Corporation.

The results of the underlying LCA for the production phase are computed using the BEES online software from the National Institute of Standards and Technology. The product studied for BEES is a 10-inch diameter pipe of one linear foot. Since every pipe diameter has a standard pipe thickness and density, VCP can also be evaluated strictly on a mass basis, which users can then convert to the mass of a desired pipe size. Results have thus been run on both a per foot and a per pound basis for the production phase.

This EPD is intended for business-to-business audiences.

# 1. General Information

| | |
|---|---|
| Product Name | Vitrified Clay Pipe |
| Manufacturers | Gladding McBean, Logan Clay Products, Building Products Company, Mission Clay Products, and Superior Clay Corporation. *Addresses are provided in Appendix A.* |
| Program | Embodied Carbon in Construction Calculator (EC3) Tool |
| Program Holder | Building Transparency |
| Program Operator | Denise Nelson Advising, LLC<br>11407 Smoketree Drive<br>North Chesterfield, VA 23236, USA |
| Issue Date | December 1, 2024 |
| Valid To | November 30, 2029 |
| Declared Units | a. 10-inch diameter pipe of one linear foot<br>b. Per pound |
| EPD Scope | Cradle-to-Grave |
| EPD Owner | Jeff Boschert,<br>President, National Clay Pipe Institute<br>850 N. Wisconsin St., Ste. 102<br>Elkhorn, WI 53121, USA<br>www.ncpi.org |
| Reference PCR | Bau-EPD PCR Part B – Construction clay products-Version-14.0- 20230920-EN15804+A2. A copy is provided in Appendix B. |
| Verification | Independent verification of the declaration according to ISO 14025 and ISO 21930. ■ Internal ☐ External |
| LCA Reviewer and EPD Verifier | Signature: Jeff J. Boschert<br>Jeff Boschert<br>President, National Clay Pipe Institute |

The Product Category Rules (PCR) (Bau-EPD PCR Part B – Construction clay products-Version-14.0 20230920-EN15804+A2) for addressing multiple fired clay construction products was selected for reference since no vitrified clay pipe specific PCRs were available. Many PCRs are available for fired clay bricks and tiles, but only this PCR also included "other products made from fired clay."

This PCR called for a functional unit of one metric ton of clay product. Our declared unit is 1 foot of 10-inch VCP, which is equal to 0.02 metric tons. The other declared unit is per pound of VCP, which is equal to 0.00045 metric tons.

For this EPD, the LCA was conducted for an average clay product produced by different companies (i.e., the functional unit is defined for a sector level). Weighted averages were used based on the production volumes of the different suppliers. As a result, the EPD is a sector-specific or association-specific average EPD. The averages of all inputs and outputs were calculated. These averages were then used to calculate the potential environmental impacts.

The EPD owner has the sole ownership, liability, and responsibility for the EPD.

# 2. Product

## 2.1 Product Description

Vitrified Clay Pipe (VCP) is used in gravity stormwater and sanitary sewer collection systems. It has been used for over 6,000 years, starting in Ephesus, in what is now Turkey. The first system in the United States was installed in Washington, DC, in 1815. Shortly thereafter, it was installed in Boston and Philadelphia. In all, there are 57 cities in the US known to have clay pipe sewers older than 100 years, as of 2024 (see Table 1 on page 5).

VCP is manufactured from clays and shales fired in kilns at temperatures around 2000 degrees F. This fuses the clay mineral particles into an inert, chemically stable compound, integrally bonded by its very nature ("vitrification") (Figure 1). It has natural corrosion and abrasion resistant qualities based on its material makeup and manufacturing. These qualities are essential in an environment that includes sewer high velocity flows and gases.

*Figure 1: VCP cross-section*

As an inert material, VCP is resistant to acids, aggressive soils, and hostile environments. It is the most chemically resistant pipe material available.  In addition, VCP sewers offer rigidity, a low friction coefficient for flow, ease of handling and installation, and flexible watertight joints.

*Table 1: The Years of VCP in Service in Cities in the U.S.*

| 100 – 200 Years of Service in the U.S. (As of 2024) | | | | |
|---|---|---|---|---|
| **Years in Service** | **Year Installed** | **Location** | | |
| **200+ Years** | 1815 | Washington, DC | | |
| 175 - 199 Years | 1829 | Boston, MA | Philadelphia, PA | |
| 150 - 174 Years | 1850 | Clinton, IA | | |
| | 1856 | Chicago, IL | | |
| | 1861 | Cleveland, OH | | |
| | 1866 | New York, NY | | |
| | 1868 | Erie, PA | | |
| | 1869 | Grand Rapids, MI | St. Louis, MO | |
| | 1870 | Hartford, CT | | |
| | 1872 | Indianapolis, IN | | |
| | 1873 | Los Angeles, CA<br>Portland, OR | New Haven, CT<br>Raleigh, NC | St. Paul, MN |
| | 1874 | Lawrence, KS | | |
| 125 – 149 Years | 1875 | Baltimore, MD | Portland, ME | |
| | 1876 | San Francisco, CA<br>St. Joseph, MO | Jacksonville, FL | Albany, GA |
| | 1877 | Davenport, IA<br>Bucyrus, OH | Kansas City, MO | New Bedford, MA |
| | 1878 | Omaha, NE | | |
| | 1879 | Camden, NJ<br>Providence, RI | Memphis, TN<br>Nashville, TN | Parkersburg, WV |
| | 1880 | Rome, GA<br>Sioux City, IA<br>Fargo, ND<br>Napa, CA | Rockford, IL<br>Red Wing, MN<br>Dallas, TX<br>Sacramento, CA | Terre Haute, IN<br>Reno, NV<br>Denver, CO<br>Woodland, CA |
| | 1881 | Kalamazoo, MI | | |
| | 1884 | Le Mars, IA | | |
| | 1888 | Salt Lake City, UT | | |
| | 1890 | San Jose, CA | | |
| | 1892 | Phoenix, AZ | Massillon, OH | |
| | 1895 | Highlands, NJ | Atlanta, GA | Santa Cruz, CA |
| 100 – 124 Years | 1904 | New Castle, DE | | |
| | 1915 | Seattle, WA | | |

The three main types of VCP produced in the U.S. include:

1. **Bell and spigot pipe** - This comes with factory-applied flexible compression joints using either a polyurethane seismic cushion or an O-Ring housed in polyester, depending on the manufacturer (Figures 2a and b).

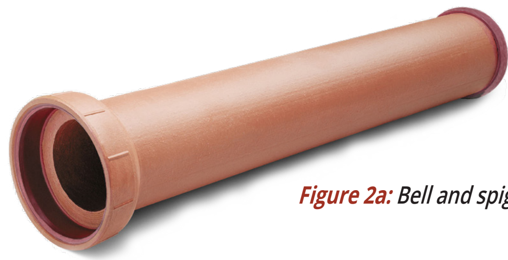


*Figure 2a: Bell and spigot pipe*

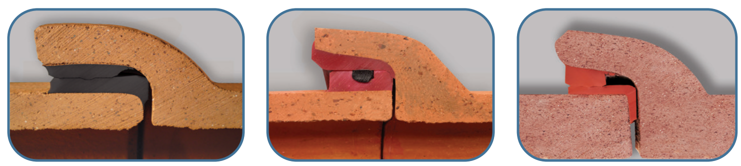


*Figure 2b: Factory-applied compression joints (3 types)*

2. **Plain-end pipe** - This pipe uses rubber compression couplings. The rubber compression couplings are applied on-site during construction. They have 301 series stainless steel tightening bands that seal the rubber coupling to the ends of the pipe (Figures 3a and b).

*Figure 3a: Plain end pipe*

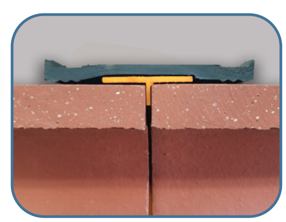


*Figure 3b: Rubber compression couplings*

3. **Low-profile joint pipe for trenchless installation** - These joints are also factory-applied and assembled during construction. They have an elastomeric gasket between the pipe ends that is secured with 316 series stainless steel collars (Figures 4a and b).


***Figure 4a:*** *Trenchless, low-profile pipe with an elastomeric gasket and stainless-steel collar compression joint*

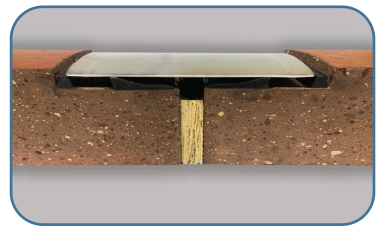


***Figure 4b:*** *Stainless-steel collar compression joint*

VCP diameters are specified based on desired flow rates and volumes. Bedding materials are specified based on anticipated trench loads. Available sizes range from 4 to 42 inches in diameter and 1 to 7 feet in length. Special VCP fittings typically include wyes, tees, bends, and cleanouts (Figure 5).

***Figure 5:*** *VCP manufacturers offer a wide variety of fittings*

## 2.2 Application

VCP is used primarily for gravity sanitary sewer collections systems but can also be used for gravity storm sewer applications. Bell and spigot pipe and plain-end pipe with rubber compression couplings are used in conventional open trench construction. Low-profile joint pipe is direct jacked using various trenchless installation methods.

## 2.3 Standards, Guidelines, and Regulations

ASTM C12 *Standard Practice for Installing Vitrified Clay Pipe Lines*

ASTM C301 *Standard Test Methods for Vitrified Clay Pipe*

ASTM C425 *Standard Specification for Compression Joints for Vitrified Clay Pipe and Fittings*

ASTM C700 *Standard Specification for Vitrified Clay Pipe, Extra Strength, Standard Strength, and Perforated*

ASTM C828 *Standard Test Method for Low-Pressure Air Test of Vitrified Clay Pipe Lines*

ASTM C896 *Standard Terminology Relating to Clay Products*

ASTM C1208/1208M *Standard Specification for Vitrified Clay Pipe and Joints for Use in Microtunneling, Sliplining, Pipe Bursting, and Tunnels*

ASTM C1920 *Standard Practice for Cleaning of Vitrified Clay Sanitary Sewer Pipeline*s

## 2.4 Technical Data

ASTM C700 *Standard Specification for Vitrified Clay Pipe, Extra Strength, Standard Strength, and Perforated* provides tables with production specifications for:

- Minimum bearing strength (lbs/linear ft) by nominal pipe size
- Absorption and acid resistance
- Hydrostatic pressure test time by thickness of barrel
- Dimensional tolerances by nominal pipe size

ASTM C425 *Standard Specification for Compression Joints for Vitrified Clay Pipe and Fittings* provides tables with production specifications for:

- Testing the flexible ring sealing elements
- Shear load testing of assembled joints with internal pressure
- Angular deflection testing of assembled joints with internal pressure

## 2.5 Base / Auxiliary Materials

Five facilities making up a majority of North American VCP production provided raw material, manufacturing, and waste data pertaining to 2005 and 2009 production. The facilities confirmed the data is still relevant for production in 2024. The resulting weighted average data are used in calculations (Appendix C). Table 2 presents the components (Figure 6) by mass percentage of the VCP product.

*Table 2: Vitrified Clay Pipe Components*

| Component | Function | Mass Fraction |
|---|---|---|
| Clay and shale | Main component | 98.75% |
| Urethane | Joint seals | 0.70% |
| Barium carbonate | Secondary component | 0.20% |
| Rubber | Joint seals | 0.15% |
| Other | Joint seals | 0.21% |
| **TOTAL:** | | **100%** |

*Figure 6: Raw Materials Mixture*

Clay and shale are quarried and brought to VCP facilities.

Urethane (ethyl carbamate) is one of the materials used for pipe seals. Despite its common name, it is not a component of polyurethanes.

Barium carbonate (witherite) is a chemical compound used in bricks, ceramic glazes, cement, and rat poison.

Rubber is one of the main materials for pipe couplings. It is any type of artificial elastomer, invariably a polymer. An elastomer is a material with the mechanical (or material) property that it can undergo much more elastic deformation under stress than most materials and still return to its previous size without permanent deformation.

The other additives in pipe production include silica sand for kiln setting and stearic acid for lubricating the extrusion mold. Other materials for flexible joint seals include polyester resin, latex, rhoplex, and acetate.

The plain end pipe joints include elastomeric couplings and 301 series stainless steel clamps.

The low-profile (trenchless) joint components include elastomeric gaskets and 316 series stainless steel collars.

## 2.6 Production

The principal steps in the manufacture of clay pipe are: mining, grinding, extruding, drying, and firing. Mined clay and shale are brought to a VCP manufacturing facility where they are blended and ground into powder in preparation for extrusion. The powder is fed into a pug mill, where water is added. This is then fed into a vacuum chamber to remove the air, resulting in a strong, dense clay material. The clay is extruded through a die to form the finished pipe.

Machines trim the pipes into appropriate lengths and load them onto pallets where they are sent to be dried at temperatures reaching 250 degrees Fahrenheit. Often, drying heat is recovered and used in other parts of the facility. Pipes are then fired in either tunnel or periodic kilns until the clay is vitrified. Firing temperatures reach approximately 2000 degrees Fahrenheit. Joints are formed (Figure 7) and joint materials are applied. The process is similar for pipe fittings (Figure 8).

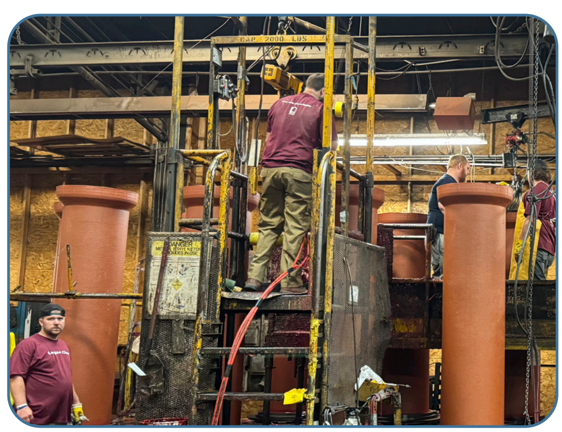


***Figure 7:*** *Manufacturing Bell and Spigot VCP Joints*

Production requires energy and water and results in minimal waste streams, including air emissions, wastewater, miscellaneous wastes, and urethane waste (also listed in Appendix C). The manufacturers test a sample of the pipes, joints, and fittings to ensure longevity and strength. The following tests are conducted:

*Figure 8: Manufacturing VCP Elbows*

- bearing strength
- acid resistance
- joint shear load
- corrosion resistance
- joint angular deflection testing

Products are also inspected for dimensional variation, roundness, straightness, end squareness, chips, and fractures.

## 2.7 Packaging

VCP is secured on reusable pallets with reusable straps (Figure 9) for delivery.

*Figure 9: VCP Strapped to Pallets for Shipping*

## 2.8 Conditions of Delivery

VCP can be delivered and stored onsite on the same reusable pallets with reusable straps.

## 2.9 Transport

The product is shipped primarily by diesel truck (98%) (Figure 10), with a small fraction of the product shipped by rail (2%). The average transportation distance from VCP manufacturing plants to the place of installation is 400 miles.

*Figure 10: A Truck Load of Pipe*

## 2.10 Processing / Installation

*Figure 11: Open Trench Installation*

VCP is typically installed in open trench construction (Figure 11). This includes trench excavation; trench wall protection with sloping, shoring, sheeting, or use of a trench box (all reusable materials); foundation preparation and dewatering (if neccessary); pipe installation; pipe joining; pipe bedding and geotextile placement; and backfill placement and compaction.

The trench excavation is typically the pipe diameter plus 24 inches wide. Cover depths can vary from 4 to 40 feet. The pipe embedment is typically granular crushed stone from a local quarry. The excavated soil is typically of good quality for reuse as trench backfill. Because VCP is a rigid pipe material, a narrow trench width is used. Depending on the cover depth, rigid conduits, such as VCP, only require bedding up to the haunches or the spring line whereas flexible pipe materials require bedding materials 12 inches over the top of the pipe barrel. With rigid pipe types, both the narrow trench width and the embedment requirements result in less importation of materials and less backhoe usage when compared to flexible pipe products.

The work typically involves a backhoe for excavating, placing the pipe, backfill, a pump for dewatering (if necessary), and a tamper for compacting the backfill. Operators on-site are required to follow appropriate erosion and sediment control practices, dust control protocols, and health and safety measures, among other standard construction site practices.

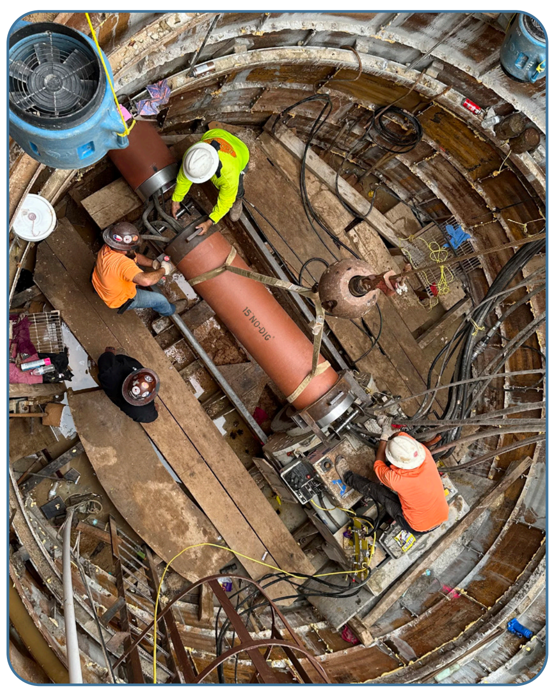


*Figure 12: Trenchless Installation at Depth*

Trenchless construction includes excavating a jacking or launch shaft and a reception shaft, tunneling to install the pipe, and building manholes at the shaft locations. VCP is a good material for direct jacking due to its high compressive strength and abrasion resistance. Trenchless installation of VCP can frequently be the preferred method at depths over 20 ft (Figure 12). VCP with low-profile joints and machined pipe ends are necessary to take the axial loading required for installation. The joints are factory-applied and assembled on-site during construction. The work typically involves a backhoe for excavation and backfill of jacking and receiving shafts, a pump for dewatering (if necessary), and a jacking or boring machine.

Once installed, VCP is then tested for acceptance via CCTV Inspection and/ or Low-Pressure Air Testing. Common practice is to test each section from manhole to manhole. For air testing, the section of the line to be tested is plugged at both ends. Air, at low pressure (< 5.0 psi), is introduced into the plugged line. The line passes the test if the rate of air loss, as measured by pressure drop, does not exceed a specified amount in a specified time. These tests have insignificant energy uses compared to the manufacturing process.

Typically, none of the product is wasted at installation since the pipes are prefabricated at the manufacturing facility, and contractors order the lengths and fittings needed.

## 2.11 Use

As an inert material, VCP is resistant to acids, aggressive soils, and hostile environments. Maintenance is typically minimal, although it can be dependent on the usage and where it is installed. Maintenance includes inspection and cleaning. Robotic video inspection is common since it is not disruptive to the use of the pipe. Cleaning can be conducted via high-pressure water jetting or mechanical means. High-pressure water jetting covers all water jetting, including the use of jets and hydro-mechanical tooling at pressures above 2000 psig (0.69 MPa). Mechanical sewer cleaning methods include equipment that uses a physical and or mechanical device that scrapes, cuts, scours, or pulls debris or materials from a sewer, such as rodders, power rodders, and bucket cleaning machines. These cleaning methods are a benefit of using VCP as other commonly used gravity sewer pipe materials cannot withstand aggressive high-pressure water jetting or any of the mechanical cleaning devices.

## 2.12 Reference Service Life

The lifetime of the pipe is assumed to be indefinite -- exceeding 100 years -- given the strength and performance of the vitrified pipe. VCP is a ceramic with material properties that do not change or degrade with time. A reference service life of 150 years is used in the model as recommended in the PCR.

## 2.13 Reuse and Recycling

VCP can be reused or recycled; however, in practice, it is used indefinitely or abandoned in place.

## 2.14 Disposal

At end of life, the pipe is typically abandoned in place. VCP does not pose any human or environmental threat when left in the ground. Removal would require excavation, backfill, and transportation that may impact traffic or other community functions.

## 2.15 Further Information

Additional information is available in the *"Vitrified Clay Pipe Engineering Manual (2017)"* National Clay Pipe Institute, Elkhorn, WI (www.ncpi.org/assets/ncpi-engineering-manual.pdf).

# 3. LCA: Calculation Rules

## 3.1 Declared Unit

The product studied for BEES is a 10-inch diameter pipe of one linear foot. Since every pipe diameter has a standard pipe thickness and density, VCP can also be evaluated on strictly a mass basis, which users can then convert to the mass of a desired pipe size. Results have thus been run on both a per foot and a per pound basis.

## 3.2 System Boundary

This is a cradle-to-grave EPD with a complete cradle-to-grave LCA for the product, including all lifecycle stages and modules, for use as a gravity sanitary sewer over a 150-year service life.

Any site-generated energy and purchased electricity is included in the system boundary. The extraction, processing, and delivery of purchased primary fuels (for example natural gas and primary fuels used to generate purchased electricity) is also included within the boundaries of the system. Regionally specific inventory data on electricity are based on subnational U.S. and Canadian consumption mixes that account for power trade between the regions. The sources for electricity (calculation procedure) have been documented.

The following activities were considered for each life-cycle stage:

**Production Stage** (Module A1, A2, and A3 may be declared as one aggregated module A1-3):

**A1 -** Extraction and processing of raw materials, including fuels used in extraction and transport within the process and any crushing or grinding required for transport.

**A2 -** Average or specific transportation of raw materials from extraction site or source to manufacturing site including empty backhauls and transportation to intermediate distribution centers or terminals.

**A3 -** Manufacturing of the product. For VCP, this typically includes crushing and grinding, screening, forming, drying, firing and cooling, and other processes specific to the properties of the clay. It also includes packaging, including transportation and waste disposal, to make product ready for shipment.

**Construction Process Stage**

**A4 -** Transport of the packed clay products to the construction site or storage yard. No special accommodations are required for storage.

**A5 –** Installation of products including any energy or water required for installation or operation of the site and wastes generated.

**Use Stage**

**B1 -** Use of constructed works in terms of any emissions to the environment.

**B2 –** Maintenance including production, and transportation of components used, cleaning, and any production or transport of wastes generated.

**B3 -** Repair, including production and transportation of components, in repair and any production or transport of wastes generated.

**B4 -** Replacement, including production and transportation of components used and any production or transport of wastes generated.

**B5 -** Refurbishment - including production and transportation of components used in repair as well as any production or transport of wastes generated.

**B6 -** Operational energy use independent of items in B1-B5.

**B7 -** Operational water use independent of items in B1-B5.

### End of Life Stage

**C1 -** De-construction and demolition at the end of the reference service life including initial on-site sorting of materials.

**C2 -** Transport to the waste processing plant and final disposal.

**C3 -** Waste processing for re-use, recovery, and/or recycling for products with an energy recovery efficiency rate higher than 60%.

**C4 -** Disposal including pre-treatment and management of disposal site.

**D –** Potential of reuse and recycling.

### Items excluded in calculations include:

- Production and manufacture of production equipment, delivery vehicles, and laboratory equipment;
- Personnel-related activities (travel, furniture, and office supplies); and
- Energy and water use related to company management and sales activities that may be located either within the factory site or at another location.

## 3.3 Flow Chart / Stages in Life Cycle

The flow diagram below (Figure 13) outlines the key elements of VCP production that were included in a life cycle assessment produced using the National Institute of Standards Technology's Building for Environmental and Economic Sustainability online software (BEES).

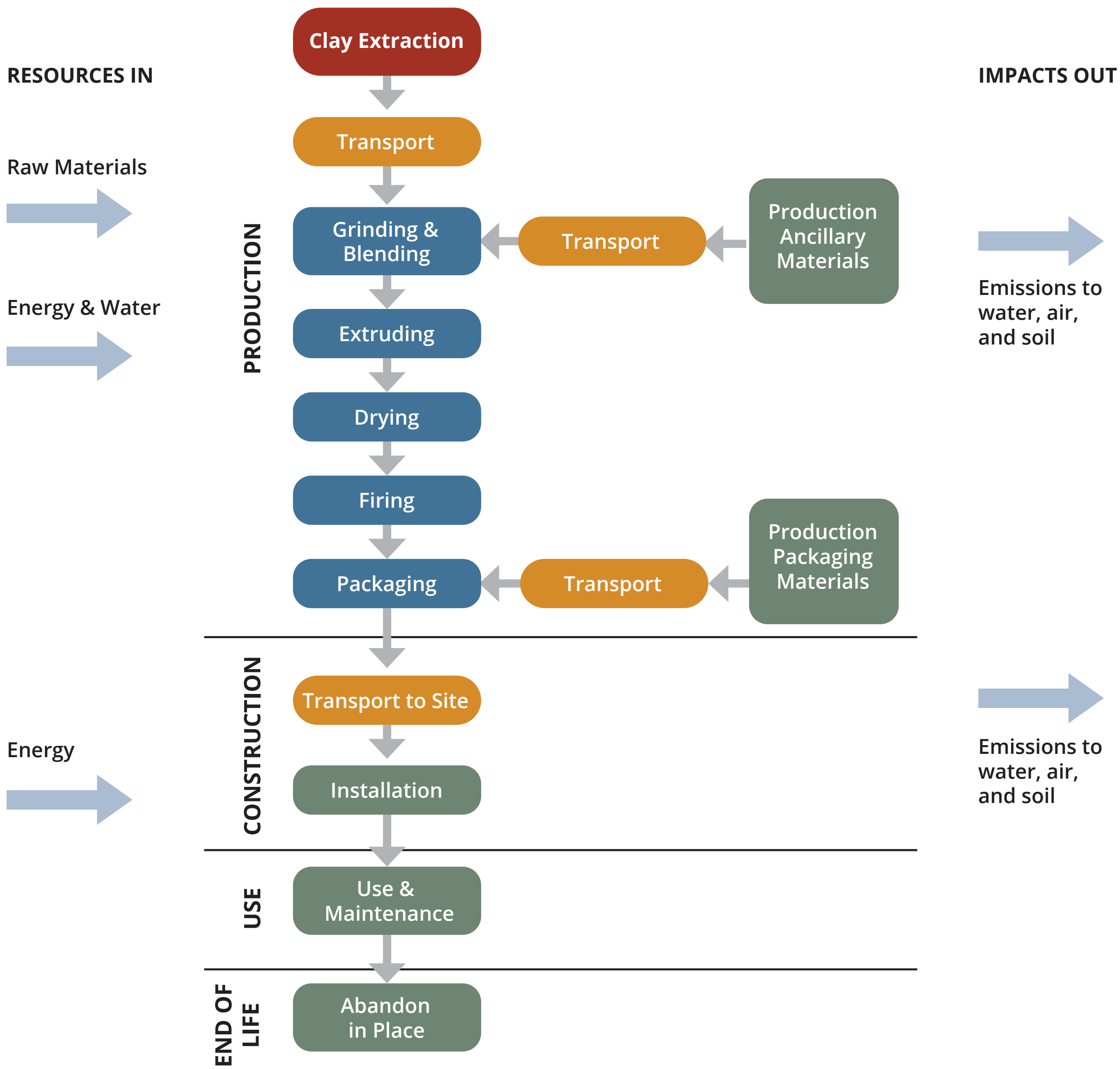



*Figure 13: Life Cycle Flow Chart*

## 3.4 Estimates and Assumptions

All significant foreground data was gathered from the manufacturers based on measured values (i.e., without estimation).

## 3.5 Cut-off Criteria

Criteria for the exclusion of inputs and outputs (cut-off rules) in the LCA and information modules and any additional information are intended to support an efficient calculation procedure. All inputs and outputs of a unit process for which data are reasonably available shall be included in the calculation. Any application of the criteria for the exclusion of inputs and outputs shall be documented. Data gaps may be filled by conservative assumptions with average or proxy data. Any assumptions for such choices shall be documented.

If data are not reasonably available, the cut-off criteria for flows to be considered within the system boundary shall be as follows.

- **Mass -** If a flow is less than 1% of the cumulative mass of the system model, it may be excluded, provided its environmental relevance is minor.
- **Energy -** If a flow is less than 1% of the cumulative energy of the system model, it may be excluded, provided its environmental relevance is minor.
- **Environmental relevance -** Material and energy flows known to have the potential to cause environmentally relevant emissions into air, water, or soil related to the environmental indicators of these PCR shall be included unless justification for exclusion is documented.

Flows that can be omitted from the system boundaries conventionally:

- Lighting, heating, cooling, and cleaning of the manufacturing plant
- Burdens related to the administrative department of the production plant
- Transportation of employees
- Accidental pollutions are often difficult to distinguish from emissions that occur under normal conditions (accidental pollutions are not measured and they are not reported separately) and therefore are not considered in the LCA
- Environmental impacts caused by the personnel of the production plants are not included in the LCA, e.g., waste from the cafeteria and sanitary installations or accidental pollution caused by human mistakes, or environmental effects caused by commuter traffic
- Manufacturing and heavy maintenance tool production and transport systems (machines, trucks, etc.)
- Equipment and maintenance in a production plant
- Packaging of waste

## 3.6 Data Sources

Five facilities making up a majority of North American VCP production provided raw material and manufacturing data pertaining to 2005 and 2009 production. The facilities confirmed the data is still relevant for production in 2024.

Life cycle data came from these sources, as noted throughout:

- National Renewable Energy Laboratory (NREL): U.S. Life-Cycle Inventory Database. 2005. Golden, CO. Found at: http://www.nrel.gov/lci/database
- PRé Consultants: SimaPro 6.0 LCA Software. 2005. The Netherlands
- Ecoinvent Centre, Ecoinvent data v2.0 (Dübendorf: Swiss Centre for Life Cycle Inventories, 2007), retrieved from: www.ecoinvent.org

The impact categories of Life Cycle Impact Assessment (LCIA) were calculated using characterization factors specified in version 2.1 of the Tool for Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI) from the Environmental Protection Agency (EPA).

## 3.7 Data Quality

The weighted average data from five manufacturers are used in the calculations.

## 3.8 Reporting Period

The raw material and manufacturing data pertained to production in 2005 and 2009. There have been no significant changes to the process to require the collection of more recent data.

## 3.9 Allocation

Allocations were not performed.

## 3.10 Comparability

EPDs from different programs and/or based on different Product Category Rules (PCR) may not be comparable. For two EPDs to be comparable, they must be based on the same PCR (including the same version number) or be based on fully-aligned PCRs or versions of PCRs; cover products with identical functions, technical performances, and use (e.g., identical declared/functional units); have equivalent system boundaries and descriptions of data; apply equivalent data quality requirements, methods of data collection, and allocation methods; apply identical cut-off rules and impact assessment methods (including the same version of characterization factors); have equivalent content declarations; and be valid at the time of comparison. For further information about comparability, see ISO 14025.

# 4. LCA: Scenarios and Additional Technical Information

For the purposes of this EPD, only open-cut installation using bell and spigot pipe with factory-applied flexible compression joints was considered. Alternative installation methods and materials would change EPD values.

## 4.1 A1-A3 Product Stage

Modules A1, A2, and A3 are being declared as one aggregated module A1-3 based on the BEES analysis.

**A1 -** Extraction and processing of raw materials: Clay quarrying data come from the U.S. LCI Database. The quarrying of shale is assumed to have the same impacts as clay. Urethane data are based on precursor data found in the U.S. LCI database, including polyether polyol and toluene diisocyanate. Rubber data come from EcoInvent. The other materials were modeled based on the U.S. LCI database, where available, and EcoInvent and other elements of the SimaPro database.

**A2 -** Average or specific transportation: Transportation distances for shipment of the raw materials from the suppliers to the manufacturing plant were provided by each manufacturer. A weighted average of the clay transport distance to manufacturers is 33 miles. The distance for the remaining materials ranges from very local to 2,000 miles. As such, 600 miles was assumed for these remaining materials. Materials are transported by diesel truck, which is based on the US LCI database.

**A3 -** Manufacturing of VCP: Production requires water and energy. Water requirements averaged 9.64 E-02 gallons per foot of 10" pipe. The facilities provided individual energy data for their processing requirements for several years (Appendix D). The average data used in analysis is listed below in Table 3. Data for all energy precombustion and use comes from the US LCI database.

*Table 3: Vitrified Clay Pipe Production Energy Requirements*

| Flow Name | Units | Quantity/lb VCP |
|---|---|---|
| Electricity | kWh | 6.7 E-2 |
| Natural gas | Therms | 4.4 E-2 |
| Diesel | Gal | 2.6 E-4 |
| Gasoline | Gal | 4.0 E-5 |
| Propane | Gal | 1.7 E-4 |

The manufacturing process produced air emissions, wastewater, and other wastes. The main process air emission comes from particulate matter from the grinding operation and amounts to a weighted average of 2.0 E-3 lb. per lb. pipe. Styrene emissions average 1.6 E-4 lb. per lb. pipe, and barium emissions average 1.2 E-7 lb. per lb. pipe. The vacuum pump generates wastewater (1.1 E-5 gal per lb. pipe), which contains approximately 10% oil. Other waste includes miscellaneous facility trash (1.57 E-2 lb. per lb. pipe) and a small amount of reacted urethane waste (8.2 E-6 lb. per lb. pipe). These are appropriately disposed offsite.

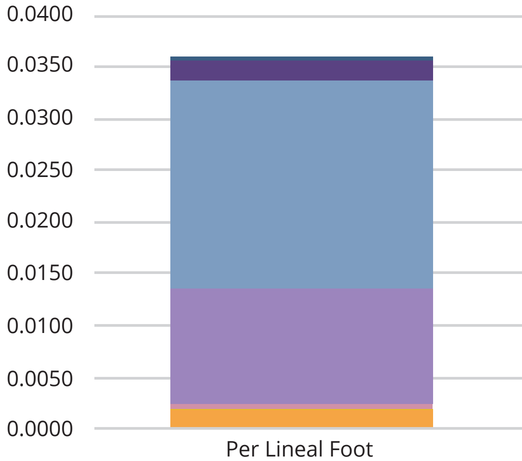
Product testing is not included in the analysis. These tests on a small sample of pipes have insignificant energy uses compared to the manufacturing process. The materials used in testing can be conserved for reuse.

As the packaging pallets and straps are reusable, their initial production and transport to the manufacturing facility are not included in the analysis.

Module A1-3 declaration based on the BEES analysis is in Table 4 and Figures 14-16 for 10-inch diameter VCP per lineal foot and Table 5 and Figures 17-19 for VCP per pound (based on 45 lbs./lineal foot of 10-inch VCP).

*Table 4: Results for 10-inch Diameter VCP per Lineal Foot*

| Impacts | Units | A1-3 |
|---|---|---|
| Acidification | millimoles of hydrogen ion equivalents | 8.13E+03 |
| Criteria Air Pollutants | micro Disability-Adjusted Life Years | 3.65E+00 |
| Ecological Toxicity | grams of 2,4-dichlorophenoxy-acetic acid equivalents | 3.69E+01 |
| Eutrophication | grams of nitrogen equivalents | 3.01E+00 |
| Fossil Fuel Depletion | megajoules of surplus energy | 3.84E+01 |
| Global Warming | grams of carbon dioxide equivalents | 1.73E+04 |
| Habitat Alteration | threatened and endangered species count | 0.00E+00 |
| Human Health, Cancer | grams of benzene equivalents | 5.40E+01 |
| Human Health, non-Cancer | grams of toluene equivalents | 9.45E+03 |
| Ozone Depletion | grams of chloroflourocarbon-11 | 1.93E-05 |
| Smog | grams of nitrogen oxide equivalents | 7.06E+01 |
| Water Intake | liters of water | 2.22E+01 |




| | Per Lineal Foot |
|---|---|
| Water Intake | 0.0003 |
| Smog | 0.0019 |
| Health Cancer | 0.0000 |
| Health Non-Cancer | 0.0000 |
| Ozone Depletion | 0.0000 |
| Habitat Alteration | 0.0000 |
| Global Warming | 0.0202 |
| Fossil Fuel Depletion | 0.0112 |
| Eutrophication | 0.0005 |
| Ecological Toxicity | 0.0001 |
| Criteria Air Pollutants | 0.0018 |
| Acidification | 0.0000 |
| **SUM** | **0.0360** |

***Figure 14:*** *A1-3 Environmental Performance per Foot*

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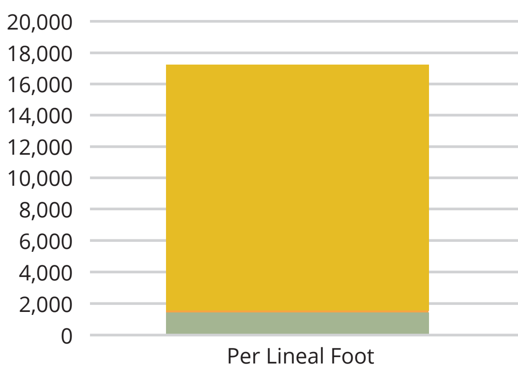
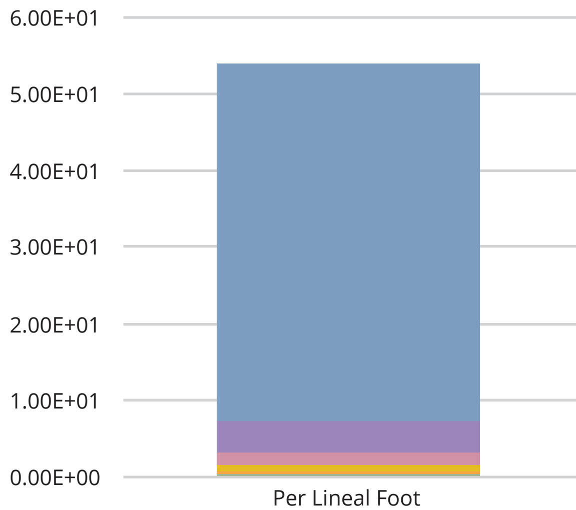



| | Per Foot (in CO2 Equivalents) |
|---|---|
| Carbon Dioxide (CO2) | 15,668 |
| Nitrous Oxide | 112 |
| Methane | 1,521 |
| **SUM** | **17,301** |

***Figure 15:*** *A1-3 Global Warming Performance per Foot*

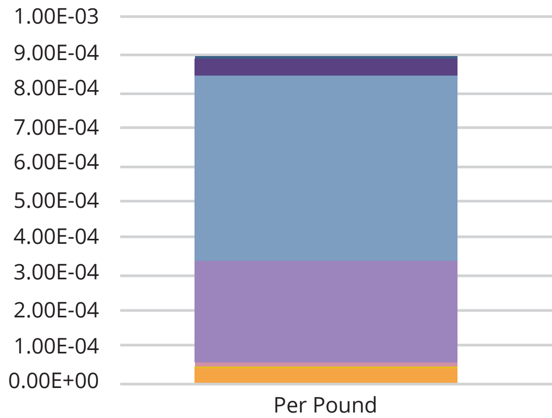



| | Per Lineal Foot |
|---|---|
| (w) Phenol | 4.68E+01 |
| (w) Arnesic | 4.12E+00 |
| (a) Dioxins | 1.62E+00 |
| (a) Arsenic | 8.20E-01 |
| (a) Benzene | 3.82E-01 |
| All other flows | 2.80E-01 |
| **SUM** | **5.40E+01** |

*Figure 16: A1-3 Human Health – Cancer Performance per Foot*

*Table 5: Results for VCP per pound*

| Impacts | Units | A1-3 |
|---|---|---|
| Acidification | millimoles of hydrogen ion equivalents | 2.03E+02 |
| Criteria Air Pollutants | micro disability-Adjusted Life Years | 9.12E-02 |
| Ecological Toxicity | grams of 2,4-dichlorophenoxy-acetic acid equivalents | 9.24E-01 |
| Eutrophication | grams of nitrogen equivalents | 7.52E-02 |
| Fossil Fuel Depletion | megajoules of surplus energy | 9.60E-01 |
| Global Warming | grams of carbon dioxide equivalents | 4.33E+02 |
| Habitat Alteration | threatened and endangered species count | 0.00E+00 |
| Human Health, Cancer | grams of benzene equivalents | 1.35E+00 |
| Human Health, non-Cancer | grams of toluene equivalents | 2.36E+02 |
| Ozone Depletion | grams of chloroflourocarbon-11 | 4.83E-07 |
| Smog | grams of nitrogen oxide equivalents | 1.77E+00 |
| Water Intake | liters of water | 5.55E-01 |




| | Per Lineal Pound |
|---|---|
| Water Intake | 8.63E-06 |
| Smog | 4.82E-05 |
| Health Cancer | 3.34E-07 |
| Health Non-Cancer | 6.91E-09 |
| Ozone Depletion | 2.93E-09 |
| Habitat Alteration | 0.00E+00 |
| Global Warming | 5.06E-04 |
| Fossil Fuel Depletion | 2.80E-04 |
| Eutrophication | 1.20E-05 |
| Ecological Toxicity | 1.27E-06 |
| Criteria Air Pollutants | 4.41E-05 |
| Acidification | 8.06E-08 |
| **SUM** | **9.01E-04** |

*Figure 17: A1-3 Environmental Performance per Pound*

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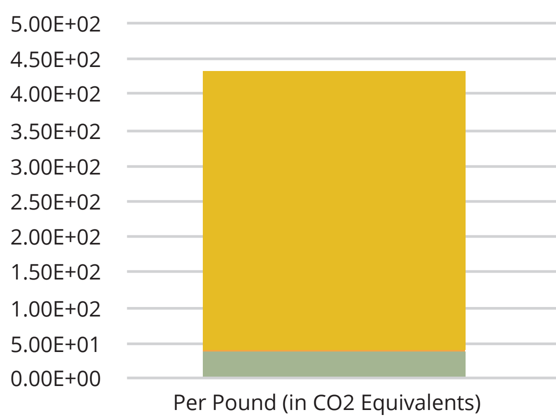
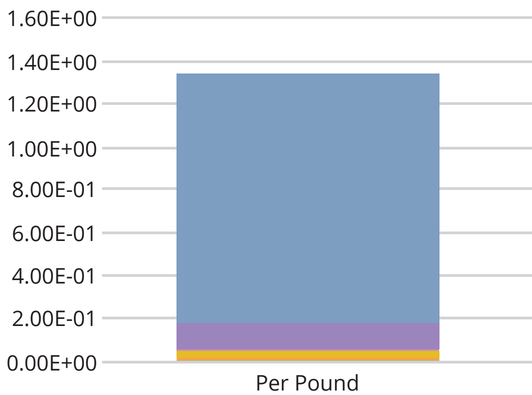



| | Per Pound (in CO2 Equivalents) |
|---|---|
| Carbon Dioxide (CO2) | 3.92E+02 |
| Nitrous Oxide | 2.79E+00 |
| Methane | 3.80E=01 |
| **SUM** | **4.33E+02** |

*Figure 18: A1-3 Global Warming Performance per Pound*




| | Per Lineal Pound |
|---|---|
| (w) Phenol | 1.17E+00 |
| (w) Arnesic | 1.03E-01 |
| (a) Dioxins | 4.06E-02 |
| (a) Arsenic | 2.08E-02 |
| (a) Benzene | 9.55E-03 |
| All other flows | 7.01E-03 |
| **SUM** | **1.35E+00** |

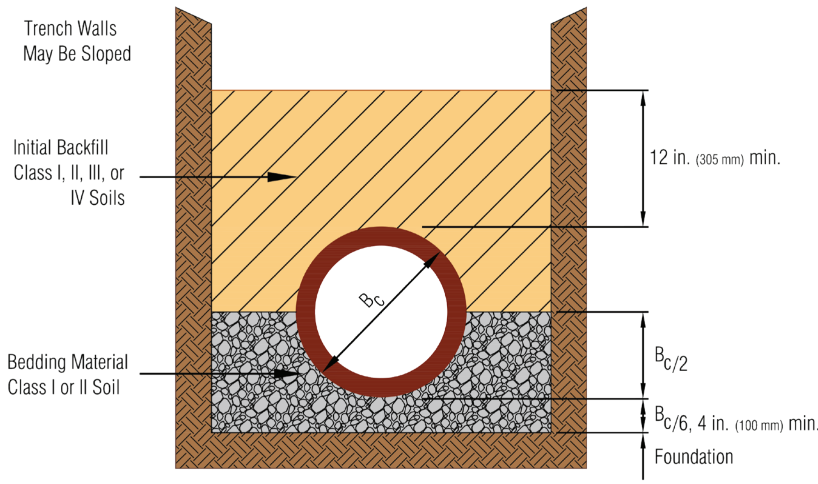
*Figure 19: A1-3 Human Health – Cancer Performance per Pound*

## 4.2 A4-A5 Construction Process Stage

**A4 -** Transport: The product is shipped primarily by diesel truck. The average transportation distance from VCP manufacturing plants to the place of installation is 400 miles. A full load weighs approximately 200,000 lbs. Data for truck transport are based on data from the US LCI database (Table 6). The emissions per foot of VCP are true for 10-inch diameter pipe only, since the calculation was based on the length of pipe that will fit on a flatbed truck. That length would increase for smaller pipes and decrease for larger pipes based on the width and height of pipe stacking. The emissions per pound of VCP are true for all pipe sizes, because the calculation was based on 200,000 lbs per truck load.

*Table 6: Transportation Impacts (200,000 lbs for 400 mi in a Diesel Truck}*

| Component | LCI Emissions (kg/km) | Total Emissions (kg) | Emissions (kg / ft of 10" VCP) | Emissions (kg / lb VCP) |
|---|---|---|---|---|
| Ammonia | 9.47E-07 | 1.22E-03 | 2.71E-07 | 6.10E-09 |
| Carbon dioxide | 7.82E-02 | 1.01E+02 | 2.24E-02 | 5.04E-04 |
| Carbon monoxide | 1.63E-04 | 2.09E-01 | 4.65E-05 | 1.05E-06 |
| Hydrocarbons | 4.39E-05 | 5.66E-02 | 1.26E-05 | 2.83E-07 |
| Methane | 5.58E-06 | 7.19E-03 | 1.60E-06 | 3.60E-08 |
| Nitrogen dioxide | 5.55E-05 | 7.15E-02 | 1.59E-05 | 3.58E-07 |
| Nitrogen oxides | 5.94E-04 | 7.65E-01 | 1.70E-04 | 3.83E-06 |
| Nitrogen oxides | 5.38E-04 | 6.94E-01 | 1.54E-04 | 3.47E-06 |
| Nitrous oxide | 7.39E-08 | 9.52E-05 | 2.12E-08 | 4.76E-10 |
| Particulate matter, ≤ 10μm | 6.39E-07 | 8.23E-04 | 1.83E-07 | 4.11E-09 |
| Particulate matter, ≤ 10μm | 2.54E-05 | 3.27E-02 | 7.27E-06 | 1.64E-07 |
| Particulate matter, ≤ 10μm | 2.13E-06 | 2.74E-03 | 6.09E-07 | 1.37E-08 |
| Particulate matter, ≤ 2.5μm | 2.46E-05 | 3.17E-02 | 7.05E-06 | 1.59E-07 |
| Particulate matter, ≤ 2.5μm | 1.53E-07 | 1.97E-04 | 4.39E-08 | 9.87E-10 |
| Particulate matter, ≤ 2.5μm | 5.57E-07 | 7.17E-04 | 1.59E-07 | 3.59E-09 |
| Sulfur dioxide | 1.24E-06 | 1.59E-03 | 3.54E-07 | 7.97E-09 |
| Volatile organic compounds | 4.50E-05 | 5.80E-02 | 1.29E-05 | 2.90E-07 |




**Class B: 1.9 Load Factor**

*Figure 20: Class B Trench Diagram*

**A5 –** Installation: A typical open trench cross section is provided in Figure 20.

The modeled installation includes excavating an estimated 12-foot deep and 3-feet wide trench, lining the trench with a reusable trench box, and placing the 10-inch diameter pipe, bedding, and backfill (Table 7).

When using crushed stone for both bedding as well as the initial backfill, 566 lbs per foot of 10 inch pipe is delivered to the site. Light-duty dump trucks can typically carry up to 6,000 pounds. A truckload of bedding can cover 10.6 feet of trench. The truck averages 50 miles round trip to deliver the bedding.

The excavated soil is used as backfill and excess soil (322 lb / ft pipe) is taken off site. A light-duty dump truck can carry the excess soil from 18.6 feet of trench. The truck averages 50 miles roundtrip to remove the excess soil.

*Table 7: Trench Variables per 1 foot Length*

| Variables | Data |
|---|---|
| Pipe - nominal I.D., inches, inside diameter | 10 |
| Pipe - approximate O.D., inches, outside diameter (Bc) | 12.05 |
| Bedding below pipe, inches, depth | 4 |
| Bedding, inches (feet), total depth | 10 (0.8) |
| Trench depth, inches (feet), total, typ | 144 (12) |
| Backfill, inches (feet), total depth | 134 (11.2) |
| Trench width, inches (feet) | 36 (3) |
| Excavation - volume, cu ft | 36 |
| Pipe - volume, cu ft | 0.80 |
| Bedding placed - volume, cu ft | 5.1 |
| Weight / volume of imported bedding placed, lb/cu.ft. | 111 |
| Weight of imported bedding, lb | 566 |
| Fill placed – volume, cu ft | 33.1 |
| Fill taken off site, volume, cu ft | 2.9 |
| Weight / volume of fill taken off site, lb/cu.ft. | 111 |
| Weight of fill taken off site, lb | 322 |

The time required to dig and refill the trench varies widely per region, soil type, climate, existing infrastructure, equipment operator, local convention, and other factors. In this model, the estimated machine runtime is 25 hours for 1,000 feet of pipe (EPD, PVC Nonpressure Pipe, 2023). This is an exceedingly conservative estimate based on the differences involved in installation of rigid and flexible pipe materials discussed in Section 2-10.

Typically, a hydraulic digger is used to dig the trench, and a small loader refills the trench. Diesel fuel usage rates are estimated to be 8 gallons/hour for the digger (Forum on Heavy Equipment, 2013) and 2 gallons/hour for the loader (The Forestry Forum, 2013). Therefore, the 25-hour scenario assumes 250 gallons of diesel is required to install 1,000 feet of pipe (0.25 gal / ft). The vehicles average 20 miles per gallon on diesel, so construction at a rate of 0.25 gal / ft is equivalent to driving 5 miles.

The installation impacts for construction and transporting bedding and excess soil are summarized in Table 8. The emissions per foot and per pound of VCP are true for 10-inch diameter pipe only, since the calculation was based on the trench geometry and density of the 10-inch pipe.

*Table 8: Trench Variables per 1 foot Length*

| Components | Emissions (kg / ft of 10" VCP) | Emissions (kg / lb VCP) |
|---|---|---|
| Ammonia | 2.35E-05 | 4.43E-06 |
| Carbon dioxide | 1.80E+00 | 3.38E-01 |
| Carbon monoxide | 2.84E-03 | 5.35E-04 |
| Hydrocarbons | 5.47E-04 | 1.03E-04 |
| Methane | 1.51E-05 | 2.83E-06 |
| Nitrogen dioxide | 9.90E-04 | 1.86E-04 |
| Nitrogen oxides | 1.17E-02 | 2.20E-03 |
| Nitrogen oxides | 1.07E-02 | 2.01E-03 |
| Nitrous oxide | 1.93E-06 | 3.64E-07 |
| Particulate matter, ≤ 10µm | 4.98E-05 | 9.37E-06 |
| Particulate matter, ≤ 10µm | 1.48E-05 | 2.79E-06 |
| Particulate matter, ≤ 10µm | 5.66E-04 | 1.06E-04 |
| Particulate matter, ≤ 2.5µm | 5.49E-04 | 1.03E-04 |
| Particulate matter, ≤ 2.5µm | 1.30E-05 | 2.45E-06 |
| Particulate matter, ≤ 2.5µm | 3.55E-06 | 6.68E-07 |
| Sulfur dioxide | 2.83E-05 | 5.33E-06 |
| Volatile organic compounds | 5.60E-04 | 1.05E-04 |

## 4.3 B1-B7 Use Stage

There are no or minimal impacts during use and maintenance. VCP materials do not require repair, replacement, or refurbishment. Operational energy and water use are not relevant for VCP products. The results for each module B1-B7 are declared as "zero".

## 4.4 C1-C4 End-of-Life Stage

At end of life, the pipe is typically abandoned in place. VCP does not pose any human or environmental threat when left in the ground, and removal would cause more environmental impacts. Since demolition, transport, waste processing, and disposal do not occur, the results for each module C1-C4 are declared as “zero”.

## 4.5 D Potential of Reuse and Recycling

As the pipe is typically abandoned in place, reuse and recycling do not occur. The results for module D are declared as “zero”.

# 5. LCA: Results

The results of an ISO 14040 compliant life cycle assessment found that the extraction and manufacturing process of vitrified clay products produces the majority of lifecycle emissions based on the energy used in production. The full lifecycle impacts are listed in Tables 9 and 10.

*Table 9: Results for 10-inch Diameter VCP per Lineal Foot*

<table>
<tr><th>Impacts</th><th>Units</th><th>A1-3</th><th>A4</th><th>A5</th><th>B1-D</th></tr>
<tr><td>Global Warming Potential</td><td>g CO2 equivalents</td><td>1.73E+04</td><td>2.24E+01</td><td>1.80E+03</td><td>0.00E+00</td></tr>
<tr><td>Acidification</td><td>g SO2 eq</td><td>ND*</td><td>2.39E-01</td><td>1.64E+01</td><td>0.00E+00</td></tr>
<tr><td>Eutrophication Air</td><td>g N eq</td><td rowspan="2">3.01E+00</td><td>1.51E-02</td><td>1.04E+00</td><td>0.00E+00</td></tr>
<tr><td>Eutrophication Water</td><td>g N eq</td><td>9.92E-02</td><td>6.83E+00</td><td>0.00E+00</td></tr>
<tr><td>Ozone Depletion</td><td>g CFC-11 eq</td><td>1.93E-05</td><td>0.00E+00</td><td>0.00E+00</td><td>0.00E+00</td></tr>
<tr><td>Smog</td><td>g O3 eq</td><td>ND*</td><td>6.95E+00</td><td>4.79E+02</td><td>0.00E+00</td></tr>
</table>

** ND = Not Declared in these units*

The results in Table 9 hold true for other pipe diameters for modules A1-A3 based on the underlying calculations and B1-D since the results are null. The Table 10 results for modules A4 and A5 are not transferable to other pipe diameters because they were calculated based on the stacking design for shipping and trench geometry specific to the 10-inch pipe.

*Table 10: Results for 10-inch Diameter VCP per Pound*

<table>
<tr><th>Impacts</th><th>Units</th><th>A1-3</th><th>A4</th><th>A5</th><th>B1-D</th></tr>
<tr><td>Global Warming Potential</td><td>g CO2 equivalents</td><td>4.33E+02</td><td>5.05E-01</td><td>3.38E+02</td><td>0.00E+00</td></tr>
<tr><td>Acidification</td><td>g SO2 eq</td><td>ND*</td><td>5.38E-03</td><td>3.09E+00</td><td>0.00E+00</td></tr>
<tr><td>Eutrophication Air</td><td>g N eq</td><td rowspan="2">7.52E-02</td><td>3.40E-04</td><td>1.95E-01</td><td>0.00E+00</td></tr>
<tr><td>Eutrophication Water</td><td>g N eq</td><td>2.23E-03</td><td>1.28E+00</td><td>0.00E+00</td></tr>
<tr><td>Ozone Depletion</td><td>g CFC-11 eq</td><td>4.83E-07</td><td>0.00E+00</td><td>0.00E+00</td><td>0.00E+00</td></tr>
<tr><td>Smog</td><td>g O3 eq</td><td>ND*</td><td>1.56E-01</td><td>9.01E+01</td><td>0.00E+00</td></tr>
</table>

** ND = Not Declared in these units*

## 6. LCA: Interpretation

Environmental impacts occur during the production, transportation, and construction stages. Overall, the impacts of using VCP are low, especially when compared to alternative sewer pipe materials, specifically the variety of plastic pipe materials.

## 7. References


ASTM C12 *Standard Practice for Installing Vitrified Clay Pipe Lines*

ASTM C301 *Standard Test Methods for Vitrified Clay Pipe*

ASTM C425 *Standard Specification for Compression Joints for Vitrified Clay Pipe and Fittings*

ASTM C700 *Standard Specification for Vitrified Clay Pipe, Extra Strength, Standard Strength, and Perforated*

ASTM C828 *Standard Test Method for Low-Pressure Air Test of Vitrified Clay Pipe Lines*

ASTM C896 *Standard Terminology Relating to Clay Products*

ASTM C1208/1208M *Standard Specification for Vitrified Clay Pipe and Joints for Use in Microtunneling, Sliplining, Pipe Bursting, and Tunnels*

ASTM C1920 *Standard Practice for Cleaning of Vitrified Clay Sanitary Sewer Pipelines*

Environmental Product Declaration, *PVC Nonpressure Pipe: Sanitary Sewer and Gravity Storm Water.* Uni-Bell PVC Pipe Association. March 21, 2023.

Forum on Heavy Equipment. https://www.heavyequipmentforums.com/showthread.php?5804-Fuel-Consumption. Accessed March 2013.

The Forestry Forum. https://www.forestryforum.com/board/index.php?topic=14063.0. Accessed March 2013.

ISO 14025:2006 Environmental labeling and declarations - Type III environmental declarations - Principles and procedures.

ISO 14040:2006/AMD 1:2020 - Environmental management - Life cycle assessment - Principles and framework.

ISO 14044:2006/AMD 1:2017/ AMD 2:2020 - Environmental management - Life cycle assessment - Requirements and guidelines.

"U.S. Life Cycle Inventory Database." (2012). National Renewable Energy Laboratory, 2012. Accessed October 6, 2024: https://www.lcacommons.gov/nrel/search.

*"Vitrified Clay Pipe Engineering Manual."* (2017). National Clay Pipe Institute, Elkhorn, WI (www.ncpi.org/assets/ncpi-engineering-manual.pdf).

## Appendices

Appendices can be accessed online at: https://www.ncpi.org/assets/VCP-EPD-Appendix-A-D.pdf