COMPARISON OF EMITTED EMISSIONS BETWEEN TRENCHLESS PIPE REPLACEMENT AND OPEN CUT UTILITY CONSTRUCTION

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ABSTRACT

Currently, there is a worldwide trend towards reducing emissions into the environment generated by human activities. Pollutant emissions into the atmosphere are a major measure of the impact on environment. The construction industry is a major producer of such emissions due in part to the magnitude of operations and the vast array of equipment. Increased urbanization has resulted in a need for the installation of an expanded underground network of infrastructure that includes gas, water, wastewater, pipelines, power, and communications systems. Today, engineers are faced with engaging the construction option that not only provides the best cost advantage, but also considers environmental sensitivities to create the most sustainable solution. Reduction of pollutants such as carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxide (NO_X), total organic compounds (TOC), and sulfur oxide (SO_X) have been identified by the United States Environmental Protection Agency as critical to sustainable development. This paper describes an approach for quantifying airborne emissions that is demonstrated through a comparison of two construction methods for installing a wastewater line. It was discovered that the option involving a traditional open cut method resulted in an overall average of about 80% greater emissions compared to trenchless pipe replacement. The findings of this paper should assist the utility construction industry in technology selection to minimize environmental impacts.

KEY WORDS

environmental, trenchless technology, emissions, underground construction

INTRODUCTION

Underground utilities are often referred to as the "forgotten" infrastructure mainly because they are physically hidden from the public eye. These include gas, water, wastewater, pipelines, power, and communications systems. Deterioration of these buried networks, due to overextending of their expected lifespan, has initiated various research efforts in this field of construction. Innovative methods of rehabilitation and installation of underground utilities such as trenchless technology have gained recent popularity as being economical, safe, and environmentally-friendly. The American Society of Civil Engineers (ASCE) 2009 report on the state of the nation's infrastructure gave a rating of D– for the water and wastewater lines in the United States (ASCE, 2009). Trenchless technologies offer a more feasible solution for underground projects, which have increased in demand due to building expansion and congestion of highways and urban areas. Currently, government agencies worldwide are raising concern over environmental impacts of human activity. Subsequently, reducing airborne emissions is vital to developing sustainable solutions.

Recognition of the urgency to curb emissions worldwide has led to an increase in research efforts aimed at developing methods to quantify and reduce emitted emissions. The construction industry, which consumes a large quantity of the fossil fuels, has been tasked with reducing airborne emissions. Sacramento, California's Air Quality Management District (AQMD) now requires that any project that exceeds a short-term construction threshold of 85 pounds per day of nitrogen oxide (NO_X) must

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mitigate the air quality impact (SMAQMD, 2008). Additionally, the State of California passed into law the Global Warming Solutions Act of 2006, which sets up the first enforceable statewide program in the U.S. to cap all greenhouse gas emissions from major industries and outlines penalties for non-compliance (Press Release GAAS:684:06, 2006). The Act requires the California Air Resources Board (CARB) to develop regulations and market mechanisms that will ultimately reduce California's greenhouse gas emissions by 25 percent by 2020.

In 2007, a series of United Nations climate change reports highlighted the need to curb emissions of greenhouse gases such as carbon dioxide that are driving global warming. The agreement is intended to impose curbs on all countries including both developed and developing countries. The United Nations-supported Kyoto Protocol was the first international agreement to curb the emissions of greenhouse gases. The goal of the Kyoto Protocol is to reduce worldwide greenhouse gas emission to 5.2 percent below 1990 levels between 2008 and 2012 (UNFCC, 2009). It sets specific emissions reduction targets for all industrialized nations, but excludes developing countries.

Canadell et al. (2007) calculated the worldwide carbon dioxide emissions in 2006 to be 35% greater than that of 1996; however, with even with considerable efforts being made to reduce the emissions, carbon dioxide emissions have increased at a rate of 3.3% per year since 2000. This supports the notion that human activities are leaving behind rather disruptive impacts on our environment. Increase in atmospheric temperature is caused by rising carbon dioxide concentrations and is not expected to decrease significantly even if carbon emissions were to completely cease. Future carbon dioxide emissions in the 21st century will hence lead to adverse climate changes on both short and long time scales that would be essentially irreversible. (Solomon et al. 2008)

The utilization of traditional open-cut methods for the installation of underground utilities has been a common practice in the construction industry for many years. Currently, there is a trend towards adopting trenchless technologies due to the minimal impact of these methods. This paper discusses and quantifies emissions from the upsizing of 200mm (8") sewer line to 250mm (10") wastewater line comparing trenchless pipe replacement (or pipe bursting) and traditional open cut methodologies.

PREVIOUS RESEARCH

The United States Environmental Protection Agency (EPA) is charged with the responsibility of protecting human health and safeguarding the environment including air, water, and land. Additionally, the EPA sets the national standards for environment protection using environmental assessment, research, and education. The agency works with government and industry to develop pollution prevention programs and energy conservation efforts.

On-going research efforts have addressed concerns with emissions from human activities that consume fossil fuels and emit harmful chemicals into the atmosphere. Models have been developed that calculate emissions from aircraft travel, household activities, automobiles, and office activities. Emissions can then be factored to represent the people who are using these services. This aim is to provide a means for individuals to neutralize their emissions.

Ghenu et al. (2008) estimated the hourly emission factors for NO_x, CO, and PM 2.5 for working days and weekends inside an urban street in France. Real time data collection was performed for a period of 6 weeks with the concentration of pollutants measured every 15 minutes. The experimental results were compared with the available Operational Street Pollution Model (OSPM). The pollution model determines the pollutant concentrations based on direct measurement in the atmosphere. The estimation of pollutant from the vehicles on the street and the vehicle characteristics determine the pollutant concentration in the area. A limitation is that models that are based on historical data may prove to be ineffective due to changes in the global climate. The real-time data showed a variation by a factor of two in comparison to the OSPM model.

Cook et al. (2006) found the use of local data to model emissions from highway sources to have a large impact on the magnitude and distribution of predicted emissions and could significantly improve the accuracy of local scale air quality modeling assessments. They discovered that local emission factors used in Philadelphia resulted in a 12–14 % reduction in the model results. This research provides an insight into the requirement for determining emission factors for the given situation analyzed. The initial approach could be to determine emissions using national averages; however, in order to accurately determine emissions from a given activity, more refined emission factors are recommended.

Gomes et al. (2007) describe the development of a carbon dioxide emissions matrix for for determination of green house gas emission in Lisbon, Portugal. Research was based on the consumption of liquid fuel and gaseous fuel by residents in the area. The methodology provides insight into the determination of total pollutants emitted in a particular area using basic equations and local data. The model is limited to local conditions and not portable.

Guggemos (2003) developed a model to determine emissions from the on-site cast-in-place concrete process. Concrete placing, curing, and construction were activities considered in the analysis. The choice of material and equipment determined the method of formwork and cast-in-place concrete placement. The processes, material, and equipment were identified before determining the environmental impacts. Based on the processes, activities were divided and emissions due to the materials and equipment were determined. Factors that determined emissions from the equipment included quality of the equipment, transport distances, cleaning process, water consumption, and wastewater generation. The emissions for the construction activities were determined based on fuel consumed and the emissions of CO_2, CO, NO_x, SO_x and VOC from the equipment and machineries that were used in the activity. The equipment emissions were calculated based on EPA developed equations (EPA 1996; EPA 2000). The material emissions were estimated based on the total energy consumed off-site for the manufacturing and production of the materials and the energy consumed on-site for the installation. Life cycle cost analysis and emissions for the three case studies provide an insight into the amount of emissions generated by the construction activities. The calculation of emissions from the steel and structural frame commercial buildings provided the ability to select a construction design and methodology during the design stage of the construction project.

The existing models discussed all calculate emissions using an emission factor based on independent data sets and then calculate total emissions based on factors to be considered. The development of these existing models reiterates the conscientious of the world towards environmental sustainability. With increased recognition for green buildings in construction, research needs to be undertaken to analyze and assess the impacts of various construction methods and relevant equipment.

The EPA's non-road diesel rule warrants refiners to reduce the sulfur level of fuel for non-road equipment to 500 parts per million (ppm) sulfur maximum (EPA, 2007). The goal of the rule is to reduce sulfur levels of fuel to meet an ultra-low standard (15 ppm) to promote new advanced emission control technologies for engines used in locomotives, ships, and other non-road equipment. The EPA has also adopted a comprehensive national program to reduce the emissions from future non-road diesel engines by integrating engine and fuel controls as a system to gain the greatest emission reductions. To meet these emission standards, engine manufacturers will produce new engines with advanced emission-control technologies similar to those already expected for highway trucks and buses. Exhaust emissions from these engines are projected to decrease by more than 90%.

EPA document EPA420-P02-016 provides the documentation behind the non-road model for estimating emissions (EPA, 2002a). The model brings together information on equipment population, equipment use and emission factors so that it can be used to estimate emissions. The emission factors need to be adjusted for in-use operation since it differs from the typical conditions. The documentation provides the logic and the considerations behind the determination of emission factors for each of the pollutants. EPA has collected data on operation characteristics of different equipment. They have also categorized the engines based on their power. The emissions data are available for different categories of engines performing different activities. With the different emission control standards that are being enforced by the EPA, there is a reduction of sulfur and nitrogen emissions. To determine emissions from the equipment and vehicles, the emission factors are calculated based on the test data available with the EPA. This approach helps to estimate pollution using equations that are applicable for particular operation.

This paper demonstrates a method for calculating emitted emissions from underground utility construction operations. A case study comparing traditional open cut versus trenchless pipe replacement is performed based on an approached developed by Sihabuddin and Ariaratnam (2009). Various standard emissions are analyzed including hydrocarbons (HC), carbon monoxide (CO), nitrogen oxides (NO_X), particulate matter (PM), carbon dioxide (CO_2) and sulfur oxides (SO_x).

CURRENT ENGINE STANDARDS

There are currently two sets or tiers of emission standards for vehicles in the United States defined as a result of the Clean Air Act Amendments of 1990. These standards restrict the emissions of carbon monoxide (CO), nitrogen oxides (NO_x), particulate matter (PM), formaldehyde (HCHO) and non-methane organic gases (NMOG) or non-methane hydrocarbons (NMHC). The Tier I standard was adopted in 1991 and was phased from 1994 to 1997. A set if transitional and initially voluntary National Low Emission Vehicle (NLEV) standards were in effect starting in 1999 for Northeastern states and 2001 for the rest of the country. The Tier II standards were adopted in 1999 and began to be phased in from 2004 onwards. The technology standards of the engines determine the emissions from the equipment and hence the determination of steady state emission factors for various pollutants. Due to differences in emission between engine models pre-1988 until 1999 (the introduction of tier 1 standards), the EPA adopted "Base" standards for engines prior to 1988 and "Tier 0" for the engine models from 1988 to 1999. The population of vehicles after 1999 is split between Tier 0, Tier 1, Tier 2, and Tier 3 emission standards. Some equipment manufactured between 2000 and 2007 in various engine power categories are split between Tier 1, Tier 2, and Tier 3 emission standard with the majority of engines progressively complying to higher emission standards each year. Since technology plays an important role in emissions emitted from construction-related equipment, identification of the control standard of equipment is necessary in determining emission quantities.

The more stringent Tier 4 standards were phased in beginning in 2008 (EPA 2006). The final rule provided in the Federal Register necessitates the manufacturers of engines to reduce the NO_x emissions by 90%, limit the concentration of NO_x in the engine exhaust, reduce the PM emissions by 60% or more and limit the concentration of PM in the engine exhaust (EPA, 2006). The more stringent standards by the EPA forces engine manufacturers to invest in efficient emission control technologies, thereby improving the pollution control in new engines. However, the use of older machines manufactured before 2008 will result in higher pollutant emissions.

EMISSION FACTORS

The emission factor is the basic tool for estimating emissions and is usually expressed as the weight of pollutant emitted divided by a unit weight, volume, distance, or duration of the activity emitting the pollutant. It is used to determine emissions from equipment or machinery that burn fuel. The general equation provided in document EPA-454/R-95-015 (EPA, 1997) is:

$$E = A \times EF \times \left[1 - \left(\frac{ER}{100}\right)\right] \quad (1)$$

where

E = emissions

A = activity rate

EF = uncontrolled emission factor

ER = overall emission reduction efficiency, %

(ER is the product of the control device destruction or removal efficiency and the capture efficiency of the control system)

The activity rate is a function of the activity that is under consideration. The activity rate determination is based on the emission factor, which was calculated based on the test data ratings. If the emission factor is expressed as the weight of pollutant released for a volume of fuel consumed by the activity, the activity rate should be the measurement of the volume of fuel consumed by that activity.

For example, in the case of emission factors expressed in terms of g/hp-hr, the activity needs to be measured in terms of the power (hp) consumed and the duration (hr) of the activity that emits the pollutants. If the emission factor is expressed in terms of g/gal, then the activity rate should be the measure of gallons of fuel burned. A more detail explanation of emission calculations for underground utility construction can be found in Sihabuddin and Ariaratnam (2009).

EMISSION FACTORS FOR NON-ROAD EQUIPMENT

Various types of equipment are typically present on a construction project. Some of the equipment are non-road and subsequently, the emissions from this equipment are calculated by hours of operation. The operation of this equipment depends on factors such as age, model year, hours of operation, and engine characteristics. Diesel fuel is typically used for non-road equipment. The major pollutants emitted by the equipment are hydrocarbons (HC), carbon monoxide (CO), nitrogen oxides (NO_x), particulate matter (PM), carbon dioxide (CO_2) and sulfur oxides (SO_x). The following sections detail a methodology for calculating emissions from non-road engines applied to construction equipment. Emission factors for each pollutant type are calculated by the manufacturing specifications and operation characteristics of the equipment.

HC, CO & NO_X Emission Factors (Non-Road)

Emission factors for hydrocarbon (HC), carbon monoxide (CO) and nitrogen oxides (NO_x) are determined by the product of steady-state emission factor, transient adjustment factor, and deterioration factor. The steady-state emission factor was determined by studying emissions from different equipment in a model year and horsepower category, under standard test conditions. Since the operating conditions differ from standard test conditions, a transient adjustment factor (TAF) was introduced to offset the emissions. The deterioration factor (DF) is the determination of the increase in emissions due to age of the engine.

PM Emission Factor (Non-Road)

The determination of emission factor for particulate matter (PM) is similar to the emission factor for HC, CO and NO_x. As PM emissions from the equipment are dependent on the fuel sulfur content, there is a necessity to adjust the emission factor for any variations in fuel sulfur. Standard fuel sulfur content is considered to be 0.33%, thereby producing an adjustment factor of zero.

CO_2 Emission Factor (Non-Road)

Emission factors for carbon dioxide (CO_2) are calculated based on brake-specific fuel consumption (BSFC), which is a measure of an engine's efficiency. BSFC is the rate of fuel consumption divided by the rate of power production. In-use adjusted BSFC is used to compute CO_2 emissions directly. BSFC and engine activity provides the means to estimate the tons of fuel consumed. It is assumed that all of the carbon in the fuel is converted to CO_2. The average carbon fraction of the fuel is estimated to be 87%. For every 12 g (atomic weight of carbon is 12) of carbon burned during the combustion of fuel, there is 44 g (molecular weight of carbon dioxide is 44) emitted into the atmosphere. A small amount of carbon is always lost to the atmosphere as hydrocarbon (HC) components. Therefore, this amount needs to be adjusted during the calculation.

SO_2 Emission Factor (Non-Road)

The determination of emission factor for sulfur dioxide (SO_2) is similar to that of the emission factor for CO_2. For every 32 g (atomic weight of sulfur is 32) of sulfur burned during the combustion of fuel, there is 64 g (molecular weight of sulfur dioxide is 44) emitted into the atmosphere. While some of the SO_2 is converted into sulfuric acid hydrated seven times ($H_2SO_4.7H_2O$), some is lost in the form of unburned fuel indicted by HC emissions. The default value of the amount of sulfur by weight in industrial diesel is 0.33%.

EMISSION FACTORS FOR ON-ROAD EQUIPMENT

Heavy duty diesel trucks are typically used for transporting materials and equipment to the jobsite. Therefore, the corresponding values of heavy duty diesel truck are used in the estimation of emissions from the equipment traveling to the site. Typical trucks used in on-road operations operate on diesel fuel and have a gross weight greater than 8,501 lbs, thereby falling under the heavy duty diesel vehicles (HDDV) category as designated by the EPA (2002b).

HC, CO & NO_X Emission Factors (On-Road)

The analysis for emission factors for hydrocarbons (HC), carbon monoxide (CO) and nitrogen oxides

(NO_x) was conducted by the EPA assuming that the emission levels produced by the certification test procedure are representative of the average in-use emission levels. These emission levels were then averaged to estimate the Zero-Mile Emission factors (EF_{ZM}) and deterioration (D) during the useful life of the vehicle. The EPA conducted tests to determine the effect of altitude on the emission factors. It was determined that altitude plays a role in increasing or decreasing emissions from on-road vehicles. Increase in altitude increases the emissions from vehicles. It is important to note that the increase in quantity of emissions differs for each pollutant. The altitude adjustment factor is the ratio of emissions in low altitude to emissions in high altitude. Since the variance in the emission factor is negligible with difference in altitude, a broad category of high/low altitude is considered. High altitude is representative of conditions approximately 1.68km (5,500 ft) above sea level, while low altitude is representative of conditions approximately 152m (500 ft) above sea level

PM Emission Factors (On-Road)

The determination of emission factor for particulate matter (PM) is similar to the emission factor for HC, CO, NO_x. Particulate matter consists of particles of organic carbon, elemental carbon, and a few traces of sulphate. The EPA provides the methodology for determining the emission factor for particulate matter less than 10 microns (EPA, 2003). The emission factor for PM is a function of vehicle class, model year, and mileage and is determined in terms of weight of pollutant released for a mile of drive. The zero-mile PM emission factor for vehicle class and model year is factored for the deterioration of the vehicle with age.

SO_2 and CO_2 Emission Factor (On-Road)

The determination of sulfur dioxide (SO_2) and carbon dioxide (CO_2) emission factors is similar to those of non-road emissions. Instead of using the brake specific fuel consumption (BSFC), the fuel density (F_D) and fuel economy (F_E) are used to determine the emission factors in terms of weight of pollutant released per mile of travel. The average fuel density as determined by EPA is 7.11 lb/gal (EPA, 2002c). The default value for the percentage of sulfur by weight in commercially available diesel fuel is 0.05%.

EMISSION CALCULATOR TOOL

An emission calculator tool, e-CALC, was developed in MS Excel using Visual Basic coding. The calculator tool estimates emissions from underground utility projects based on EPA-approved methodology. Required input data can be obtained from daily progress reports or productivity estimates, while equipment-specific information should be acquired from the contractor. Non-road equipment data include: power; model year; engine technology; useful hours and cumulative hours to date; fuel characteristics such as type and sulfur content; and activity characteristics such as representative equipment cycle, power used and hours of use. The data required to calculate emissions generated from on-road transportation equipment include: model year; gross vehicle weight; mileage; fuel characteristics such as type and sulfur content; and activity characteristics such as altitude of operation, number of trips, one way distance and return distance.

As with any computer tool, the accuracy of output information depends on the accuracy of the input data. The calculator is a tool intended for contractors, engineers, and owners to obtain an estimate of the environmental impact of their proposed underground utility project. The tool provides a comparison of emissions generated from two possible installation methods with default information available for four typical utility construction methods: 1) horizontal directional drilling; 2) trenchless pipe replacement; 3) trenching; and 4) traditional open-cut. It should be noted that the tool is portable and can be applied to any construction process that incorporates machinery and equipment.

COMPARISON OF OPEN CUT AND TRENCHLESS PIPE REPLACEMENT EMISSIONS

It is necessary to have similar project specifications in order to compare two underground utility construction methods. To compare emissions generated from two different utility construction methods, a case study on a project with trenchless pipe replacement (or pipe bursting) and traditional open cut

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options is demonstrated. A contractor that employs both methods provided a breakdown of task durations and equipment details. It should be noted that the actual project was completed using pipe bursting methodology. Equipment and activity data were collected onsite by monitoring the construction operation.

The project consisted of upsizing a 200mm (8") clay wastewater line to a 250mm (10") high density polyethylene (HDPE) line in the Town of Los Lunas, 16 miles north of Albuquerque, New Mexico. The installation depth was 2.1m (7 ft) and length was 106m (349 ft) spanning between two manholes. It should be noted that there were two marked 100mm (4") service laterals along the alignment.

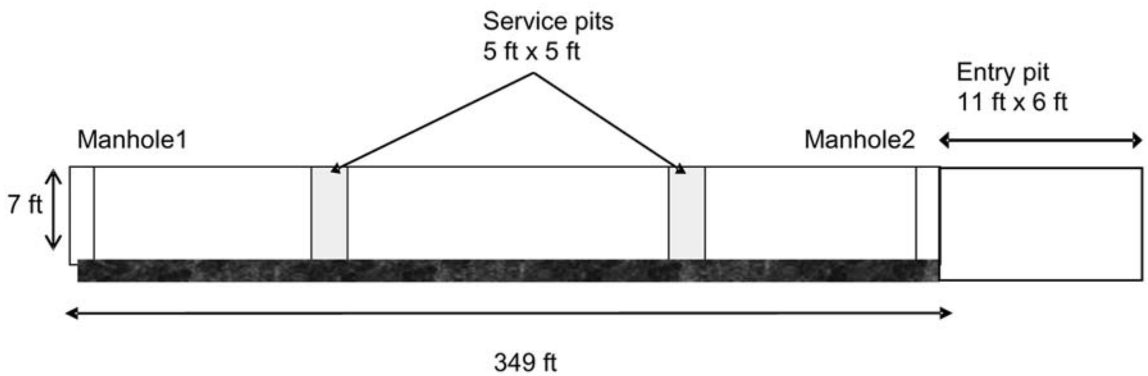
Option 1: Trenchless Pipe Replacement

Trenchless pipe replacement (or pipe bursting) involves excavation of an entry pit for pulling the new pipe and service pits for re-connecting the service lateral. Service pits at the lateral locations provide access for re-connection to the main after the installation. The existing pipe was burst using a pneumatic method of pipe bursting. Additional information on the pipe bursting process can be found in Ariaratnam and Bennett (2005).

The crew started working on the entry pits and service pits one day prior to the actual pipe replacement operation. Initially, the existing wastewater line was inspected using Closed-Circuit Television (CCTV) and the lateral connections were identified and marked on the site. The lateral crossings required two service pit locations. The entry pit for pulling in the new 250mm (10") HDPE pipe was excavated near one of the manholes. Twelve meter (40 ft) sections of HDPE pipe were fused using a butt fusion technology on site. Traffic flow was restricted to one lane along the length of the alignment. Excavated materials from the entry and service pits were used during the backfilling operation. Figure 1 illustrates the profile and dimensions of the alignment.

Site Activities The entry pit and service pits were excavated using a Volvo BL70 backhoe. The size of the entry pit was 11 ft × 6 ft and had box shoring to prevent caving in. The excavated service pits were each 5 ft × 5 ft. A winch was placed at Manhole 1 (MH 1) and the new pipe was installed from Manhole 2 (MH 2). The winch was positioned above MH 1 and the winch cable was pushed towards the entry pit. The bursting head was connected the winch cable as soon as the it reached the entry pit location. The other end of the bursting head was connected to the new 250mm (10") HDPE pipe using a swivel. The swivel helps to prevent any torque transferring from the bursting head to the pipe during installation. The existing 200mm (8") clay pipe was burst by the bursting head while the new product pipe was simultaneously pulled through the expanded borehole created by the bursting head. At the end of the pull, the head was disconnected from the pipe. Then the head was adjusted to move inside the existing pipe to exit at

FIGURE 1. Wastewater project alignment details.



the entry pit. Minimal backfill and road restoration activities were required at the excavation locations. The backfill was done in 300mm (1 ft) layers and a hand-held compactor was used to compact the soil in the service pits. At the entry pit, a soil compactor with a drum size of 900mm (3 ft) was used for compaction. Table 1 presents all non-road and on-road equipment involved in the project. The dependency of activities and equipment involved in the installation are illustrated in Figure 2.

Field Data and Calculations The construction operation at the site of the pipe bursting for upsizing the existing 200mm (8") clay pipe to 250mm (10") HDPE pipe was studied. The actual equipment operating times and usage were recorded for calculating emissions presented in Table 2. Project details were inputs into the emissions calculator tool to determine the estimated emissions. Figure 3 illustrates the emissions generated by the pipe bursting process.

Option 2: Traditional Open Cut Construction

Open cut construction is the traditional method of installing underground utilities. In the open cut method of installation, the entire alignment of the new pipe must be excavated to facilitate pipe placement and a large site area, in comparison to the pipe bursting method, is required for movement of equipment. The contractor's estimator was consulted to provide project productivity estimates if the project had been completed using open cut methods. Since the contractor performs both open cut and pipe bursting projects in New Mexico, the details on activity durations were readily available from their database. Details of the non-road and on-road equipment required for the open cut construction were obtained from the contractor's equipment inventory.

Site Activities The site activity commences with excavation a 1,200mm (4 ft) trench wide of the entire stretch of the alignment. Since the excavation is 2.1m (7 ft) deep, shoring is required to be placed along the entire trench alignment. For the purpose of dust control, a water tank of 4,000 gal capacity is required to spray water at the site. The excavated material is used to backfill the trench. Similar equipment to those used in the pipe bursting option is used for compaction and paving. As with pipe bursting, 12m (40 ft) sections of HDPE pipe were fused using a butt fusion technology on site. The non-road

TABLE 1. Details of equipment involved for pipe bursting

Name	Model	Power	Activities
Winch	Hydroguide HG20	36.5 hp	1. Pull the winch cable (idling) 2. Pull in the tool with pipe 3. Pullback the bursting head (idling)
Backhoe	Volvo BL70	70 hp	1. Excavation of entry pit 2. Placing the shoring 3. Excavation of 2 service pits 4. Backfill the pits in 1ft layer
Air compressor	Ingersoll 425	145 hp	1. Air to the pneumatic head 2. Pullback the piercing tool
Hand compactor	MDR 9G	10 hp	Compaction in service pits
Soil compactor	Ingersoll PT125R	80 hp	Compaction in the entry pit
Paver	CAT AP1055B	158 hp	Paving with asphalt
Asphalt compactor	Ingersoll SD115D	174 hp	Compaction of asphalt layer
Truck	Ford F450	HDDV 4	Transport compressor & accessories
Truck	Ford F450	HDDV 3	Transport winch & accessories
Truck	Peterbilt	HDDV 8A	Transport equipment

FIGURE 2. Pipe bursting processes map.

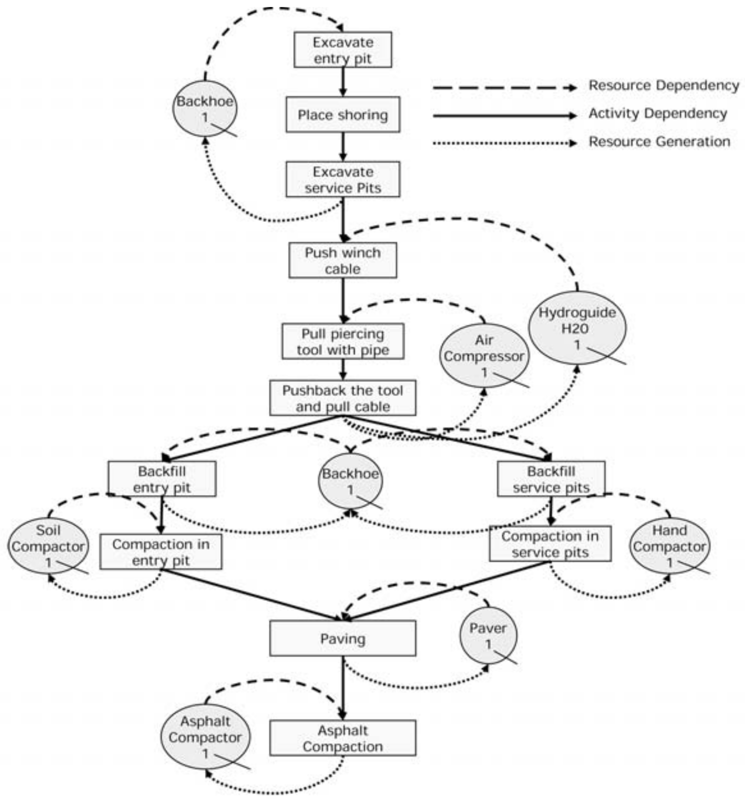


TABLE 2. Field data collected for pipe bursting.

Project: Upsizing of 8" clay pipe to 10" HDPE for 349 ft from manhole to manhole at 7ft depth
Contractor: AUI Inc
Location: Intersection of State Rd 6 & Hwy 314, Los Lunas, NM
Method of construction: Pipe Bursting

Equipment							Activity		
Name	**Model**	**Engine Model (Tier)**	**Model Year**	**Rated hp**	**Cum. Usage (hrs)**	**Useful Life (hrs)**	**Name**	**Total Time (mins)**	**Load Factor**
Hydroguide winch	HG20	Tier 0	1998	36.5	1630	5000	Pulling the cable	15	25
							Pulling the product pipe	35	75
							Pullback the mole	10	25
Air compressor	Ingersoll 425	Tier 2	2004	145	884	5000	Air to the pneumatic head	35	100
							Pulllback the piercing tool	10	100
Backhoe	Volvo BL70	Tier 2	2005	70	1407	5000	Excavation of entry pit	90	100
							Placing the shoring	30	55
							Excavation of service pits - 2 nos	210	100
							Backfilling the pits in 1 ft layers	60	60
Hand compactor	MDR 9G	Tier 0	1985	10	240	500	Compaction in the service pits	60	100
Soil compactor	Ingersol PT125R	Tier 1	1999	80	543	5000	Compaction of 1ft layers	45	100
Paver	CAT AP1055B	Tier 1	2001	158	1874	10000	Paving with asphalt	15	100
Asphalt compactor	Ingesol SD115D	Tier 1	1997	174	7632	10000	Compaction of asphalt layer	15	100

Truck					Activity			
Name	**Model**	**Model Year**	**GVW (lbs) or Class**	**Mileage**	**Name**	**Oneway Dist. (mi)**	**Return Dist. (mi)**	**Trips**
Truck	Ford F450	2001	15000	142689	Transport air compressor	16	16	1
Truck	Ford F350	2000	12500	210922	Transport winch	16	16	1
Transport	Peterbilt	1998	Class 8A	72654	Transport equipment	16	16	1

FIGURE 3. Summary of emissions for pipe bursting.

EQUIPMENT

Input Values

Name	Details						Fuel Details		Project Details		
	Make & Model	Rated Power (Hp)	Model Year	Control Tech	Useful Life (hrs)	Cum. Hrs (hrs)	Fuel (Type)	Sulfur (%)	Equipment Type	Load factor (%)	Usage (hrs)
Hydroguide Winch	HG20	36.5	1998	Tier 0	5000	1630	Diesel	0.33	Other Construction Equipn	25	0.42
Hydroguide Winch	HG20	36.5	1998	Tier 0	5000	1630	Diesel	0.33	Other Construction Equipn	75	0.58
Air Compressor	Ingersoll 425	145	2004	Tier 2	5000	884	Diesel	0.33	Other Construction Equipn	100	0.75
Backhoe	Volvo BL70	70	2006	Tier 2	5000	1407	Diesel	0.33	Tractors/Loaders/Backhoe	100	5
Backhoe	Volvo BL70	70	2006	Tier 2	5000	1407	Diesel	0.33	Tractors/Loaders/Backhoe	55	0.5
Backhoe	Volvo BL70	70	2006	Tier 2	5000	1407	Diesel	0.33	Tractors/Loaders/Backhoe	60	1
Hand Compactor	MDR 9G	10	1985	Tier 0	500	280	Diesel	0.33	Plate Compactors	100	1
Soil Compactor	Ingersoll PT125R	80	1999	Tier 1	5000	543	Diesel	0.33	Rollers	100	0.75
Paver	CAT AP1055B	158	2001	Tier 1	10000	1874	Diesel	0.33	Pavers	100	0.25
Asphalt Compactor	Ingersoll SD40	174	1997	Tier 1	10000	7632	Diesel	0.33	Rollers	100	0.25

Output Values

Name	Emission Factor (g/hp-hr)						Emissions					
	HC	CO	NOx	PM	CO2	SOx	HC (lbs)	CO (lbs)	NOx (lbs)	PM (lbs)	CO2 *(S/T)	SOx (lbs)
Hydroguide Winch	1.9	7.8	6.6	1.0	590.2	1.2	0.02	0.07	0.06	0.01	0.00	0.01
Hydroguide Winch	1.9	8.0	6.6	1.1	590.2	1.2	0.07	0.28	0.23	0.04	0.01	0.04
Air Compressor	0.4	1.3	3.9	0.2	535.2	1.1	0.09	0.32	0.94	0.06	0.06	0.26
Backhoe	0.8	6.3	5.2	0.5	693.9	1.4	0.66	4.82	4.00	0.41	0.27	1.08
Backhoe	0.8	6.2	5.2	0.5	693.9	1.4	0.04	0.26	0.22	0.02	0.01	0.06
Backhoe	0.8	6.2	5.2	0.5	693.9	1.4	0.08	0.57	0.48	0.05	0.03	0.13
Hand Compactor	1.5	5.5	10.1	1.3	585.5	1.2	0.03	0.12	0.22	0.03	0.01	0.03
Soil Compactor	0.5	3.7	5.3	0.6	594.5	1.2	0.07	0.48	0.71	0.08	0.04	0.16
Paver	0.4	1.4	5.4	0.4	535.2	1.1	0.03	0.12	0.47	0.03	0.02	0.09
Asphalt Compactor	0.4	1.4	5.5	0.5	535.2	1.1	0.04	0.14	0.52	0.04	0.03	0.10

TRANSPORT

Input Values

Name	Details				Fuel Details		Project Details			
	Make	GVW	Model Year	Mileage	Fuel	Sulfur	Altitude	# of trips	Dist. One-way	Dist. Return (mi)
Transport Truck	Ford F450	14,001-16,000	2001	142689	Diesel	0.05	Low	1	16	16
Transport Truck	Ford F350	10,001-14,000	2000	210922	Diesel	0.05	Low	1	16	16
Haul Truck	Peterbilt	33,001-60,000	1998	64275	Diesel	0.05	Low	1	16	16

Output Values

Name	Emission Factor (g/mi)						Emissions					
	HC	CO	NOx	PM	CO2	SOx	HC (lbs)	CO (lbs)	NOx (lbs)	PM (lbs)	CO2 *(S/T)	SOx (lbs)
Transport Truck	0.4	1.8	4.8	0.1	1007.4	0.3	0.03	0.13	0.34	0.01	0.04	0.02
Transport Truck	0.4	1.6	4.1	0.1	881.2	0.3	0.02	0.11	0.29	0.01	0.03	0.02
Haul Truck	0.6	3.0	10.2	0.2	1559.2	0.5	0.04	0.21	0.72	0.02	0.05	0.03

	HC	CO	NOx	PM	CO2	SOx
Total Emissions	**1.21 lbs**	**7.64 lbs**	**9.2 lbs**	**0.81 lbs**	**0.61 S/T**	**2.05 lbs**

* 1 S/T = 2000 lbs

and on-road equipment are presented in Table 3. The dependency of activities and equipment involved in the installation are illustrated in Figure 4.

Field Data and Calculations The construction operation at the site for replacing the existing 200mm (8") clay pipe with a 250mm (10") HDPE pipe using tradition open cut was studied. The actual equipment operating times and usage were recorded for calculating emissions presented in Table 4. Project details were inputs into the emissions calculator tool to determine the estimated emissions. Figure 5 illustrates the emissions generated by the open cut process.

Comparison of Emissions

The total emissions calculated from the two utility methods are compared in Figure 6. The results reveal the emissions from the open cut option to be approximately 79% greater than those generated from the pipe bursting operation. The total project time including mobilization and demobilization was three working days for the pipe bursting option, while the estimated duration for completing the project specifications using open cut was seven working days. In addition to time, cost, and social benefits, trenchless methods such as pipe bursting provide a better environmental benefit as evident by the major reduction in airborne emission compared to open cut. It is anticipated that future project requirements will include a component of emission assessment in addition to cost during the design and method selection.

CONCLUSIONS AND RECOMMENDATIONS

This paper demonstrated a model for calculating emitted emissions for underground utility construction. An emissions calculator tool was developed to provide the means for comparing two competing methods. The tool has default equipment for four different utility construction methods and can be tailored to meet individual project characteristics. The impact of traditional open cut construction on the environment was demonstrated through a case study comparison with trenchless pipe replacement (or pipe bursting) on a wastewater infrastructure project in New Mexico. The results found that emissions generated from open cut were approximately 77% higher in greenhouse gases and about 80% higher in criteria pollutant emissions compared to the pipe bursting option. This is a result of the increased productivity and reduced equipment requirements offered by the trenchless option. It is envisioned that quantification of emission data will be

TABLE 3. Details of equipment involved for open cut construction

Name	Model	Power	Activities
Excavator	John Deere 120	90 hp	1. Excavate the trench 2. Place the shoring 3. Place the pipe in the trench 4. Remove shoring from the trench
Water pump	Honda WT30X	10 hp	Water spraying fro dust control
Loader	John Deere 644H	130 hp	Backfill the trench in 1ft layers
Hand compactor	MDR 9G	10 hp	Compaction in service pits
Soil compactor	Ingersoll PT125R	80 hp	Compaction in the entry pit
Paver	CAT AP1055B	158 hp	Paving with asphalt
Asphalt compactor	Ingersoll SD115D	174 hp	Compaction of asphalt layer
Water truck	Mac – 4000 gal	HDDV 8A	Haul water to the site
Truck	Ford F450	HDDV 4	Transport equipment
Truck	Ford F450	HDDV 3	Transport equipment
Truck	Peterbilt	HDDV 8A	Transport equipment

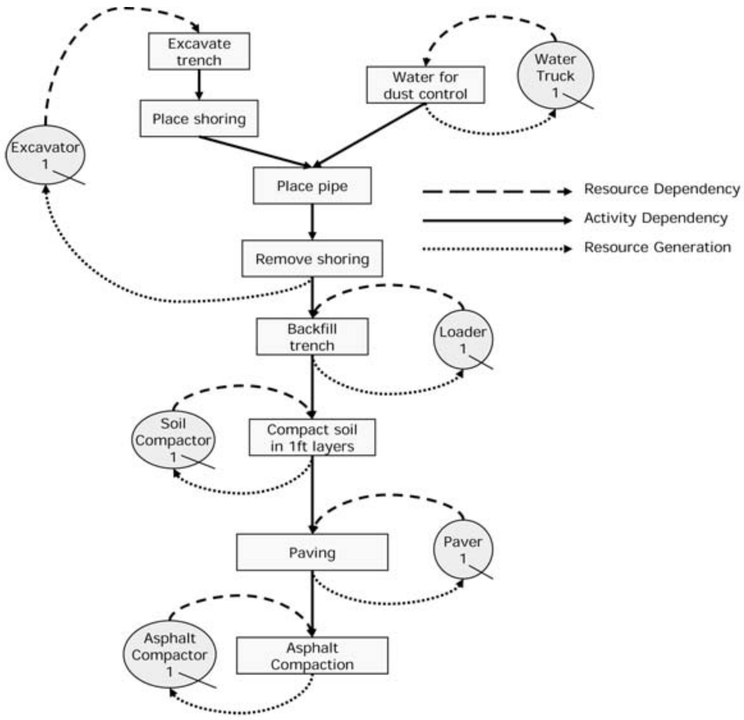


FIGURE 4. Open cut construction process map.

TABLE 4. Estimation of usage data determined for open cut construction.

Project: Upsizing of 8" clay pipe to 10" HDPE for 349 ft from manhole to manhole at a depth of 7ft
Estiamtion Contractor: AUI Inc
Location: Intersection of State Rd 6 & Hwy 314, Los Lunas, NM
Method of construction: Open cut

Equipment							Activity		
Name	**Model**	**Engine Model (Tier)**	**Model Year**	**Rated hp**	**Cum. Usage (hrs)**	**Useful Life (hrs)**	**Name**	**Total Time (mins)**	**Load Factor**
Excavator	John Deeere 120	Tier 1	2001	90	2102	8000	Excavation	1200	100
							Placing the shoring	240	75
							Place the pipe	30	75
							Removing the shoring	120	100
Water Pump	Honda WT30X	Tier 1	2000	10	130	500	Dust control at site	1200	100
Loader	John Deere 644H	Tier 1	2000	130	6532	10000	Backfill the trench in 1ft layers	360	60
Soil compactor	Ingersol PT125R	Tier 1	1999	80	543	5000	Comapction of 1ft layers	360	100
Paver	CAT AP1055B	Tier 1	2001	158	1874	10000	Paving the 4ft width	90	100
Asphalt compactor	Ingesol SD115D	Tier 1	1997	174	7632	10000	Compaction of asphalt layer	60	100

Truck					Activity			
Name	**Model**	**Model Year**	**GVW (lbs) or Class**	**Mileage**	**Name**	**Oneway Dist. (mi)**	**Return Dist. (mi)**	**Trips**
Water Truck	Mac	1989	50000	94985	Move to site	16	16	1
Water Truck	Mac	1989	50000	94985	Water for dust control	4	4	9
Truck	Ford F450	2001	15000	142689	Transport equipment	16	16	1
Truck	Ford F350	2000	12500	210922	Transport equipment	16	16	1
Transport	Peterbilt	1998	Class 8A	72654	Transport equipment	16	16	1

FIGURE 5. Emissions calculations for open cut construction

EQUIPMENT

Input Values

Name	Details						Fuel Details		Project Details		
	Make & Model	Rated Power (Hp)	Model Year	Control Tech	Useful Life (hrs)	Cum. Hrs (hrs)	Fuel (Type)	Sulfur (%)	Equipment Type	Load factor (%)	Usage (hrs)
Excavator	John Deere 120	90	2001	Tier 1	8000	2102	Diesel	0.33	Excavators	100	22
Excavator	John Deere 120	90	2001	Tier 1	8000	2102	Diesel	0.33	Excavators	75	4.5
Water Pump	Honda WT30X	10	2000	Tier 1	500	130	Diesel	0.33	Other Construction Equipr	100	20
Loader	John Deere 644H	130	2000	Tier 1	10000	6532	Diesel	0.33	Rubber Tire Loaders	60	6
Soil Compactor	Ingersoll PT125R	80	1999	Tier 1	5000	543	Diesel	0.33	Rollers	100	6
Paver	CAT AP1055B	158	2001	Tier 1	10000	1874	Diesel	0.33	Pavers	100	1.5
Asphalt Compactor	Ingersoll SD40	174	1997	Tier 1	10000	7632	Diesel	0.33	Rollers	100	1

Output Values

Name	Emission Factor (g/hp-hr)						Emissions					
	HC	CO	NOx	PM	CO2	SOx	HC (lbs)	CO (lbs)	NOx (lbs)	PM (lbs)	CO2 *(S/T)	SOx (lbs)
Excavator	0.6	3.7	5.4	0.7	594.5	1.2	2.41	16.22	23.36	2.86	1.30	5.25
Excavator	0.6	3.7	5.3	0.6	594.5	1.2	0.37	2.47	3.58	0.43	0.20	0.81
Water Pump	0.8	6.5	5.0	0.6	593.7	1.2	0.36	2.85	2.20	0.27	0.13	0.53
Loader	0.4	1.4	5.4	0.4	535.2	1.1	0.37	1.42	5.59	0.42	0.28	1.12
Soil Compactor	0.5	3.7	5.3	0.6	594.5	1.2	0.58	3.87	5.64	0.65	0.31	1.27
Paver	0.4	1.4	5.4	0.4	535.2	1.1	0.19	0.71	2.82	0.20	0.14	0.57
Asphalt Compactor	0.4	1.4	5.5	0.5	535.2	1.1	0.14	0.55	2.10	0.18	0.10	0.42

TRANSPORT

Input Values

Name	Details				Fuel Details		Project Details			
	Make	GVW	Model Year	Mileage	Fuel	Sulfur	Altitude	# of trips	Dist. One-way (mi)	Dist. Return (mi)
Water Truck	Mac	33,001-60,000	1989	94985	Diesel	0.05	Low	1	16	16
Water Truck	Mac	33,001-60,000	1989	94985	Diesel	0.05	Low	9	4	4
Transport Truck	Ford F450	14,001-16,000	2001	142689	Diesel	0.05	Low	1	16	16
Transport Truck	Ford F350	10,001-14,000	2000	210922	Diesel	0.05	Low	1	16	16
Transport Truck	Peterbilt	33,001-60,000	1998	64275	Diesel	0.05	Low	1	16	16

Output Values

Name	Emission Factor (g/mi)						Emissions					
	HC	CO	NOx	PM	CO2	SOx	HC (lbs)	CO (lbs)	NOx (lbs)	PM (lbs)	CO2 *(S/T)	SOx (lbs)
Water Truck	1.4	4.1	18.6	1.6	1682.1	0.5	0.10	0.29	1.31	0.11	0.06	0.04
Water Truck	1.4	4.1	18.6	1.6	1682.1	0.5	0.22	0.66	2.96	0.25	0.13	0.08
Transport Truck	0.4	1.8	4.8	0.1	1007.4	0.3	0.03	0.13	0.34	0.01	0.04	0.02
Transport Truck	0.4	1.6	4.1	0.1	881.2	0.3	0.02	0.11	0.29	0.01	0.03	0.02
Transport Truck	0.6	3.0	10.2	0.2	1559.2	0.5	0.04	0.21	0.72	0.02	0.05	0.03

	HC	CO	NOx	PM	CO2	SOx
Total Emissions	**4.84 lbs**	**29.49 lbs**	**50.92 lbs**	**5.39 lbs**	**2.78 S/T**	**10.15 lbs**

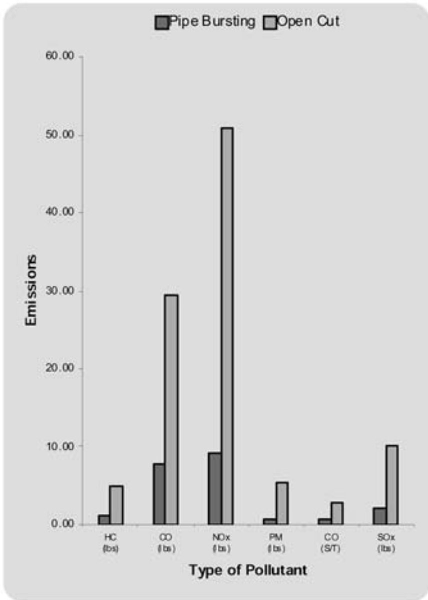
* 1 S/T = 2000 lbs

FIGURE 6. Comparison of emissions for pipe bursting and open cut construction.

COMPARISON CHART
Pipe Bursting VS Open Cut

Emissions		
Total	Pollutant	% Red (-) or Inc. (+)
1.21 lbs	HC	-75.0%
7.64 lbs	CO	-74.1%
9.19 lbs	NOx	-82.0%
0.81 lbs	PM	-85.0%
0.61 S/T*	CO	-78.1%
2.04 lbs	SOx	-79.9%

Equipment		Transport	
Hydroguide Winch	1.0 hrs	Transport Truck	32.0 mi
Air Compressor	0.8 hrs	Transport Truck	32.0 mi
Backhoe	6.5 hrs	Haul Truck	32.0 mi
Hand Compactor	1.0 hrs		
Soil Compactor	0.8 hrs		
Paver	0.3 hrs		
Asphalt Compactor	0.3 hrs		



Emissions		
% Red (-) or Inc. (+)	Pollutant	Total
0.0%	HC	4.84 lbs
0.0%	CO	29.48 lbs
0.0%	NOx	50.92 lbs
0.0%	PM	5.39 lbs
0.0%	CO	2.78 S/T*
0.0%	SOx	10.15 lbs

Transport		Equipment	
40.0 mi	Water Truck	26.5 hrs	Excavator
32.0 mi	Transport Truck	20.0 hrs	Water Pump
32.0 mi	Transport Truck	6.0 hrs	Loader
32.0 mi	Transport Truck	6.0 hrs	Soil Compactor
		1.5 hrs	Paver
		1.0 hrs	Asphalt Compactor

Average Emission Reduction (Pipe Bursting) = 80%

* 1 S/T = 2000 lbs

a factor in deciding between construction methods on future projects in addition to cost given current environmental sensitivity.

It is recommended that the emissions calculator tool be used on future utility construction projects to further gather information comparing the generated emissions of various construction technology options. This could aid in setting target acceptable emission levels for specific projects. To date, the calculator tool has been used on twelve projects and four different utility construction methods.

REFERENCES

Ariaratnam, S.T. and Bennett, R.D. (2005). *Pipe bursting good practices,* North American Society for Trenchless Technology, Arlington, VA.

ASCE (2009) *Report card for America's infrastructure,* American Society of Civil Engineers, Reston, VA http://www.asce.org/reportcard/2009/grades.cfm (Apr 29, 09)

Canadell, J., Que, C., Raupach, M., Field, C, Buitenhuis, E., Ciais, P., Conway, T., Gillett, N., Houghton, R.A., and Marland, G. (2007) "Contributions to accelerating atmospheric CO2 growth from economic activity, carbon intensity, and efficiency of natural sinks." Proceedings of the National Academic of Sciences, Vol. 104, No. 47, pp. 18866–18870.

Cook R., Touma J.S., Beidler A., and Strum M. (2006). "Preparing highway emissions inventories for urban scale modeling: A case study in Philadelphia" Transportation Research Part D: Transport and Environment, Vol. 11, Issue 6, pp 396–407.

EPA. (2007). "Non-road diesel equipment." Office of Transportation and Air Quality, United States Environmental Protection Agency, Washington D.C., http://www.epa.gov/nonroad-diesel/ (Mar. 12, 2008).

EPA. (2006). "Standards of performance for stationary compression ignition internal combustion engines; final rule." Federal Register Vol. 71, No. 132, 39156 – 39182. United States Environmental Protection Agency, Washington D.C.

EPA (2003). "Mobile 6.1 particulate emission factor model technical description: final report" Document No. EPA 420-R3-001 Assessment and Modeling Division, Office of Transportation and Air Quality, United States Environmental Protection Agency, Washington D.C.

EPA. (2002a). "Exhaust and crankcase emission factors for nonroad engine modeling—compression ignition." EPA420-

P02-016, Assessment and Modeling Division, Office of Transportation and Air Quality, United States Environmental Protection Agency, Washington D.C.
EPA. (2002b). "Update of heavy-duty emission levels (model years 1988-2004) for use in MOBILE6." EPA420-R-02-018, Assessment and Modeling Division, Office of Transportation and Air Quality, United States Environmental Protection Agency, Washington D.C.
EPA. (2002c). "Update heavy-duty engine emission conversion factors for MOBILE6, analysis of BSFCs and calculation of heavy-duty engine emission conversion factors." EPA420-R-02-005, Assessment and Modeling Division, Office of Transportation and Air Quality, United States Environmental Protection Agency, Washington D.C.
EPA (2000). "Highway vehicles: heavy duty diesel trucks." AP42 Compilation of Air Pollution Emission Factors. Vol. II: Mobile Sources, Assessment and Modeling Division, Office of Transportation and Air Quality, United States Environmental Protection Agency, Washington D.C.
EPA (1997). "Procedures for preparing the emission factor documents." Document No. EPA-454/R-95-015, Office of Air Quality Planning and Standards, Office of Air and Radiation, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina.
EPA (1996). "Gasoline and diesel industrial engines." AP42 Compilation of Air Pollution Emission Factors. Vol I: Stationary Sources, Section 3.3, Assessment and Modeling Division, Office of Transportation and Air Quality, United States Environmental Protection Agency, Washington D.C.
Ghenu A., Rosant J.M., and Sini J.F. (2008). "Dispersion of pollutants and estimation of emissions in a street canyon in Rouen, France." *Journal of Environmental Modeling & Software*, Vol. 23, 314–321.
Gomes, J., Nascimento, J., and Rodrigues, H. (2007). "Development of a local carbon dioxide emissions inventory based on energy demand and waste production" *Journal of Air & Waste Management*, Vol 57. 1032–1037.
Guggemos, A.A. (2003). "Environmental impacts of on-site construction processes: focus on structural frames." Ph.D. Dissertation, Dept. of Civil Engineering, University of California-Berkeley.
Press Release GAAS:684:06 (2006). "Gov. Schwarzenegger signs landmark legislation to reduce greenhouse gas emissions." Office of the Governor, Los Angeles, California, http://gov.ca.gov/index.php?/press-release/4111/ (Mar. 18, 2008).
Sihabuddin, S.S., and Ariaratnam, S.T. (2009). "Methodology for estimating emissions in underground utility construction operations." Journal of Engineering, Design and Technology, Vol. 7, No. 1, Emerald Group Publishing, pp. 37-64.
Solomon, S., Plattner, G.K., Knutti, R., and Friedlingstein, P. (2007). "Irreversible climate change due to carbon dioxide emissions." Proceedings of the National Academic of Sciences, Vol. 106, No. 6, pp. 1704–1709.
SMAQMD (2008) "AQMD recommended mitigation for reducing emissions from heavy-duty construction vehicles." Sacramento Metropolitan Air Quality Management District, Sacramento, CA, http://www.airquality.org/ceqa/mitigation-heavy-construction.shtml#footnote1 (Apr. 21, 2008)
UNFCC (2009) "Kyoto Protocol." United Nations Framework Convention on Climate Change, Haus Carstanjen, Bonn, Germany. http://unfccc.int/kyoto_protocol/items/2830.php (April 29, 2009).