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Lifecycle Carbon Footprint Analysis of Transportation Capital Projects

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16. Abstract

This report documents the development of GASCAP, the Greenhouse Gas Analysis System for Transportation Capital Projects. The report provides extensive detail on the assumptions underlying the emissions factors for materials, construction equipment, and preliminary work on a life-cycle maintenance module. Appendices incude a review of methods for incorporating the effects of induced travel demand into a sketch planning tool, plus additional documentation for various elements of GASCAP. A user guide is also included as are a selection of case studies that were conducted to provide initial tests of the software. Further research directions to extend the usability of GASCAP are also included.

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EXECUTIVE SUMMARY

This report summarizes the development of the GASCAP software for analyzing the life-cycle greenhouse gas (GHG) emissions of transportation capital construction projects. GASCAP is a spreadsheet-based tool that allows users to input information directly from NJDOT project bid sheets. Additional information must be entered for specific equipment used during the project. One-time maintenance projects that are specified within bid sheets may also be evaluated for their greenhouse gas emissions. Additional modules of GASCAP allow input of information on recycled materials used in pavements, assumptions on how the project will be staged, an assessment of alternative lighting, and a module for assessing GHG emissions from rail projects. The software is designed to be easy to use. Simple documentation is provided that guides users through each module of the software.

GASCAP provides life-cycle emissions estimates for the major GHGs. These include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and black carbon (BC). We also include estimates for the oxidation to CO_2 of volatile organic compounds (VOC) and carbon monoxide (CO).

The model outputs estimates of both direct emissions and upstream emissions. The latter are primarily due to the process fuels used for material production and electricity generation. This also includes the emissions associated with mining and processing aggregate materials, which are an input to both asphalt and concrete production.

Road and bridge construction primarily use three materials: asphalt, concrete, and steel. For asphalt a temperature dependent estimate that spans the range of asphalt types from Hot Mix Asphalt to more carbon efficient Warm Mix Asphalt was developed. This allows users to estimate the difference in emissions from using these mixes of asphalt. For concrete we distinguish the various components of production, including the chemical release of CO_2 that occurs in the production of cement. GHG emissions from steel production are also broken down into various components that represent different stages of the production process. These are the three principal materials that are used in most construction projects. Additional materials that are included are copper (mainly for catenary rail systems) and aluminum.

Many small components are included in GASCAP. The model includes over 1000 individual bid sheet items, such as pipes for water, gas, and sewage, and drainage structures, and slope and channel protection, among others. Formulas based on the geometry of specific items have been calculated to provide estimates of material volume in the appropriate units for each item. These are easily input by the user using bid sheet numbers.

GASCAP uses existing information on both direct and upstream emissions factors derived from existing sources of data, determined by the US Environmental Protection Agency (EPA), the US Department of Energy (DOE), and other research efforts. Our main sources are the AP-42 emissions factors compiled by EPA, the GREET life-cycle analysis models developed by the Argonne National Laboratory (ANL) for DOE, the PaLATE model developed at the University of California with support from CalTrans and USDOT, the GreenDOT model developed by the NCHRP for lighting emissions factors, and EPA emission models for on-road and non-road vehicles (MOVES and NONROAD). These sources are supplemented with academic sources and our own estimates and assumptions based on a variety of published sources.

The first two modules of GASCAP are a materials module and an equipment module. The materials module is input using bid sheet information while the equipment module requires the specification of construction equipment used on the project.

The recycling module calculates off-sets to emissions based on the use of recycled materials in pavements and concrete. It is assumed that these materials would not be used elsewhere and thus the benefit of using them is the displacement of other materials used as aggregate in paving materials and concrete.

GASCAP includes a module that allows the input of project staging assumptions. The location of the project is used as a basis to estimate the distance that materials and people are transported to the site, and the movement of construction equipment on and off-site if this is a part of the staging strategy. Assumptions are also input on lighting requirements for night work.

A lighting module is included that allows the estimate of emissions from different lighting types and power ratings of lamps. Assumptions must be input on the expected number of years of operation. These factors are taken from the GreenDOT model developed for an NCHRP project.

GASCAP includes a rail module for NJ Transit capital projects. The model uses a bottom-up approach to calculate emissions from tracks, catenary equipment, and parking facilities, to the greatest extent possible. Other components are based on averages derived from other published estimates for specific rail systems.

The lifecycle maintenance module of GASCAP is not yet completed. This will require additional work and the use of data from NJDOT currently being analyzed by another project. The intent is to link the recommended maintenance procedures to capital projects and calculate the lifecycle emissions from those maintenance activities over the lifetime of the project.

This final report documents the assumptions and sources of the data underlying the GASCAP model. The report serves primarily as a reference manual. A user guide for the software is also included.

As part of this project we also included a review of techniques to estimate the induced travel from new project construction. Implementation of an approach to do this was not included in the scope of this project. Our review identified existing techniques that might be suitable for developing into a sketch planning tool using New Jersey data.

Finally, various items of additional work are identified for the GASCAP tool. In particular the version delivered is in beta and requires testing by NJDOT staff to determine any problems with format, data, and structure, as well as to identify any major omissions. No training has been completed for staff, however, the software is designed to be very user-friendly.

INTRODUCTION

The Carbon Footprint Project is part of the State of New Jersey's effort to substantially reduce GHG emissions from all sources within the state and from electricity consumed in New Jersey but produced out of state, according to the Global Warming Response Act (GWRA), approved July 6, 2007. The GWRA defines GHG as carbon dioxide (CO_2), methane (CH_4), Nitrous Oxide (N_2O), hydrofluorocarbons (HFC), perfluorocarbons (PFC), and sulfur hexafluoride (SF_6), as well as any other gas or substance that the New Jersey Department of Environmental Protection (NJDEP) determines to be a contributor to global warming. These gases are recognized nationally (EPA 2009b) and internationally (Climate Registry 2008, IPCC 2009) as the principal contributors to global warming. These gases are referred to as direct GHG in the Environmental Protection Agency (EPA) inventory (EPA 2009b). Indirect GHGs may have greenhouse properties, but are not stable in the atmosphere. Carbon monoxide (CO), and volatile organic compounds (VOC) but not methane, are reactive enough that they generally oxidize quickly to CO_2. EPA equipment modeling uses this assumption (EPA 2004b). Other nitrogen oxides (NO_X) are mostly transformed before they reach the upper troposphere and probably do not contribute appreciably to global warming (Wayne 1991). Sulfur dioxide (SO_2) oxidizes in weeks and precipitates out as acid rain, but is a minor factor in global warming.

GHG emissions may be measured in CO_2 equivalents (CO_2e) or global warming potential factors (GWP), which are synonymous. A molecule of SF_6 has the global warming potential of 23,900 molecules of CO_2, as shown in Table 1. CO_2 is the principal product of combustion, and other chemical processes, such as cement, lime, and iron and steel production, and is taken up by green plants as biomass. VOC and CH_4 are usually fugitive emissions from energy production and waste disposal (Wang 1996). N_2O emissions are produced from adipic and nitric acid production and fertilizer use. HFCs are used mostly in refrigeration and air conditioning (IPCC 2000). PFCs are used primarily in some aluminum and semiconductor manufacturing processes (IPCC 2000). SF_6 is used in electricity production and transmission, magnesium production, and semiconductor manufacturing(IPCC 2000). Of these materials only the first three were addressed in the models we reviewed. PFCs, HFCs, and SF_6 emissions from transportation projects are not well documented in the literature.

GHG emissions are distinguished by source (Climate Registry 2008). This materials review includes combustion emissions from stationary sources such as for electricity generation, boilers, and furnaces. Process emissions that result from physical or chemical processes from manufacturing are also included. Truck per mile GHG emissions are included to account for materials transportation to the job site. Emissions from the processing of fuels are treated as upstream emissions for the fuel and engine oil consumed by construction equipment.

Table 1. CO2 Equivalence for GWRA Defined Greenhouse Gases

GHG Name	Formula	CO_2e/GWP
Carbon dioxide	CO_2	1
Methane	CH_4	21
Nitrous oxide	N_2O	310
Hydrofluorocarbons	Varies	12-11,700
Perfluorocarbons	Varies	6,500-7,400
Sulfur Hexafluoride	SF_6	23,900
Source: (Climate Registry 2008)		

To properly compare the GHG emissions a lifecycle approach is used. This means that not only are direct emissions counted, i.e. those caused directly by the processes under the contractors' control, but also indirect emissions caused by processes not under the contractors' control (Climate Registry 2008, Greenhalgh et al. 2005, Raganathan et al. 2009). Indirect GHG emissions include upstream emissions, downstream emissions, and electricity generation. Upstream emissions include those associated with the extraction of raw materials or feedstocks in the case of fuels, transportation of these from the extraction to the refining or processing site, refining or processing, and distribution to the job site (Delucchi 2003, Elcock 2007, Horvath 2004a). Downstream emissions include those associated with demolition, and disposal and recycling of spent materials.

There is a strong preference in the guidance literature for direct measurement of GHG emissions (Climate Registry 2008)(Ewing, Cervero 2010)(Ewing, Cervero 2010). However, for materials we assume that beyond the ability to specify parameters of materials by placing an order with suppliers, the process of preparing materials is out of the control of contractors. We therefore attempt to account for variation in the types and subtypes of materials regulated by the state and ordered by its contractors, but use the best available approximation for materials available to New Jersey contractors, often from national averages. In this way we attempt to account for extraction, transportation, processing, and distribution of aggregate, asphalt, cement, iron and steel, as well as the fuels, electricity and secondary materials used to process them, in addition to the emissions due to application of the materials. The GASCAP tool accounts for GHG emissions with sensitivity to what a contractor has knowledge and decision-making power over.

Based on the information in this review, GASCAP will allow a user to aggregate material inputs based on the volume or weight of materials used and the embodied energy in those materials. GASCAP will allow users to enter volume, dimensions or weight of materials, expected equipment use and maintenance assumptions and from this return lifetime GHG emissions for the project, with exceptions noted in this report. GASCAP is not intended for the calculation of emission inventories, but rather is meant to provide a method for comparing the GHG impacts associated with different construction techniques and different projects.

A review of NJDOT capital projects was conducted using an online draft of the NJDOT Statewide Transportation Improvement Program (STIP) for FY 2010-2019 and an online listing published by the Customer Services Department of NJDOT's Division of Procurement (Forsyth, Krizek & Rodríguez 2009) of highway contracts for construction and maintenance for FY 1996-2010, commonly known as "bid-sheets." The first document describes itself as inclusive of New Jersey's transportation program in a single volume (Handy, Cao & Mokhtarian 2006). Programs and projects for NJDOT and NJ Transit are addressed in separate sections. The second source includes itemized individual contracts with bids from all bidders for FY 2009.

REVIEW OF ENERGY AND MATERIAL INPUTS

This section presents assumptions made about energy and material inputs to construction materials for transportation projects for the GASCAP model. Emissions factors for aggregates, asphalt, cement and concrete, and steel are documented.

Aggregates are discussed separately from asphalt and concrete because they are used in both. Aggregate production involves primarily extraction and crushing. It is essentially extracted in the same way as limestone, the principal input of cement. Soil and other fill are not addressed because the principal work done in their production is extraction.

We develop a model to estimate the process energy used to heat asphalt because of the variety of temperatures now used to heat warm and cold mix asphalt. The model addresses evaporative emissions from cutback asphalts as well.

Cement is treated as a single process. There are differences in cement but not in the lime content, which is the principal source of GHG emissions. Differences in mix specifications for asphalt and concrete are based on the ratio of aggregate to binding material.

Steel GHG emissions are estimated based on national averages. However, we estimate separately for cast, rolled, and stamped steel products.

The principal source of GHG emissions involved with recycling and disposal of pavement are due to transportation of the materials. We draw our boundary at delivery to the recycling plant because the subsequent processing is done on the inputs to other projects. Table 2 lists the materials covered and principal data sources.

A brief discussion of gaps in what we can cover is included. We present some emission factors for some additional materials for which emission factors are readily available from the GREET models.

Table 2. Materials Covered by Principal Source.

	Principal Source	Reference
Process Fuels		
Coal	GREET Fuel Cycle	(Argonne National Laboratory 2009)
Natural Gas	GREET Fuel Cycle	(Argonne National Laboratory 2009)
Conventional Gasoline	GREET Fuel Cycle	(Argonne National Laboratory 2009)
Distillate Fuel Oil	GREET Fuel Cycle	(Argonne National Laboratory 2009)
Residual Oil	GREET Fuel Cycle	(Argonne National Laboratory 2009)
LPG	GREET Fuel Cycle	(Argonne National Laboratory 2009)
Coke	GREET Vehicle Cycle	(Argonne National Laboratory 2009)
Petroleum Coke	GREET Fuel Cycle	(Argonne National Laboratory 2009)
Asphalt	GREET Fuel Cycle	(Argonne National Laboratory 2009)
Electricity	GREET Fuel Cycle	(Argonne National Laboratory 2009)
Aggregates	USDOE publication	(BCS 2002a)
Asphalt		
Heating Model	Gencore Presentation	(Hunt 2010)
Warm Mix	American Trade Initiatives paper	(D'Angelo et al. 2008)
Fugitive Emissions	EPA AP-42	(EPA 1979)
Cutback Fugitive Emissions	EPA AP-42	(EPA 1979)
Cement/Concrete	USDOE paper	(Choate 2003)
Steel	GREET Vehicle Cycle	(Argonne National Laboratory 2007)
Other Materials	GREET Vehicle Cycle	(Argonne National Laboratory 2007)

Key Models Used for Estimating Emissions

The process of estimating emission factors was primarily informed by three sources. These include the Pavement Life-cycle Assessment Tool for Environmental and Economic Effects (PaLATE) model developed at the University of California, Berkeley (Horvath et al. 2007), the The Greenhouse gases, Regulated Emissions, and Energy use in Transportation (GREET) models developed by Argonne National Laboratory (Argonne National Laboratory 2009, Argonne National Laboratory 2007), and the Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Sources (AP-42) developed by the EPA Office of Transportation and Air Quality (OTAQ) (EPA 2010a). We also extract information from EPA's MOVES model for any transportation emissions associated with materials production, in this case for transport to recycling plants. In all cases we attempt to use well established sources but we have supplemented these with additional information or calculations where needed.

The PaLATE model estimates life-cycle emissions for concrete and asphalt pavement, base, and fill components for sub-base. This model addresses disposal and recycling of materials from transportation projects, i.e. concrete and asphalt, and allows the user to specify recycled additives for inclusion in concrete and asphalt or fill. PaLATE is somewhat limited in that its scope is limited to pavement, upstream emissions are not addressed, and PaLATE only models conventional diesel fuel. Among GHG only CO_2 but not CH_4 or N_2O are addressed. Asphalt modeling is limited to hot mix, while newer more carbon efficient alternatives such as warm mix and cold mix asphalt are not addressed.

The GREET model is a life cycle GHG emissions modeling tool with two components, a fuel cycle model (Argonne National Laboratory 2009) and a vehicle cycle model (Argonne National Laboratory 2007). The Fuel Cycle component (GREET 1.8c) models upstream GHG emissions from the production of a wide variety of fuels that have coal, petroleum, and biomass as their feedstocks. The Vehicle Cycle component (GREET 2.7) estimates upstream GHG emissions for steel and other materials used in the manufacture of automobiles and trucks that are transferable to the material inputs of transportation capital projects. Both models estimate CO_2, CH_4, and N_2O emissions. GREET modeling of CO_2 emissions are estimated as emissions resulting directly from combustion. GREET also provides a CO_2 estimate that also accounts for oxidation of CO and VOCs in the atmosphere (Burnham, Wang & Wu 2006). This is done by multiplying both by the ratio of the carbon fraction of each to the carbon fraction of CO_2. Both models use this method (Argonne National Laboratory 2009, Argonne National Laboratory 2007).

AP-42 is a clearing house of emissions factors of varying quality created by EPA (EPA 2010a). Quality assessment for AP-42 is based on a letter grade. An “A” emission factor is based on tests from randomly chosen facilities for which variability is minimal. A “B” emission factor is based on tests that may lack this randomness but expected variability is minimal. A “C” emission factor is based in part on tests that may have questionable or untested methodologies. A “D” emission factor may be based on a small number of facilities or there may be reason to suspect higher variability in the population of facilities. An “E” emission factor is based on tests of poorer quality, based possibly on more non-random selection, where there might be a higher likelihood of variation within the facility population. Emission factors for CH_4 and N_2O are generally of poorer quality than CO_2 emission factors. Where no alternatives could be found, “D” and “E” emission factors have been used. Where possible we have attempted to validate emission factors on the basis of other literature.

Process Fuels

In this section we present emission factors for CO_2, CH_4, and N_2O for fuels used in industrial processes for production of asphalt, cement, and steel. We use emission factors from the Argonne National Laboratories GREET Fuel Cycle and Vehicle Cycle models (Argonne National Laboratory 2009, Argonne National Laboratory 2007). This model is the basis for EPA's recent proposed renewable fuel standard, and is preferred over the AP-42 estimates which do not include CH_4 and N_20 emissions for some fuels and it does not include upstream emissions. The lifecycle process used in GREET and the fuel pathways by which fuels are produced from feedstocks is briefly discussed. Emission factors are presented for the three greenhouse gases.

These processes have also been rated in AP-42[1] We investigated the use of these for our process fuel emission factors, but found that in general the quality ratings provided in the documentation were not high. Thus, we use the GREET model estimates.

GREET Models

For fuels a five stage lifecycle approach is used based on the GREET Fuel Cycle model (Argonne National Laboratory 2009). A similar approach is used by the National Energy Technology Laboratory for an inventory of lifecycle emissions from petroleum based fuels used in the United States (Gerdes, Skone 2008a). Both methods were developed to address lifecycle emissions for fuels consumed in vehicles, including aircraft in the latter case. Both models address emissions that result from combustion of process fuels, related feedstocks, and fugitive or flared emissions. The five stages are listed by ANL and NETL designations:

1. Feedstock extraction / Raw material acquisition.
2. Feedstock transportation, storage, and distribution / Raw material transport
3. Refining / Fuel production
4. Transportation, storage, and distribution to the delivery system / Transport of Fuels to Refueling Station
5. Consumption / Operation

Petroleum is extracted from land and sea-based deposits and transported to refineries by pipeline, ship, truck and rail (Gerdes, Skone 2008a). Petroleum distillation is essentially a three stage cyclical process by which hydrocarbons are separated by their weights (Speight 2007). In the first stage, atmospheric distillation, crude is gradually heated under oxygen poor conditions to extract the lighter hydrocarbons. LPG is extracted at this stage. The second stage is vacuum distillation, in which heavier hydrocarbons including number 2 fuel oil which is equivalent to diesel oil are removed under vacuum conditions. What is left after vacuum distillation is called the *residuum*, which includes residual fuel oil, waxes, and asphalt binder. Residuum components may be further processed by heating to higher temperatures, which causes the remaining heavy hydrocarbons to break into smaller molecules, which may be subjected again to distillation. Petroleum coke, which has lost its volatile components results from all three

[1] Available at http://www.epa.gov/ttnchie1/ap42/.

steps described here and is often considered a byproduct to be avoided. However, the residuum may also be deliberately coked (Speight 2007).[2]

The GREET Fuel Cycle Model (Argonne National Laboratory 2009) defines upstream emissions for each pollutant as the mass of that pollutant in grams per MMBtu (Btu x 10^6) from combustion and upstream emissions that in turn, went into producing that process fuel based on the quantity used, energy content and emissions rate for each process fuel (Wang, Huang 1999). Fuel consumption is based on an estimation of efficiency which refers to the ratio of energy contained in the fuel to the energy contained in all feedstocks including those lost to fugitive emissions, and process fuels (Wang, Huang 1999, Wang 2008).

shows upstream and combustion emissions derived from the GREET model for process fuels, including asphalt which is derived from petroleum. Various default assumptions are built into the GREET Fuel Cycle Model (Argonne National Laboratory 2009) in producing these estimates.

GREET Model Defaults and Other Assumptions

Fuel-specific refinery emissions are based on a global petroleum refinery efficiency coefficient, which is the ratio of the energy in finished refinery products to the sum of the energy in the crude, other feedstocks, and process fuels (Wang 2008). Specific refinery energy efficiencies are calculated based on industry rule of thumb assumptions that 60% of all process fuels are used to produce gasoline, 25% are used to produce diesel, and 15% are used to produce all other products. Gasoline accounts for 47.0% of energy content, diesel for 25.7% and all other products are 27.3%. On this basis fuel-specific refinery intensities are 1.28, 0.97, and 0.55 for gasoline, diesel and other products, respectively (Wang 2008). This gives process efficiencies of 87.7%, 90.3%, and 94.3% gasoline, diesel, and other products respectively.

Where the Fuel Cycle does not apportion fuel-specific refinery production efficiencies we apportion upstream emissions for each GHG on an energy basis by adding extraction and transportation emissions for crude petroleum in g/MMBtu to the refinery specific emissions, also in g/MMBtu. In this way we estimated the upstream emissions for residual oil, petroleum coke, and asphalt. In the case of asphalt we assumed the same processing as residual oil because both are residua, and corrected for Lower Heating Values (LHV) of 94.2 for residual oil and 85.1 for asphalt (Wang, Lee & Molburg 2004). This correction is further justified by the use of a constant refinery efficiency for all other products in the GREET Fuel Cycle model.

Our principal interest in natural gas for purposes of materials production is as both feedstock and fuel for use in stationary industrial boilers. Natural gas is extracted from and recovered from oil and natural gas fields (Wang, Huang 1999). Transmission is generally through pipelines to processing plants. During processing heavier

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[2] Coking occurs in the petroleum refining process when hydrocarbons are heated to the point that all of the hydrogen is lost leaving essentially pure carbon. For a full explanation of this process see (Speight 2007).

hydrocarbons and impurities are removed including butane and propane, the two principal components of LPG. LPG from natural gas has a higher refinery or processing efficiency from natural gas (96.5%) than from petroleum (94.3%). Transmission and storage after processing are again through pipelines. Natural gas and LPG from natural gas are both modeled as transportation fuels and as such require no further manipulation.

Coal is of interest for materials production as a fuel in its own right and as a feedstock for coke. GREET models assume a high efficiency for coke of about 99.3% for mining and 99.4% for transportation (Wang, Huang 1999). Diesel fuel and electricity are used in mining of coal. Transportation is by railroad car, barge, truck, and others (slurry pipelines). Coal has significant fugitive emissions associated with extraction. Like most other fossil fuels, uncleaned coal generally has some sulfur (Speight 2007, Wang, Huang 1999). According to the report that accompanied the GREET 2.7 Vehicle Cycle model (Burnham, Wang & Wu 2006) coke is made by heating metallurgical coal until the volatile components and some impurities, 25% - 30% of its mass is removed. There are large emissions of CH4, CO, and VOCs, however these are generally captured and used as coke oven gas (COG). Emissions of particulates are also potentially high, but are greatly reduced by control measures.

Table 3. GHG Emissions of Process Fuels in g/MMBtu.

Upstream Emissions of Process Fuels (g/MMBtu)

	Coal[1]	Natural Gas[1]	Conv. Gasoline[1]	Distillate Fuel Oil[1]	Residual Oil[3]	LPG[1]	Coke[2]	Petroleum Coke[3]	Asphalt[3]
CO_2	1,648	12,693	16,812	15,487	7,326	9,195	1,947	22,427	19,537
CH_4	119.20	199.10	108.74	104.52	37.23	115.28	166.54	127.68	109.00
N_2O	0.0313	0.2610	1.1400	0.2483	0.1179	0.1583	0.0346	0.3866	0.3154

Combustion Emissions of Process Fuels (g/MMBtu)

	Coal[1]	Natural Gas[1]	Conv. Gasoline[1]	Distillate Fuel Oil[1]	Residual Oil[1]	LPG[1] (Propane)	Coke[4]	Petroleum Coke[1]	Asphalt[4]
CO_2	108,363	59,379	75,645	78,169	85,045	68,024	N/A	104,716	N/A
CH_4	4.00	1.10	5.19	0.18	3.24	1.08	N/A	4.00	N/A
N_2O	1.0000	1.1000	2.4000	0.3900	0.3600	4.8600	N/A	1.0000	N/A

Upstream and Combustion Emissions of Process Fuels Combined (g/MMBtu)

	Coal[3]	Natural Gas[3]	Conv. Gasoline[3]	Distillate Fuel Oil[3]	Residual Oil[3]	LPG[3] (Propane)	Coke[4]	Petroleum Coke[3]	Asphalt[4]
CO_2	110,012	72,072	92,457	93,656	92,370	77,218	N/A	127,143	N/A
CH_4	123.20	200.20	114	104.70	40.47	116.36	N/A	131.68	N/A

N_2O	1.0313	1.3610	3.5400	0.6383	0.4779	5.0183	N/A	1.3866	N/A

Sources:

1. GREET Fuel Cycle Model 1.8c (Argonne National Laboratory 2009).
2. GREET Vehicle Cycle Model 2.7 (Argonne National Laboratory 2007).
3. Our Calculations for Crude Extraction and Refining Share - energy basis from Fuel Cycle model and Summation of Combined Emissions.
4. See subsequent sections for asphalt and steel production.

Combustion emissions were not presented for asphalt because it is not a fuel. Combustion emissions for coke were not presented either, because coke as modeled in the GREET 2.7 Vehicle Cycle model (Argonne National Laboratory 2007) is only one component of blast furnace emissions. It will be accounted for as such in the discussion of iron and steel production below.

The estimates presented in Table 3 are national averages, but represent the best available information on lifecycle emissions of process fuels.

Electricity

Indirect emissions from purchased electricity are required reporting under the Climate Registry's *General Reporting Protocol* and the *GHG Protocol Project Accounting* published by World Business Council for Sustainable Development and the World Resources Institute (Climate Registry 2008, Greenhalgh et al. 2005).GHG emissions from electricity on the grid include those resulting from generation, transmission and distribution. Transmission and distribution emissions are reported as indirect emissions only by electric companies to avoid double counting. Electric power consumers are required only to report generation emissions. The electricity emission factors presented here are used primarily to account for embodied energy in purchased materials. It is assumed that little purchased electricity is used in transportation capital projects. As that is the case transmission and distribution emissions are beyond the scope of this project and general GHG emission factors are called for. GHG emissions from electricity are the sum of emissions from the fuels used to generate power.

The GHG emission factors for purchased electricity used here are taken from the GREET 1.8c Fuel Cycle model (Argonne National Laboratory 2009). The Northeast US emission factors are preferred to the emission factors for GHG in the United States as a whole because we assume that materials purchased and applied by contractors in New Jersey are more likely to originate in the Northeast than elsewhere. The Northeast includes New England, New York State, New Jersey, Delaware, and most of Maryland and Pennsylvania (Hirst 2004). **Error! Reference source not found.** shows the distribution of sources of electricity in the Northeast and the United States as a whole, assuming transmission losses of 8% (Argonne National Laboratory 2009).

Table 4. Mix of Energy Sources for Electricity Production in the United States and the Northeast US.

	United States	Northeast US
Residual Oil	1.10%	2.20%
Natural Gas	18.30%	21.70%
Coal	50.40%	29.90%
Nuclear Power	20.00%	33.90%
Biomass	0.70%	2.20%
Other Sources*	9.50%	10.10%

* hydro electric, wind, and geothermal energy are offered as examples.
Source: GREET 1.8c Fuel Cycle model (Argonne National Laboratory 2009)

Table 5. GHG Emission factors for Electricity Production in the United States and the Northeast US.

	United States		Northeast US	
	g/kWh	g/MMBtu	g/kWh	g/MMBtu
VOC	0.0102	2.988	0.0116	3.394
CO	0.5938	174.047	0.1356	39.745
CH4	0.0130	3.801	0.0122	3.568
N2O	0.0091	2.674	0.0092	2.682
CO2	704	206,399	492	144,113
CO2 (incl. VOC, CO)	705	206,682	492	144,186

Source: GREET 1.8c Fuel Cycle model (Argonne National Laboratory 2009)

As a result electricity from the grid in the Northeast has lower GHG emissions per kWh than in the United States as a whole, largely because of its greater reliance on nuclear power and natural gas and lower reliance on coal.

shows GHG emission factors from electricity production in the United States and the Northeast. Biomass and clean energy sources such as wind power account for 10% of the US mix and 12% in the Northeast.

Aggregates

Aggregates are mineral components added to cement in the production of concrete and are also dried, heated and added to asphalt binder in the production of asphalt. Aggregates may be fine or coarse. Virgin fines are the consistency of sand. Virgin coarse aggregates are crushed stone or gravel. Combined fine and coarse aggregates account for 82% of concrete by weight (Choate 2003). Coarse and fine aggregates make up at least 92% of asphalt by weight if no recycled asphalt pavement (RAP) is used (OTAQ 2004b). AP-42 emissions guidance (EPA 2010a) for fine aggregates and coarse aggregates indicate that particulate matter is the primary emission from extraction of aggregates. CO_2 emissions result from equipment use, primarily dryers. As modeled in PaLATE (Horvath et al. 2007) sand and coarse aggregates are input separately but the same emission factor is applied, and the PaLATE model uses the same emission factors for aggregates used for both concrete and asphalt.

Table 6. GHG Emissions from Limestone and Crushed Rock Production in the United States 1997.

Production								
1.2	Billion tons		1.00E+09					
Energy Consumption								
	Units		CO_2		CH_4		N_2O	
Coal[1]		MMBtu	g/MMBtu	g/ s ton	g/MMBtu	g/ s ton	g/MMBtu	g/ s ton
43	Thousand tons	965,806	110,012	88.542	123.203	0.099	1.031	0.001
Fuel oil[2]								
4	Million bbl.	21,579,600	93,656	1684.219	104.703	1.883	0.638	0.011
Gas								
5.4	Billion Cubic Ft.	5,308,200	72,072	318.809	200.197	0.886	1.361	0.006
Gasoline								
14.7	Million Gallons	1,706,523	92,457	131.483	113.931	0.162	3.540	0.005
Net Electricity Purchased								
4,584	Million kWh	15,681,130	144,186	1884.167	3.568	0.047	2.682	0.035
Total		45,241,259	512,383	4,107.220	545.602	3.077	9.252	0.058

1. Assume Bituminous coal
2. Assume diesel fuel oil
Sources: (BCS 2002b)
GREET Fuel Cycle Model 1.8c (Argonne National Laboratory 2009).

We assume that the extraction of coarse and fine virgin aggregates for asphalt and concrete produce indistinguishable GHG emission factors. An energy and environmental profile of the mining sector prepared for the USDOE equates limestone and crushed rock extraction GHG emissions (BCS 2002b). That study shows total production of limestone and crushed rock of 1.2 billion short tons of material in 1997 and provides a breakdown of energy use by fuel type and electricity use. The results for the entire US are shown in Table 7.

We use the AP-42 guidance default assumptions (EPA 2010a, RTI International 2004) to estimate fugitive emissions for one short ton of HMA heated to 325oF with 5% binder by weight. The weight of the binder is 100 lbs. The AP-42 default assumption for volume loss (V) is -0.5%. Applying the formulas and converting lbs to grams we estimate load out emissions of 1.773g VOC, 0.612g CO and 0.123g CH4, and silo filling emissions of 5.196g VOC, 0.535g CO and 0.359g CH4. To estimate CO2 emissions we multiply VOC and CO emissions by the ratio of the carbon fraction of each to the carbon fraction of CO2 and add the results as done in the GREET Fuel Cycle model and NONROAD (EPA 2004b, Argonne National Laboratory 2009). We estimate CO2 load out emissions to be 6.613 g per ton and silo filling emissions to be 17.400 g per ton of HMA.

GHG emissions were estimated by converting fuel and electricity consumption by energy type to MMBtu. Using the GREET 1.8c Fuel Model (Argonne National Laboratory 2009) factors for fuel and electricity, we estimate that extraction and processing of a short ton of aggregate results in 4,107 g of CO_2, 3.076 g of CH_4, and 0.058 g of N_2O. These estimates include extraction, transportation, and processing, but not emissions involved in distribution to the job site.

Asphalt

Asphalt pavement is a mixture of roughly four to eight percent bituminous binder and the balance is course and fine aggregates or recycled material. When mixed, rolled and set the pavement has air voids. Binder is a residual of petroleum refining that consists of the heavier components of crude oil that remain after two stages of distillation. Upstream GHG emissions from the refining process are based on our analysis of process fuel inputs and for aggregate are based on our previous discussion. Direct GHG emissions include products of combustion associated with heating and evaporation and combustion of the binder material. Downstream GHG emissions include those associated with removal and disposal of *spent* asphalt pavement. GHG reducing technologies in asphalt production focus on recycling and reduced heating requirements.

Asphalt fugitive emissions from combustion and evaporation during the production process are minor. A laboratory analysis evaluated with a regression model (Mallick, Bergendahl 2009) showed a strong correlation between CO_2 emissions and heating temperature (R^2 = 0.976). Heating temperature, the amount of warm mix asphalt (WMA) binder used, and the amount of added asphalt were their independent variables. This is strong evidence that production temperature is a valid and simple modeling approach to estimating GHG emissions for asphalt.

Asphalt binder increases pliability and volume at higher temperatures and may shrink and become brittle at lower temperatures (US Army Corps of Engineers 2000). As a liquid, binder is serviceable if it has sufficient viscosity or stiffness to hold its shape at warm ambient temperatures and does not break at cold temperatures under the stress of traffic. Asphalt pavement fails by deforming or cracking. It is referred to as flexible pavement as opposed to concrete, which is known as rigid pavement (Zapata, Gambatese 2005). The lifetime of asphalt pavement is constrained by the oxidation of the binder, which slowly causes the pavement to become less flexible and more brittle.

The inputs for GASCAP are similar to those used in the PaLATE model (Horvath et al. 2007). For pavement, the user will specify the length, width, and depth to establish volume. The user will also specify binder proportion, moisture content, and heating temperature and the rating if cutback asphalt is used.[3] The defaults are 5% binder at 325^{o}F and 4% moisture content in the aggregate. These defaults are taken from

[3] Cutback asphalt refers to binder material that has added hydrocarbon solvents which lower the application temperature. The solvents evaporate after the material is applied, which allows the asphalt to harden. The evaporated solvents must be accounted for as fugitive emissions.

industry standards which are discussed below. Volume will be multiplied by density for the binder and aggregates separately. Treatments that do not include aggregates such as tack coats will be entered separately as a volume and converted to weight. Upstream emissions, heating emissions, fugitive emissions, and downstream emissions will be disaggregated. These will be expressed as grams of each GHG and GWP per short ton of material.

We develop a method to estimate heating emissions based on the specific temperature needed to heat asphalt. This method will account for upstream and combustion emissions and fugitive emissions. It was necessary to model asphalt production in this way because of the variability of heating requirements and fuel consumption presented by WMA, and this will provide a means to compare the GHG emissions from alternative technologies.

The Asphalt GHG Emissions Model

Asphalt is mixed and applied at temperatures high enough to make the mixture malleable without causing it to burn significantly. To accomplish this more economically, additives may be included to lower the viscosity so that the mixture is malleable at lower temperatures. Hot mix asphalt (HMA) is heated to temperatures ranging from 300-325^{o}F (149-163^{o}C) or 302-338^{o}F (150-170^{o}C) (EPA 2010a, Meil 2006, White et al. 2010). Heating asphalt to extremely high temperatures causes the binder to breakdown or crack (Speight 2007). Our GHG emissions model for asphalt has three steps. We address HMA as a reference case and account for GHG reductions from reducing heat inputs. We then account for fugitive emissions from cutback.

Hot Mix Asphalt Combustion Emissions.

By one estimate between 70% and 90% of the fuel used to heat asphalt is natural gas and most of the balance is #2 fuel oil (EPA 2010a). Our default assumption is that 80% of the fuel used is natural gas and 20% is fuel oil. A model of energy use in US asphalt production suggests that 8.5% of energy consumed is used for extraction of raw materials and placement, 40% of the energy is used to produce the binder, 48% is used to mix and dry the aggregate and 3.5% is used to store binder at a workable temperature (Zapata, Gambatese 2005). Estimates of upstream emissions vary considerably because of differences in parsing energy use in the extraction and refining of crude petroleum among the fractions (Argonne National Laboratory 2009, Zapata, Gambatese 2005). The energy required to mix and dry one short ton of asphalt with 5% binder is estimated at 318,649 Btu in the United States (Zapata, Gambatese 2005) and 380,179 Btu in Canada (Meil 2006). This difference is not inconsequential but may be explained by variation in moisture content in the aggregate, as demonstrated in **Figure 1. Latent and Specific Heat for Drying and Heating Aggregate and Binder.Figure 1**.

Knowing total energy use and asphalt production in the United States we estimate that the average mix at the national level was 4.75% binder (Zapata, Gambatese 2005). Standard HMA is modeled here on the basis of 5% binder and 95% aggregates with a moisture content of 4%. This ratio is commonly used elsewhere in the literature (Meil 2006, White et al. 2010). The desired moisture content of aggregate before heating is 3% or less, while aggregate used for asphalt production in the United States is often 5% or higher (D'Angelo et al. 2008). We assume a default for aggregate moisture is the average of these two benchmarks of 4%.

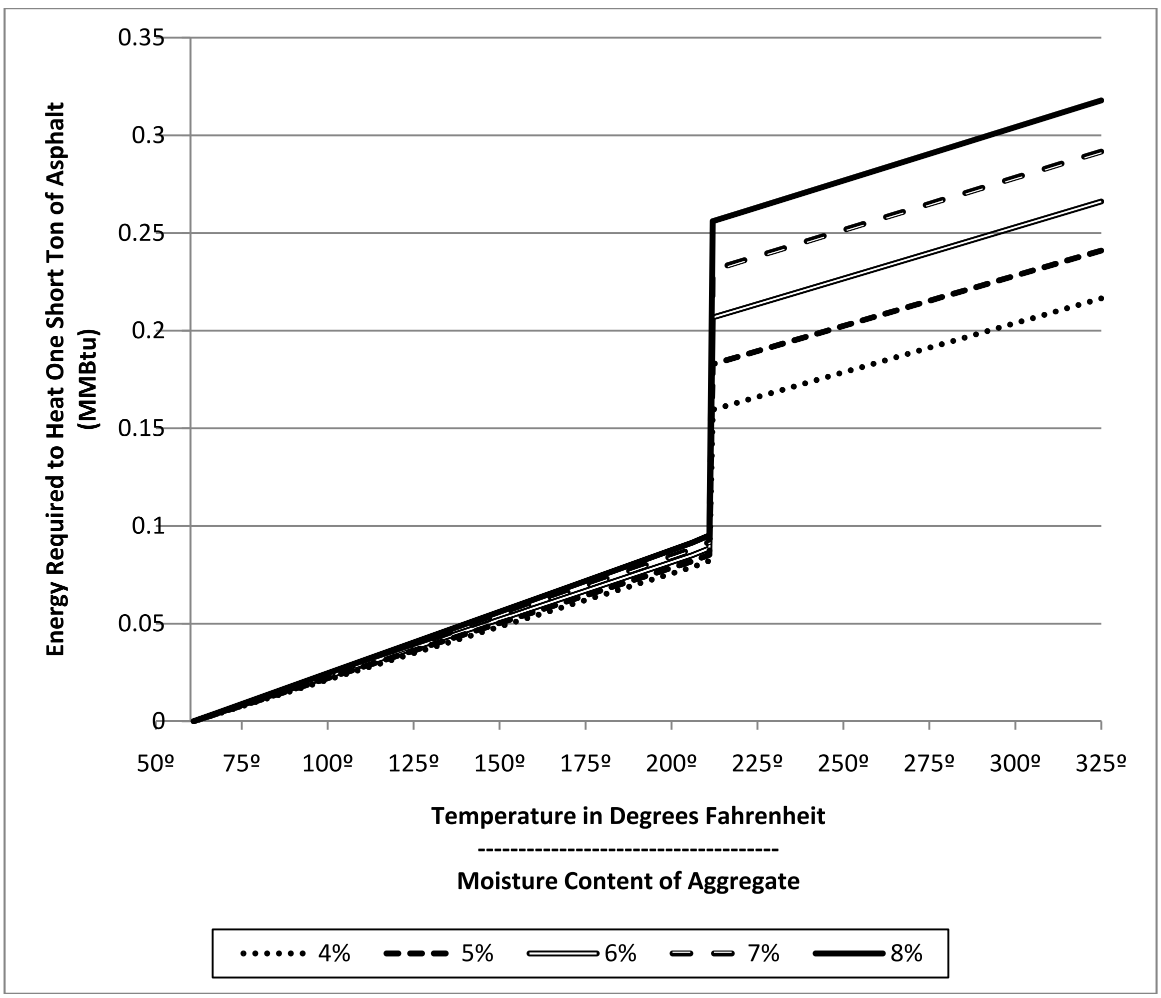
Our heating model follows the procedure used by Gencor (Hunt 2010). We estimate the energy (*Q*) required to heat materials as the product of the specific heat value (*c*), the mass of the material (*m*) in pounds, and the temperature differential (*ΔT*) in degrees Fahrenheit.

$Q = c \cdot m \cdot \Delta T$

The following specific heat values are used:

- *c*(water) = 1.00 Btu/lb
- *c*(steam) = 0.50 Btu/lb
- *c*(aggregate) = 0.22 Btu/lb

Figure 1. Latent and Specific Heat for Drying and Heating Aggregate and Binder.



The model inputs are heating temperature, binder content, and moisture content of the aggregate. The heating requirements for binder and aggregate are estimated, as is the specific temperature to heat the moisture in the aggregate to the boiling point, the latent heat to evaporate the moisture, and the specific temperature to heat the steam to the target production temperature. The specific temperture for binder is estimated from the average specific heat values at 60°F (16 °C) and 325°F (163 °C) at 0.468 Btu per degree per pound (Abraham 1945). The other assumptions are based on Gencor (Hunt 2010). The latent heat required to evaporate water is 970 Btu per pound. Ambient temperature is 60°F (16 °C). Unless the mixture is not heated above the boiling point of water there is latent heat. Water is heated to a maximum of 212°F (100 °C) and steam is heated from 212°F (100 °C) to the final heating temperature. Aggregates and binder are heated from ambient temperature to the final heating temperature. Figure 1 shows heating functions for HMA heated from an ambient temperature of 60°F (16 °C) to a final heating temperature of 325°F (163 °C) with moisture in the aggregate between 4% and 8%. Our model estimates energy use to heat one short ton of HMA with 5% binder and 4% moisture in the aggregate at 216,461 BTU at 100% efficiency. This estimate does not account for waste heat, or the mixing energy. It also does not account for the energy required to maintain binder at a mixing temperature. The American estimate of energy expended was 318,649 Btu per ton (Zapata, Gambatese 2005). The heating required is the ratio of the specific heat calculated at 100% and the observed American average. That ratio is 67.93%. This proportion will be used as a factor to convert heating requirement estimates for HMA, WMA and cutback asphalts to a realistic estimate of energy consumption.

Fugitive Asphalt Emissions

When asphalt is heated a small part of the hydrocarbon in the binder oxidizes and lighter components produced during heating evaporate (EPA 2010a). These emissions occur mostly when the heated binder-aggregate mixture, known as asphalt concrete, is removed from the oven--*load out emissions*--and during silo storage--silo filling emissions. Fugitive emissions also occur when asphalt binder is added to storage tanks. Load out and silo filling emissions are estimated using the method described in Table 7**Error! Reference source not found.**. We do not have an estimate for storage tank emissions, which is a minor gap in our method. Fugitive emissions were estimated based on the AP-42 guidance (EPA 2010a, RTI International 2004). The model estimates total organic compounds (TOC) and CO as logistic functions of the absolute temperature in degrees Fahrenheit (Rankine scale). For load out emissions, VOCs make up 94% of the TOCs by weight and CH_4 makes up 6.5%. (the sum does not add up to 100% due to rounding errors). Virtually all silo filling TOC emissions are VOCs (100%) and CH_4 makes up 0.26% of these. VOCs and CO oxidize to CO_2 in the atmosphere. Emissions calculated based on Table 7are expressed in lbs per short ton.

We use the AP-42 guidance default assumptions (EPA 2010a, RTI International 2004) to estimate fugitive emissions for one short ton of HMA heated to 325°F with 5% binder by weight. The weight of the binder is 100 lbs. The AP-42 default assumption for volume loss (V) is -0.5%. Applying the formulas and converting lbs to grams we estimate load out emissions of 1.773g VOC, 0.612g CO and 0.123g CH_4, and silo filling emissions of 5.196g VOC, 0.535g CO and 0.359g CH_4. To estimate CO_2 emissions we multiply VOC and CO emissions by the ratio of the carbon fraction of each to the carbon fraction of CO_2 and add the results as done in the GREET Fuel Cycle model (Argonne National Laboratory 2009)(ANL 2009) and NONROAD (EPA 2004b). We estimate CO_2 load out emissions to be 6.613 g per ton and silo filling emissions to be 17.400 g per ton of HMA.

Table 7. Fugitive Asphalt Emissions Estimation Method.

Load Out Emissions	Silo Filling Emissions
$VOC = 0.94 * 0.0172 * (-V) * e^{((0.0251)(T °F + 460) - 20.43)}$	$VOC = 0.0504 * (-V) * e^{((0.0251)(T °F + 460) - 20.43)}$
$CO = 0.00558 * (-V) * e^{((0.0251)(T °F + 460) - 20.43)}$	$CO = 0.00488 * (-V) * e^{((0.0251)(T °F + 460) - 20.43)}$
$CO_2 = VOC * 85/27.3 + CO * 42.9/27.3$	$CO_2 = VOC * 85/27.3 + CO * 42.9/27.3$
$CH_4 = 0.065 * 0.0172 * (-V) * e^{((0.0251)(T °F + 460) - 20.43)}$	$CH_4 = 0.0026 * 0.0504 * (-V) * e^{((0.0251)(T °F + 460) - 20.43)}$
Storage Tank Emissions were not covered.	
Emissions are expressed as lbs per short ton. Sources: VOC, CO and CH_4 fugitive emission factors, AP-42 (OTAQ 2004b, RTI International 2004); CO_2 conversion from VOC and CO, GREET Fuel Cycle Model 1.8c (ANL 2009)	

Warm Mix Asphalt - Combustion and Fugitive Emissions

WMA use water or organic additives that lower the viscosity of the binder and consequently lower the required heating temperature (D'Angelo et al. 2008). The additives are heavy organic materials, such as waxes or fatty amides, that do not evaporate readily at ambient or heating temperatures. These materials may be produced from petroleum feedstock but in practice are generally made using the Fischer-Tropsch process (D'Angelo et al. 2008). Another technique is to use foaming agents and procedures to cause the moisture in the aggregate to foam; this lowers the binder viscosity until the water evaporates allowing the pavement to set.

displays the upstream, combustion and fugitive emissions associated with five WMA products from a review of European practice (D'Angelo et al. 2008) including HMA for reference. Upstream emissions for binder and aggregates are not included because they are not sensitive to heating temperatures, but are included in GASCAP.

Table 8. Upstream, Combustion, and Fugitive Emissions from HMA and Five WMA Binders

HMA - reference - 325°F (163 °C)

	Upstream fuel g/ton	Combustion g/ton	Fugitive g/ton
CO_2	4,075.324	19,416.812	24.013
CH_4	55.412	0.282	0.482
N_20	0.079	0.295	N/A

Sasobit -Fischer-Tropsch wax - 289°F (143 °C)

	Upstream fuel g/ton	Combustion g/ton	Fugitive g/ton
CO_2	3,741.145	17,824.625	9.728
CH_4	50.869	0.259	0.195
N_20	0.073	0.270	N/A

LEA - foaming agent - 212°F (100 °C)

	Upstream fuel g/ton	Combustion g/ton	Fugitive g/ton
CO_2	3,026.375	14,419.114	1.408
CH_4	41.150	0.209	0.028
N_20	0.059	0.219	N/A

3E LT or Ecoflex - propietary process - 271°F (133 °C)

	Upstream fuel g/ton	Combustion g/ton	Fugitive g/ton
CO_2	3,574.056	17,028.532	6.192
CH_4	48.597	0.247	0.124
N_20	0.070	0.258	N/A

LEAB - foaming agent - 194°F (90 °C)

	Upstream fuel g/ton	Combustion g/ton	Fugitive g/ton
CO_2	1,511.925	7,203.541	0.896
CH_4	20.558	0.105	0.018
N_20	0.029	0.109	N/A

Evotherm - hot aggregate coated with emulsion - 239°F (115 °C)

	Upstream fuel g/ton	Combustion g/ton	Fugitive g/ton
CO_2	3,277.009	15,613.255	2.773
CH_4	44.558	0.227	0.056
N_20	0.064	0.237	N/A

Sources:
1. (D'Angelo et al. 2008)
2. Carbon Footprint asphalt emissions model

Note: Temperature conversions were calculated and not taken from D’Angelo et al.

Of the products in

, Sasobit and 3E LT include 2%-3% organic compounds. LEA and LEAB include foaming agents that make up less than 1% of the binder material. These materials make up minor proportions of binder (D'Angelo et al. 2008). We have not evaluated the GHG impact of producing these additives. Fugitive emissions are a minor source of GHG emissions from asphalt. HMA fugitive emissions are substantially than less for CO_2 emissions than the combined upstream and direct emissions from fuel use. As temperatures decline from 325^{o}F fugitive emissions drop off rapidly.

Cutback Asphalt GHG Emissions

Cutback asphalt refers to binder material that has added hydrocarbon solvents that lower the temperature at which the asphalt is applied, by lowering the viscosity. The solvents evaporate after the material is applied, which allows the asphalt to harden. The evaporated solvents must be accounted for as fugitive emissions in addition to emissions from heating. Cutback asphalts are rated by the speed by which they cure (AASHTO 2007). Curing speed is accomplished by varying the density of the added hydrocarbon solvents. The solvents used are 0.7 kg/l for rapid cure (RC) additives, 0.8 kg/l for medium cure (MC) additives, and 0.9 kg/l for slow cure (SC) additives (OTAQ 1979). Asphalt binder has a density of about 1.1 kg/l. It is assumed that 95% of rapid cure cutbacks, 70% of medium cure cutbacks and 25% of slow cure cutbacks evaporate as VOCs. Cutbacks modeled in the AP-42 guidance contain 25%, 35% or 45% solvent (EPA 1979).

A VOC emission factor was derived from the AP-42 guidance (EPA 1979). The volume of evaporative VOC emissions is:

$$EF_{VOC} = Solvprop * Solvdens / (Solvprop * Solvdens + (1 - Solvprop) * 1.1) * Emissionsprop$$

where EF_{VOC} is the VOC emission factor; *Solvprop* is the proportion of solvent in the binder; *Solvdens* is the density of the sovlents in kg/l; 1.1 kg/l is the density of asphalt; and *Emissionsprop* is the proportion of solvents that evaporate.

shows estimates for VOC emissions and resulting CO_2 emissions. It was possible to verify application of the AP-42 formulas by correctly recreating Table 4.5-1 of the AP-42 guidance for cutback asphalt using the formula presented in the guidance (EPA 1979). Applying the formulas in this way makes it possible for GASCAP users to change default solvent density and proportions. This approach is suitable for estimating VOC emissions from cutback with a C rating.

shows CO_2 emissions on a per gallon and per ton basis estimated from carbon content.

Table 9. Fugitive emissions from use of cutback asphalt.

VOC Emissions			
% of volume lost	Solvent Proportion		
Type of Cutback	25%	35%	45%
Rapid cure	17%	24%	33%
Medium cure	14%	20%	26%
Slow cure	5%	8%	10%
Source: AP-42 Section 4.5 (EPA 1979)			
CO_2 Emissions			
g/gal	Solvent Proportion		
Type of Cutback	25%	35%	45%
Rapid cure	1,959	2,743	3,527
Medium cure	1,650	2,310	2,970
Slow cure	663	928	1,193
CO_2 Emissions			
g/ton	Solvent Proportion		
Type of Cutback	25%	35%	45%
Rapid cure	469,584	684,810	918,751
Medium cure	385,794	556,397	737,607
Slow cure	151,316	215,956	283,156

Cement and Concrete

Concrete is composed of cement, water, and coarse and fine aggregate. Aggregate is a material such as sand, gravel, crushed stone, etc that provides the shape to concrete. Cement and water combine to form the paste that when dried and hard holds the aggregates together. Cement makes up 7 to 15% of concrete by weight (Marceau, Nisbet & VanGeem 2007). Though a small component, cement accounts for the vast majority of the GHG emissions from production of concrete. This is due to CO_2 emissions when cement is heated to temperatures of approximately 2,750^{o}F, which results in conversion of limestone ($CaCO_3$) into lime (CaO) releasing CO_2 from the conversion reaction and combustion emissions from the fuel used for heating (EPA 2010a). Cement represents approximately 86% energy consumption in concrete production and between 89% and 96% of CO_2 emissions according to two life cycle inventories for the United States (Choate 2003, Marceau, Nisbet & VanGeem 2007).

The cement content of concrete has an important impact on the overall GHG emissions and energy consumption of concrete. There are many classifications of cement, however three grades Type I, Type II and Type III, that include cement classified as Type 1/2, account for at least 95% of Portland cement production (FHWA 1999). These three have CaO content of between 61.37% and 61.61% (Clemeña 1972). We model cement as Portland cement because it accounts for nearly all (93%) of US production (Greer, Dougherty & Sweeney 2000) and is favored in the transportation sector. Other types of cement are produced through roughly the same processes and while we do not describe these in detail, we can account for them in the final model through minor modification of the multipliers used for standard Portland cement.

Users of GASCAP are asked to input cement content of the mix design and fine and coarse aggregates as virgin aggregates or recycled material, water and additives. The model will separately estimate GHG emissions from the cement, the virgin aggregates and any recycled aggregates. Emissions are based on an inventory of the cement industry done for the US Department of Energy (Choate 2003). Emissions from fuel consumption are based on the GREET Fuel Cycle model (Argonne National Laboratory 2009).

Manufacturing Process

Cement production has mechanical and chemical components. The mechanical process involves movement of materials through a cement manufacturing plant from quarry to shipment to construction site. Manufacturing sites are often located where the quarrying is taking place, so the raw feedstock for the plant is already on site. The GHG emissions from transportation of recycled materials from the worksite to the plant are charged to the firm disposing of the recycled cement, not those using the recycled cement. The GHG impact of sending concrete to a cement plant is generally lower than the carbon cost of disposing of it in a landfill, but higher than onsite recycling (Horvath 2004b).

Calcium is the primary raw material used in cement manufacturing. Silicon, aluminum, and iron are used as well. The calcium is most often found as limestone, but chalk, marl, sea shells, and aragonite are used as well. The silicon, aluminum, and iron usually are found in sand, shale, clay, and/or iron ore (EPA 2010a). After crushing the material is prepared to enter the kiln through either a wet process or a dry process (EPA 2010a). The wet process involves adding water to the materials to form a slurry that is ground to the needed consistency. The dry process involves drying materials before or during grinding to reduce the moisture content to less than 1%. In either case the raw materials are mixed uniformly to optimize chemical reactions in the kiln. In the kiln the mix is heated to at least 1450^{o}C (2,642^{o}F) (WBCSD 2010). Clinker is cooled with ambient air which reduces the temperature from 1100^{o}C (2,012^{o}F) to about 93^{o}C (199^{o}F) with ambient air. It is ground down into a fine powder and mixed with any materials added, such as gypsum, to give the cement desired qualities affecting set time and strength. The cement is then stored, bagged, or loaded into a truck and shipped off to a build site (EPA 2010a).

The chemical processes in cement kilns transform limestone into cement clinker. The chemical and physical transformation of the raw material in the heating process as described in AP42, involves the evaporation of moisture at 212^{o}F (EPA 2010a). Silicon, aluminum, and iron oxides form at about 800^{o}F. Calcination occurs between 1650 ^{o}F and 1800 ^{o}F. During calcination limestone ($CaCO_3$) breaks down to lime (CaO) and emits CO_2. These emissions are the second largest major source of CO_2 emissions in cement manufacturing aside from the energy used to heat the kiln (Choate 2003). Clinker forms at about 2750^{o}F when oxides, primarily silicates Ca_2SiO_4 or Ca_3SiO_5 form.

Aluminum and iron provide a high temperature medium for calcium silicate to form into clinker nodules. Aluminum and iron do not react chemically in this process.

Cement produced as described above is a fine grey powder. Mixed with water it forms a paste, which when placed in a mold, sets and hardens holding coarse and fine aggregates in place. GHG emissions from concrete are mostly from cement manufacturing, while aggregate is by far the largest component of concrete by weight. According to the Portland Cement Association (PCA) aggregate makes up roughly 67% of wet concrete (PCA 2009). A DOE report estimates aggregates at 82% (Choate 2003). The NJDOT *Standard Specifications for Road and Bridge Construction* (NJDOT 2007) specifies maximum water : cement ratios between 0.400 and 0.577 for most classes of concrete; the minimum cement content is between 564 and 658 lbs. per cubic yard. Assuming that a cubic meter of concrete mixture weighs approximately 2.3 metric tonnes (Meil 2006), we can approximate that a cubic yard of concrete mixture weighs approximately 3,877 lbs. This puts the minimum cement content of concrete mixture for most NJDOT projects at between 15.8% and 17.0%. Users of GASCAP have the ability to change all three concrete inputs.

GHG Emissions

Our approach to modeling GHG emissions for concrete is taken from DOE (Choate 2003). We account for quarrying, cement manufacturing, and concrete production and transport. Quarrying involves the extraction of cement and extraction and crushing of aggregates. GHG emissions for extraction processing and distribution of aggregates are discussed above. The process for extracting cement and the GHG emissions are essentially the same as for extracting aggregates (BCS 2002b). Cement grinding, firing and finish milling have just been discussed. Concrete manufacturing involves the mechanical mixing and transport of the material, which are done primarily using electricity and diesel, respectively (Choate 2003). GHG emissions from water in this model are limited to transportation of the concrete. We assume pumping and any storage GHG emissions for water are negligible. **Error! Reference source not found.** shows GHG emissions for a ton of concrete based on a DOE paper (Choate 2003).

Energy consumption and CO_2 emission estimates are presented in the DOE report on a per metric tonne basis (Choate 2003). The findings are presented in that report as Btu per tonne of cement and tonnes CO_2 per tonne cement. These estimates as presented in Table 10 are converted to Btu per short ton of concrete assuming a 12% to 82% ratio of cement to total aggregates (Choate 2003) for direct and upstream energy use and GHG emissions. We have not estimated emission factors for waste fuels, most of which are spent solvents and lubricants of various weights and assume that they have the same GHG emission factors as the other process fuels. These waste fuels account for about 7% of the energy in cement manufacturing. CO_2 emissions from kiln reactions are converted to g CO_2 per short ton of concrete. Direct and upstream GHG emissions from fuel combustion are converted into grams using the GREET Fuel Cycle model (Argonne National Laboratory 2009) emission factors based on DOE reports on the mix of direct and upstream fuel use (Choate 2003).

Table 10. Concrete GHG Emissions Assuming 12% Cement, 82% Aggregates, and 6% Water.

	Direct CO_2 Production g/ton Concrete	Upstream CO_2 Production g/ton Concrete	Direct CH_4 Production g/ton Concrete	Upstream CH_4 Production g/ton Concrete	Direct N_2O Production g/ton Concrete	Upstream N_2O Production g/ton Concrete
Quarrying						
cement raw materials	524	386	0.393	0.289	1.181	0.869
concrete raw materials	3,583	2,635	2.684	1.974	8.071	5.936
Cement Manufacturing						
energy consumption	62,012	3,657	2.140	81.986	0.681	0.067
kiln reactions	62,978					
Concrete Manufacturing						
raw material mixing	5,906	761	0.146	33.781	0.110	0.016
Transport	6,313	1,251	0.015	8.441	0.031	0.020
Total	141,316	8,690	5.377	126.471	10.074	6.908

Sources:

Table A.11 - Energy Use per Tonne Associated with U.S. Cement Manufacturing and Concrete Production from U.S. Cement (Choate 2003).

Source Table A.8 - Energy Consumed by Fuel Type in Cement Manufacturing (excluding Quarrying) (Choate 2003).

GREET Fuel Cycle Model 1.8c (Argonne National Laboratory 2009).

Alternative Technologies in Cement and Carbon sequestration

The primary focus for Green innovation in concrete is on recycled materials and carbon capture. Recycling involves transportation of waste material from build sites and reuse in building processes. One approach is to add inert materials to the concrete mix. This lowers the amount of cement used in the concrete. This can be done without significantly reducing the strength. Fly ash and slag are used in this way (Marceau, Nisbet & VanGeem 2007). As a result fly ash and slag are not disposed of in landfills and the volume of cement used is reduced, with potentially large reductions in GHG emissions.

Old concrete may also be used as aggregate for new Concrete. One recycling method is to crush the old concrete from a road demolition to the desired aggregate size and add it to the concrete mix as an aggregate rather than shipping in virgin aggregate. Onsite recycling eliminates transportation emissions as well as emissions from manufacturing new aggregate.

Finished concrete is known to absorb CO_2 (PCA 2009). When mixed with water and aggregate cement, it becomes reactive with air. Cement reacts with CO_2 in the air with lime to form limestone through carbonation.

$Ca(OH)_2 + CO_2 = CaCO_3 + H_2O$

To the extent that the cement has carbonized, the use of concrete as aggregate is a carbon sink. Noncarbonated cement is more reactive and makes for a weaker aggregate than waste concrete that is already carbonated. Carbonation is limited by the tendency to carbonate along a thin edge of a concrete structure. A barrier forms that prevents CO_2 from penetrating further and reacting with the concrete. The carbon sink effect of concrete recycling could be optimized by crushing the material, exposing its surface and stockpiling it until the carbonation process is optimized (Stolaroff, Lowry & Keith 2005). By one estimate as much as half of the CO_2 emitted during the chemical process of its initial manufacture may be recovered in this way (PCA 2009). Variability is such that we will not attempt to quantify this effect in the model, but will leave this for future consideration.

Recycled cement kiln dust may be used as a sink for SO_2, NO_X, and VOCs. It may also be used as a feedstock for potassium fertilizer production with recovery of initial investment in 3.1 years (Tureen 2003). Any use of recycled materials as feedstock would displace the carbon emissions from normal production of that feedstock from other uses.

Given the current state of knowledge on the GHG emissions reductions from these newer technologies, we do not include them in GASCAP.

Iron and Steel

Steel is highly purified and alloyed iron. Iron because of its reactivity exists mostly as iron oxides in its natural state and the process of refining iron into steel involves removal of oxygen and other impurities from iron ore with coke. Coke is an energy intensive purified form of coal that has had its volatile components burned away with other impurities. Iron is refined in a blast furnace where iron ore, fluxes, and coke are heated in an oxygen starved environment that draws the oxygen out of the ore. Fluxes are materials such as limestone that bond with sulfur and other impurities in iron ore to form slag (AISI 2009). Both coke production and blast furnace production are energy intensive and produce large quantities of carbon, much of which is reclaimed. Transportation construction uses large amounts of steel in bridges, guardrails, signs, reinforcing bars and other minor components of the transportation system. Upstream GHG emissions from the production and working of steel should be expected to be high from the carbon intensity of production as well as from the sheer volume of steel used in capital projects. GASCAP requires the user to select items listed on NJDOT bid-sheets for materials of calculable weight. If the weight is not known, the user will be asked to enter the weight. We will be using this approach with large inputs such as structural steel.

Manufacturing Process

Based on the GREET Vehicle Cycle 2.7 model we break steel production into seven processes including ore extraction, pelletizing and sinter production, coke production, blast furnace, basic oxygen furnace (BOF), electric arc furnace (EAF), and forming. The blast furnace process produces pig iron. The BOF and EAF processes purify pig iron into steel. Sheet production and rolling and stamping (Argonne National Laboratory 2007) and casting (Andersen, Hyman 2001) are the processes by which steel products are formed. The primary material inputs of finished steel are coal, iron ore, limestone, natural gas, and scrap iron and steel.

Ore Extraction

Iron is very reactive and exists mostly as iron oxides in its natural state (BCS 2002b). The most common of these is hematite (Fe_2O_3), which with magnetite (Fe_3O_4) make up taconite. Taconite is a low grade ore that contains 25% - 30% iron. The iron in taconite must be purified before it is suitable for forging in a blast furnace. This is accomplished by a variety of methods, primarily by crushing the ore and removing the high grade components with magnets. Iron ores are extracted using either open pit or shaft mining methods. Drilling, blasting, loading, and transportation to the blast furnace account for 91% of the energy requirements for ore extraction. Transportation alone accounts for 75% of the energy requirements (BCS 2002b). The GREET Vehicle Model 2.7 estimates the mass of ore required to produce steel based on taconite ore (Argonne National Laboratory 2007).

Pellet and Sinter Production

Agglomeration is a process by which iron ores are concentrated by sintering and pelletizing. Sintering involves insertion of a combination of iron ore, coke oven gas, limestone and others into an oven at high temperatures (2000 – 2700^oF) (EPA 2010a, BCS 2002b). The mixture melts agglomerates into clumps that are crushed, much like clinker. Sinter is a flux-rich source of additional iron used in the blast furnace recovered from the waste products of primary iron production. The collection process for sintering material also keeps these dusts out of the water and air which would have been a source of pollution and environmental harm for workers in older iron production methods (EPA 2010a). Roughly 2.5 tons of raw material including water and fuel are required to produce 1 ton of sinter (EPA 2010a). Pelletizing involves heating crushed sinter or iron ore in a drum which causes the material to agglomerate into pellets of about half an inch (BCS 2002b). Coal dust may be added to improve fuel content.

Coke Production

Coke is used as fuel and as an oxygen sink to produce iron in blast furnaces. The coking process is described in AP-42 (EPA 2010a). Coke is produced by crushing low sulfur low ash coal and burning off the volatile components. Coal powder may be mixed with water and oil to control density. The mixture is fed into an air tight oven to allow the coal mixture to be heated in an oxygen-free environment without burning the coal. The heating requirement is roughly 15 to 18 hours at 1,650°F to 1100 °F. Upon removal the coke is quenched with water to prevent it from catching fire. It is crushed into pieces suitable for iron production in the blast furnace. Coke oven gases (COG) account for 20% - 30% of the mass of the coal. These are collected through duct systems for use as fuel in other processes such as sintering. COG is desirable as fuel because of its high VOC and CO content (EPA 2010a).

Iron Production

The blast furnace provides an oxygen starved environment where iron oxides are reduced to iron by the oxidation of carbon (AISI 2009). Iron bearing material, whether ore or recovered (i.e., from recycled sources), is heated to a high temperature in the presence of a flux, using coke as the fuel (EPA 2010a). Blast furnace temperatures must exceed 1600°F to reduce the ore from oxides and sulfides, a minor component (AISI 2009). The reaction forms molten reduced iron, i.e. pig iron, CO, and slag. Blast furnace gas (BFG), like COG is recovered but is of lower value as fuel because of high CO content.

Steel Production (Basic Oxygen Furnace)

The Basic Oxygen Furnace (BOF) production method uses 24% scrap steel and 76% virgin iron (Andersen, Hyman 2001). This process reduces the carbon content of pig iron and scrap in a high oxygen environment (EPA 2010a). In the presence of oxygen carbon and other impurities are oxidized with some of the iron. The heat from oxidation is sufficient to melt iron with little added fuel. The primary gaseous byproduct is CO, which is generally vented to a gas cleaning device (EPA 2010a).

Steel Production (Electric Arc Furnace)

Nearly all of the raw material (98%) used in the Electric Arc Furnace (EAF) method is scrap steel (Andersen, Hyman 2001). EAFs produce carbon and alloy steels (EPA 2010a). Scrap, flux and alloy material are introduced to an EAF on a batch basis. The mixture is heated by current running through a carbon electrode. Slag and steel are poured off separately. The electrodes are gradually consumed in this process making them a source of carbon emissions (EPA 2010a).

Forming

Steel may be formed in three ways: casting, rolling and stamping. All steel is cast, whether into ingots including specialized forms, or as continuous casts (Argonne National Laboratory 2007, Andersen, Hyman 2001). Steel cast into its final shape produces no further GHG emissions. GHG emission factors are estimated for rolled and stamped steel products (Argonne National Laboratory 2007). Galvanizing is a finishing procedure that we have not addressed.

GHG Emissions

Our approach to modeling GHG emissions for steel is taken directly from the GREET Vehicle Cycle model 2.7 (Argonne National Laboratory 2007). For each step in the steel making process GHG emission factors are estimated in grams of GHG per ton of intermediate material, with conversion factors that specify the mass of each material needed to produce one ton of finished steel. We convert the emission factors to grams of GHG per ton of steel. Our conversions are shown in
, which presents GHG emission factors for cast, rolled and stamped finished steel products and shows the contribution that each process makes to GHG emissions from a ton of steel.

For the development GASCAP we will provide estimates of the weight of standard steel products from NJDOT's bidsheets. This may not be possible with larger structural pieces. In that case the user will be required to enter the weight of the item.

Table 11. GREET Vehicle Cycle Model Emission Factors for Steel.

Process Emission Factors per Ton Steel

	(1) Ore Recovery	(2) Ore Pelletizing & Sintering	(3) Coke Production	(4) Blast Furnace	(5) Basic O2 Furnace	(6) Electric Arc Furnace	(7) Sheet Production & Rolling	(8) Stamping
	g/ton steel	g/ton steel	g/ton steel	g/ton steel	g/ton steel	g/ton steel	g/ton steel	g/ton steel
CO2	25,957	276,673	148,069	1,363,165	1,570,966	85,315	718,637	522,460
CH4	29.47	551.49	390.45	686.36	396.08	217.77	1,730.67	1,179.46
N2O	0.63	3.80	3.05	0.62	1.01	1.14	11.78	8.33

Finished Product Emissions per Ton Steel

	∑ (1-6) Cast Steel	∑ (1-7) Rolled Steel	∑ (1-8) Stamped Steel
	g/ton steel	g/ton steel	g/ton steel
CO2	3,470,145	4,188,781	4,711,241
CH4	2,271.62	4,002.29	5,181.75
N2O	10.25	22.03	22.03

Finished Product Emissions per lb Steel

	∑ (1-6) Cast Steel	∑ (1-7) Rolled Steel	∑ (1-8) Stamped Steel
	g/lb steel	g/lb steel	g/lb steel
CO2	1,735	2,094	2,356
CH4	1.14	2.00	2.59
N2O	0.01	0.01	0.01

Source: GREET Vehicle Cycle Model 2.7 (Argonne National Laboratory 2007).

Alternative Technologies in Steel Making

The American Iron and Steel Institute (AISI) has claimed great improvements in efficiency for the industry (Woods 2010). Among its claims are to have recycled 82 million tons in 2008; reduced energy consumption by 31% since 1990 and GHG emissions by 45% since 1975. The US steel industry in particular has been struggling to remain globally competitive since the 1970s as the US manufacturing industry has declined, and these investments are the way that it has remained competitive (Woods 2010). The industry also boasts a research initiative called CO_2 Breakthrough(AISI 2007). This program researches iron and steel production techniques that may reduce CO2 emissions. Some examples of new technologies are listed in
. We are not aware if any of these are in commercial use and present them only for reference.

Table 12. New Technologies in Steel Making

Paired Straight Hearth Furnace – this is a new type of iron making unit that is capable of producing iron by using coal as the energy input rather than coke. This would allow iron to be produced with 30% less energy as the coking process could be avoided altogether {{135 DOE 2009}}.
Molten Oxide Electrolysis – this is a form of molten salt electrolysis that utilizes a carbon free anode, so that oxygen is produced as a byproduct rather than CO or CO_2 {{488 AISI 2005}}.
Hydrogen Flash Smelting is a project in conjunction with the University of Utah that is attempting to use Hydrogen as a blast furnace fuel rather than carbon {{489 Schorch, L.L. 2008}}.
AISI CO2 Breakthrough project #9955 – Another program is attempting to expose the exhaust stream of the steel furnace to slag. It is hoped that the process would bind CO_2 in the exhaust stream to alkaline material in the slag to form carbonates that could be recovered for sale {{490 AISI 2005}}.
The Commonwealth Scientific and Industrial Research Organisation (CSIRO) is Australia's national R&D agency. CSIRO is developing a project to substitute charcoal from hardwood and farming biomass for coal in steel making {{130 Jahanshahi, S. 2007}}. The process is advanced as a sustainable means to reduce noxious gas emissions due to the lower sulfur and ash levels. It would at the very least eliminate GHG emissions from fossil fuel.

Transportation of Construction Materials and Disposal

Transportation of materials use in construction projects is accounted for by using EPA's MOVES emissions models. Qualified coarse aggregates may come from considerable distances for use in NJ transportation projects. Authorized sellers of argillite, carbonate, gneiss, gravel, and traprock may be found in NJ or PA. However these sellers may compete with sellers from as far away as Ontario. Shale, slate and granite sellers are not located in NJ or PA. We should expect considerable variation in distribution costs. These will be estimated by querying users on the distance from the job site to the distributor assuming a round trip (The staging module of GASCAP includes an automatic calculator based on Google Maps). The emissions of all GHG pollutants will be based on assuming the MOVES model. Emissions factors for different vehicle and equipment types used in construction projects are discussed in the next section of this report.

We account for disposal of road debris based on the GHG emissions associated with transporting debris to a landfill or recycling facility. The PaLATE model (Horvath et al. 2007) assumes that emissions associated with recycled paving materials result from transportation of those materials to or from the job site. Recycled asphalt pavement (RAP) and reclaimed concrete material (RCM) are treated as byproducts of road demolition. GHG emissions connected with them are captured in the equipment used to conduct the demolition and remove these materials. Recycled materials may be sent to a landfill where unlike municipal solid waste they do not produce GHG emissions (EPA 2010a), except as they are handled by heavy equipment. Recycled materials are used as aggregate for asphalt and concrete (Horvath et al. 2007). They provide energy savings by reducing the amount and hence the GHG emissions from the extraction and processing of virgin aggregate. Other materials modeled in PaLATE including baghouse fines, flyash, ground glass, kiln dust, blast furnace slag, and others are byproducts of other industrial processes and are treated in the same way as RAP and RCM. Aside from recycling in place, reasonable estimates of distances from jobsites to landfills, recycling facilities and distributors of virgin aggregates and substitutes will be needed.

Other Materials

We have addressed the material requirements of the core issues of pavement. We have covered the inputs of asphalt and reinforced concrete, and many of the treatments used to maintain and repair these. The PaLATE Model (Horvath et al. 2007) allows use of the same materials used for the base and pavement layers in the subbase, with the exception of soil. Fill of various kinds and topsoil are assumed to have no process GHG emissions associated except for extraction and transport. The extraction component is an equipment input. Transport will be calculated as per ton per mile from a heavy truck using EPA's MOVES model. Pedestrian facilities include sidewalks and possibly trails. The principal materials used for these are concrete and asphalt. Gravel can be accounted for as it is similar to aggregate.

For the most part we have addressed bridges, dams, culverts, tunnels and related structures. From a volumetric perspective we have addressed the materials that make up the bulk of these structures. However, we have not included minor inputs such as paint, plastics, epoxy, galvanizing of steel. **Error! Reference source not found.** shows emission factors for rubber and three varieties of plastics and a default. Emission factors for zinc are presented. Zinc is primarily used for galvanizing in the GREET 2.7 Vehicle Cycle model (Argonne National Laboratory 2007). The zinc emission factors should be applicable to galvanizing of steel used in transportation capital projects. The Vehicle Cycle model includes a number of other metals. Emission factors for virgin and recycled aluminum are also shown in **Error! Reference source not found.**.

Table 13. Plastics, Rubber, Galvanizing Material, and Aluminum Emission Factors.

Plastics	Final Polypropylene Product: Combined		Final Average Plastic Product: Combined		Final Glass Fiber-Reinforced Plastic Product: Combined		Final Carbon Fiber-Reinforced Plastic Product: Combined	
	g / ton	**g / lb**	**g / ton**	**g / lb**	**g / ton**	**g / lb**	**g / ton**	**g / lb**
CO_2	3,257,690	1,629	4,137,271	2,069	4,995,743	2,498	10,007,762	5,004
CH_4	5,271.525	2.636	6,236.881	3.118	7,629.053	3.815	16,027.336	8.014
N_2O	38.835	0.019	42.572	0.021	48.701	0.024	96.097	0.048
	Rubber		**Zinc**		**Virgin Aluminum**		**Recycled Aluminum**	
	g / ton	**g / lb**	**g / ton**	**g / lb**	**g / ton**	**g / lb**	**g / ton**	**g / lb**
CO_2	2,759,383	1,380	7,637,808	3,819	10,582,916	5,291	2,796,398	1,398
CH_4	5,122.608	2.561	13,894.108	6.947	16319.137	8.160	6483.458	3.242
N_2O	29.818	0.015	84.455	0.042	126.263	0.063	44.861	0.022

Source: GREET 2.7 Vehicle Cycle model (Argonne National Laboratory 2007).

Table 14. Fertilizer and Herbicide Inputs

	Fertilizer				Herbicides			
	Nitrogen	Phosphate	Potasium	Carbonate	Atrazine	Metolachlor	Acetochlor	Cyanazine
	g /lb	g /lb	g /lb	g /lb	g /lb	g /lb	g /lb	g /lb
CO2	1,100	444	296	269	7,510	10,886	10,978	7,953
CH4	1.309	0.801	0.437	0.408	10.876	15.771	15.904	11.519
N2O	0.740	0.008	0.004	0.004	0.084	0.121	0.122	0.089

Source: GREET 1.8c Fuel Cycle model (Argonne National Laboratory 2009).

GHG emissions from landscaping and erosion control are to a large extent based on equipment used for these activities, since it mainly involves moving soil and rock (equipment fuel consumption is addressed in the next section of this report). Concrete structures where the need arises could be handled by our model as developed. Emissions from crushed stone could be estimated from the emission factors reported in the aggregates section of this report. GHG emissions from rip rap can be estimated in the same way. Planting and fertilizing of shrubs or grass as erosion control has yet to be addressed. GHG emissions from fertilizers and herbicides used in highway landscaping are shown in **Error! Reference source not found.** from the GREET 1.8c Fuel Cycle model(Argonne National Laboratory 2009).

REVIEW OF LIFE-CYCLE CONSTRUCTION EQUIPMENT EMISSIONS

This section addresses assumptions to be made for the modeling of greenhouse gas (GHG) emissions from construction equipment in GASCAP. The model will account for lifecycle emissions from construction equipment, materials, and maintenance practices for transportation facilities in New Jersey. The principal focus of this section is on the lifecycle emissions associated with fuels consumed by construction equipment during operations for construction, rehabilitation, and maintenance of transportation facilities. We cover both existing equipment but with an additional focus on technological improvements and increased use of biofuels.

The model used addresses direct and upstream emissions from fuel consumption in construction equipment. Direct emissions are GHG emissions that result from fuel combustion in construction equipment under the control of contractors or the New Jersey Department of Transportation. Upstream emissions are GHG emissions that result from the extraction, transportation, refining, and distribution of fuels used in construction projects. The Argonne National Laboratory GREET 1.8c Fuel Cycle Model (Argonne National Laboratory 2009) is used to estimate upstream emissions for fuels used in construction equipment. The GREET model estimates CO_2, CH_4, and N_2O emissions and was designed to estimate upstream and direct emissions for on-road vehicles. The EPA Office of Transportation and Air Quality NONROAD model was designed to estimate criteria pollutants in off-road equipment (EPA 2008a). (EPA 2008a)(EPA 2008a) NONROAD was accessed by writing scripts for the National Mobile Inventory Model (NMIM) application. NMIM provides access to the MOBILE and NONROAD models. Although NMIM uses the 2008 version of NONROAD, it is documented here based on NONROAD 2005.[4] Carbon dioxide (CO_2) emissions are estimated from brake-specific fuel consumption (BSFC) on the assumption that nearly all of the carbon in fuel is oxidized to CO_2 either in the engine or in the atmosphere. Methane (CH_4) and nitrous oxide (N_2O) are modeled by manipulation of the NONROAD model and by adapting emission factors from the GREET model, respectively. Black carbon particulate matter was estimated by applying a speciation factor from the literature.

We note the following limitations with the NONROAD model:

- CO_2 as modeled in the GREET model includes oxidized fugitive and partially burned hydrocarbons and carbon monoxide (CO), whereas NONROAD only

[4], The NONROAD 2008 documentation was not published on the EPA website until August 2010 and does not differ substantially with respect to our assumptions about construction equipment. The changes in NONROAD 2008 primarily concern emission reductions for recreational equipment following incorporation of EPA standards in 2008 and changes in evaporative emissions as a result of use of ethanol as an additive to gasoline. Since the Carbon Footprint model uses NMIM's unadjusted NONROAD 2008 evaporative emission estimations our results are unaffected. (EPA 2009a)(EPA 2009a)

includes the latter. We account for oxidization of hydrocarbons emitted as volatile fugitive and partially burned fuel based on carbon content.

- Methane (CH_4) emissions are not directly modeled although it is possible to estimate hydrocarbon emissions with or without CH_4, which allows estimation of CH_4 as a residual.
- Nitrous oxide (N_2O) is not modeled.
- Black carbon or elemental carbon particulate matter is not estimated.

The balance of this section is a discussion of how GASCAP accounts for the global warming potential (GWP) of GHGs and black carbon. After discussing GHGs, black carbon, and the relevant accounting principles, we briefly address the chemistry of fuel consumption. We establish a basis with which to account for direct emissions that occur as a result of equipment inputs using standard fossil fuels. The NONROAD 2008 model through NMIM is used to address emissions of GHGs and criteria pollutants from standard fossil fuels including diesel oil (EPA 2004a)(EPA 2004a)(EPA 2004a) and gasoline as petroleum-based products and compressed natural gas (CNG) and liquefied petroleum gas (LPG) (EPA 2005b), which may be produced from either petroleum or natural gas. We discuss alternatives to petroleum and natural gas-based fuels including biomass and coal-based alternatives using the GREET model (Argonne National Laboratory 2009). Since the GREET model is a full lifecycle model it allows us to present upstream, direct, and combined emissions for all variants of the four fuel types modeled in NONROAD. Because NONROAD does not model the alternative fuels covered in the GREET model, we recognize that there is uncertainty in the performance and direct emissions of alternative fuels in existing non-road construction equipment. The GREET model treats direct emissions of alternative fuels as identical to those of standard fuels.

NONROAD – Direct Emissions

The NONROAD model is based on EPA regulation of criteria pollutants for off-road spark ignition (typically using gasoline, but also alternative fuels) and compression ignition engines (which use diesel fuel). These regulations were developed and phased in during the 1990s and the first decade of the 21st century (EPA 2004a, EPA 2005b). The phasing in of these regulations introduces an element of temporal variation because it is presumed in NONROAD that new equipment met the existing standards for the year in which it was manufactured. Criteria pollutants include hydrocarbons (HC), carbon monoxide (CO), oxides of nitrogen excluding nitrous oxide (NO_X), sulfur dioxide (SO_2), and particulate matter both smaller than 2.5 microns ($PM_{2.5}$) and smaller than 10 microns in diameter (PM_{10}). The last two categories overlap. BSFC is covered and is the basis of CO_2, and SO_2 emissions and a correction to the particulate matter based on sulfur content of diesel(EPA 2004a, EPA 2005b).

<u>Spark Ignition Emission Standards Implementation</u>

Spark ignition engines use gasoline, CNG, and LPG as fuel. They are classified by size as large and small with a dividing line of 25 hp(EPA 2005b). Both engine types are sub-classified. Small engines have five designations by Roman numeral (I-V). All small spark ignition engines are gasoline powered. Classes I and II are non-handheld machines. Class I is smaller than 225 cc and Class II is larger. Class I engines have power ratings between 3 and 6 hp. Power ratings for Class II are from 6 to 25 hp. Classes III through V are handheld. Class III is smaller than 20cc with a power range 0-1 hp. Class IV is between 20cc and 50cc with a power range of 1-3 hp. Class V includes handheld devices with engines larger than 50cc and a power range 3-6 hp. NONROAD does not adjust for transient adjustment factors[5] in spark-ignition engines smaller than 25 hp(EPA 2005b).

Phase 1 regulation for large spark ignition engines took effect in 2004 and were replaced by Phase 2 regulations in 2007 for gasoline engines larger than 25 hp and all CNG and LPG engines which are all larger than 25 hp. Phase 1 emission standards for smaller gasoline engines with power ratings less than or equal to 25 hp began in 1996 and was completed in 1997 (EPA 2005b). Phase 2 implementation for smaller gasoline engines was incremental and varied by engine class.

Non-handheld gasoline machines include two-stroke and four-stroke gasoline engines with power ratings from 0 to 6 hp (Class I) and from 6 to 25 hp (Class II) (EPA 2005b)(EPA 2005b)(EPA 2005b). Phase 2 emission standards implementation for the larger Class II engines was begun in 2001 and completed in 2005. Implementation of Phase 2 standards for Class I engines began in 2007 and was completed in 2008.

Handheld gasoline engines are all small two-stroke engines (EPA 2005b). Phase 2 emission standards for Class III engines rated 1 hp or less and Class IV engines rated from 1 to 3 were implemented between 2002 and 2005. In 2002 25% of the population of Class III and Class IV equipment was on the new standard in the first year. The Phase 2 share increased in 25% increments until the Phase 1 standard was replaced in 2005. Phase 2 standards for larger Class V handheld equipment rated between 3 and 6 hp were not implemented until 2004 – 2007, but using the same incremental approach used with Classes III and IV and the smaller non-handheld engines in Class I.

Compression Ignition Emission Standards Implementation

Larger diesel engines with power ratings from 175 to 750 hp were the first compression ignition engines to have full regulation of criteria pollutants (EPA 2004a). Tier 1 regulations established emission standards for HC, NO_X, CO, and PM emissions in 1996. Tier 2 regulations tightened and consolidated the emission standards for HC and NO_X into a combined standard for NMHC and NO_X. Emission standards for CO and PM were tightened as well. Tier 2 regulations took effect between 2001 and 2003. In 2006 Tier 3 tightened the emission standard for NMHC and NO_X. Table 15 shows federal emission standards modeled in NONROAD for compression ignition or diesel engines (EPA 2004a).

[5] NONROAD uses transient adjustment factors to compensate for the variability of engine load. NONROAD estimates are taken from laboratory results without the variability of load that occurs under normal real world use (EPA 2004a, EPA 2005b)

Table 15. Compression Ignition Emission Standards--NONROAD.

Power Rating (hp)	(hp) Model Years	Regulation	Emission Standards (g/hp-hr) HC	NMHC+NOx	CO	NOx	PM	NONROAD Tech Types
<11	2000-2004	Tier 1		7.8	6.0		0.75	T1
	2005-2007	Tier 2		5.6	6.0		0.60	T2
	2008+	Tier 4					0.30	T4A, T4B
≥11 to<25	2000-2004	Tier 1		7.1	4.9		0.60	T1
	2005-2007	Tier 2		5.6	4.9		0.60	T2
	2008+	Tier 4					0.30	T4A, T4B
≥25 to<50	1999-2003	Tier 1		7.1	4.1		0.60	T1
	2004-2007	Tier 2		5.6	4.1		0.45	T2
	2008-2012	Tier 4 transitional					0.22	T4A
	2013+	Tier 4 final		3.5			0.02	T4
≥50 to<75	1998-2003	Tier 1				6.9		T1
	2004-2007	Tier 2		5.6	3.7		0.30	T2
	2008-2012	Tier 3		3.5	3.7			T3
	2008-2012	Tier 4 transitional					0.22	T4A
	2013+	Tier 4 final		3.5			0.02	T4
≥75 to<100	1998-2003	Tier 1				6.9		T1
	2004-2007	Tier 2		5.6	3.7		0.30	T2
	2008-2011	Tier 3		3.5	3.7			T3B
	2012-2013	Tier 4 transitional	0.14 (50%)			0.30 (50%)	0.01	50% T4 50% T4N
	2014+	Tier 4 final	0.14			0.30	0.01	T4N
≥100 to<175	1997-2002	Tier 1				6.9		T1
	2003-2006	Tier 2		4.9	3.7		0.22	T2
	2007-2011	Tier 3		3.0	3.7			T3
	2012-2013	Tier 4 transitional	0.14 (50%)			0.30 (50%)	0.01	50% T4 50% T4N
	2014+	Tier 4 final	0.14			0.30	0.01	T4N

Source: Table 1 from Exhaust and Crankcase Emission Factors for Nonroad Engine Modeling--Compression-Ignition (EPA 2004a).

Table 15. Compression Ignition Emission Standards—NONROAD – continued.

Power Rating (hp)	Model Years	Regulation	Emission Standards (g/hp-hr)					NONROAD Tech Types
			HC	NMHC+NOx	CO	NOx	PM	
≥175 to<300	1996-2002	Tier 1	1.0		8.5	6.9	0.4	T1
	2003-2005	Tier 2		4.9	2.6		0.15	T2
	2006-2010	Tier 3		3.0	2.6			T3
	2011-2013	Tier 4 transitional	0.14 (50%)			0.30 (50 %)	0.01	50% T4 50% T4N
	2014+	Tier 4 final	0.14			0.30	0.01	T4N
≥300 to<600	1996-2000	Tier 1	1.0		8.5	6.9	0.4	T1
	2001-2005	Tier 2		4.8	2.6		0.15	T2
	2006-2010	Tier 3		3.0	2.6			T3
	2011-2013	Tier 4 transitional	0.14 (50%)			0.30 (50 %)	0.01	50% T4 50% T4N
	2014+	Tier 4 final	0.14			0.30	0.01	T4N
≥600 to<750	1996-2001	Tier 1	1.0		8.5	6.9	0.4	T1
	2002-2005	Tier 2		4.8	2.6		0.15	T2
	2006-2010	Tier 3		3.0	2.6			T3
	2011-2013	Tier 4 transitional	0.14 (50%)			0.30 (50 %)	0.01	50% T4 50% T4N
	2014+	Tier 4 final	0.14			0.30	0.01	T4N
>750 except generator sets	2000-2005	Tier 1	1.0		8.5	6.9	0.4	T1
	2006-2010	Tier 2		4.8	2.6		0.15	T2
	2011-2014	Tier 4 transitional	0.3			2.6	0.08	T4
	2015+	Tier 4 final	0.14			2.6	0.03	T4N
Generator sets >750 to<1200	2000-2005	Tier 1	1.0		8.5	6.9	0.4	T1
	2006-2010	Tier 2		4.8	2.6		0.15	T2
	2011-2014	Tier 4 transitional	0.3		2.6		0.08	T4
	2015+	Tier 4 final	0.14			0.5	0.02	T4N
Generator sets >1200	2000-2005	Tier 1	1.0		8.5	6.9	0.4	T1
	2006-2010	Tier 2		4.8	2.6		0.15	T2
	2011-2014	Tier 4 transitional	0.3			0.5	0.08	T4
	2015+	Tier 4 final	0.14			0.5	0.02	T4N
Source: Table 1 from Exhaust and Crankcase Emission Factors for Nonroad Engine Modeling--Compression-Ignition (EPA 2004a).								

The largest diesel engines with power ratings greater than 750 hp were first regulated in 2000. The Tier 1 regulations established HC, CO, NO_X, and PM standards identical to the Tier 1 standards established for 175 – 750 hp equipment four years earlier (EPA 2004a). In 2006 Tier 2 regulations tightened the emission standards to the Tier 2 levels for 175 to 750 hp equipment for pollutants and combined NMHC and NO_X for equipment rated in excess of 750 hp. These standards differ from the Tier 3 emission standards for 175 to 750 hp equipment only in that the emission standard for NMHC and NO_X is somewhat stricter. In 2011 transitional Tier 4 regulations will reduce emission standards for PM, HC, and NO_X. Methane will be regulated as an HC component and HC and NO_X will be under separate standards. In 2015 the HC and PM emissions standards will be tightened further.

For diesel engines between 50 hp and 175 hp Tier 1 regulations begin earlier (1997-8) than Tier 1 regulations for smaller diesel engines but only address NO_X emissions (EPA 2004a). It is only with the implementation of Tier 2 in 2003-4 that emissions standards for combined NMHC and NO_X, CO, and PM are established, although the emissions standards are comparable with other Tier 2 standards. With Tier 3 regulations emissions standards for NMHC and NO_X were tightened in 2007-8. Tier 4 regulations will tighten emission standards for PM and establish separate significantly more stringent emission standards for HC and NO_X for engines between 75 and 175 hp to be phased in from 2012-14.

For smaller diesel engines (<50 hp) Tier 1 regulations introduced standards for combined non-methane hydrocarbons (NMHC) and NO_X, CO, and PM (EPA 2004a). Tier 2 regulations tightened emission standards for PM from engines between 25 and 50 hp and NMHC and NO_X from all engines smaller than 50 HP. Tier 4 halved permissible PM levels from Tier 2 levels. This anticipates drastic reductions in sulfur content for diesel fuel. Tier 1 emission standards for diesel engines between 25 and 50 hp were implemented in 1999 and replaced with Tier 2 standards in 2004. Tier 4 emission standards were implemented in 2008. A more stringent PM standard will be implemented in 2013. Emission standards for smaller diesel engines less than 11 hp and between 11 and 25 hp were implemented at the same time. For engines rated less than 25 hp Tier 1 emission standards were implemented in 2000 and replaced by Tier 2 standards in 2005. Tier 4 emission standards were implemented for smaller engines in 2008.

Modeling Approach

The engines modeled in GREET are on the large end of what is modeled in NONROAD non(EPA 2004a, EPA 2005b), and do not contain the detailed disaggregation by vehicle type, vintage, and power rating. The impact of this assumption is minor because we know BSFC from NONROAD, are using the GREET model for upstream emissions only, and The GREET model treats direct emissions from analogous fuels produced from multiple pathways as equal (Argonne National Laboratory 2009). We model direct emissions from non-road engines using NONROAD for the relevant fuels: diesel, gasoline, CNG and LPG. We then model upstream emissions from these fuels using the GREET model for each of the fuels from each fuel pathway. The GREET model treats direct emissions from fuels produced from different pathways as equal. We are justified for this reason in modeling direct emissions as standard fuels. We summarize the models used as sources for data in

Table 16. Models Used to Estimate GHG Emissions

	CO_2	CH_4	N_2O	BC
Upstream Emissions[1]	GREET[7]	GREET[7]	GREET[7]	EPA model[6]
Direct Emissions				
Exhaust Emissions[1]	NONROAD[3]	NONROAD[4]	GREET[5]	EPA model[6]
Evaporative Emissions[2]	NONROAD[7]	NONROAD[7]	N/A	N/A

1. Upstream and exhaust emissions are for diesel, gasoline, CNG, and LPG.
2. Evaporative emissions are for gasoline only.
3. CO_2 emissions are taken from NONROAD except that the carbon from NMOG is adjusted stoichiometrically and added to the NONROAD estimate.
4. CH_4 is estimated as a residual of TOG and NMOG.
5. N_2O is estimated as a constant 0.006 g/hp-hr per GREET.
6. BC is estimated as the product of NONROAD PM2.5 and fuel specific black carbon speciation factors for diesel and gasoline and a generic speciation factor for CNG and LPG (Battye, Boyer & Pace 2002).
7. Uncorrected emissions are used.

NONROAD and MOBILE were designed primarily to model criteria pollutants including organic compounds of various designations. Particulate matter is composed of sulfates, nitrate and organic and elemental carbon (Liu et al. 2005)(Liu et al. 2005)(Liu et al. 2005). CO_2 emissions are calculated as a residual from the carbon content of the fuel after VOCs are accounted for. It is therefore presumed correctly that most of the CO is converted into CO_2 or behaves as CO_2 in the atmosphere (Wayne 1991). CH_4 may be calculated as a residual, i.e. the difference between total organic gases (TOG) and non-methane organic gases (NMOG). N_2O cannot be estimated directly or indirectly through NONROAD. It is possible to estimate the sulfate and carbon fractions of particulate matter, but it is not possible to distinguish between elemental and organic carbon in the particulate matter. The Motor Vehicle Emission Simulator (MOVES) model distinguishes between elemental and organic carbon particulate matter, but does not yet have a released off-road component (EPA 2010d)(EPA 2010d)(EPA 2010d). Construction equipment emissions include those associated with combustion of fuel and losses of fuel to evaporation.

The California Department of Transportation (CalTrans) in conjunction with the University of California at Davis developed a spreadsheet tool to estimate for PM, NO_X, CO_2, CO, and THC emissions from diesel retrofits and replacements between 2010 and 2015 (Wang et al. 2008)(Wang et al. 2008)(Wang et al. 2008). Their spreadsheet tool was used to estimate emissions reductions at the regional level for six equipment types[6], which account for 49% of NO_X emissions. Emissions were measured at the county level using OFFROAD (the California equivalent to NONROAD). Regional assumptions for population, activity level, and power rating were taken from OFFROAD. Caltrans decision to use activity data from OFFROAD was because they aggregate the data to the county level.

[6] Equipment types include rollers, rubber tire loaders, graders, generator sets, scrapers, and tractor-loader-backhoes.

The NONROAD 2008 model (EPA 2004a, EPA 2005b) addresses construction equipment by its function, power rating, fuel consumption rate and fuel type. We are not able to estimate activity from the NONROAD model. NONROAD activity data is based on aggregated data used for inventories at the county state or national level (EPA 2004b, EPA 2005c).In order to apply NONROAD at the microscopic level scripts i.e. short macros, were used to estimate one hour of activity for each machine we modeled. Accurate activity data for New Jersey construction, rehabilitation and general maintenance should take into account factors such as climate and actual practices. The modeling approach used here is an approximation because it estimates emissions based on an average hour of use estimated from steady state laboratory measurements. However, emissions are dependent on load and idling time. Direct measurement can be done using Portable Emissions Measurement Systems (PEMS). This would allow emissions assessment under a variety of circumstances to determine differences in task, idling time, weather, and other machine specific conditions that NONROAD does not account for (Rasdorf et al. 2010)(Rasdorf et al. 2010)(Rasdorf et al. 2010). However, direct measurement is expensive and is currently an active area of research; for example, detailed activity data and an understanding of the operating modes of various construction equipment needs to be determined. One example is a large study (Rasdorf et al. 2010) that analyzed emissions for nine types of equipment[7] at one power rating each. The types of equipment selected were intended to include the types with the highest emissions of criteria pollutants, but does not cover all the possible equipment that might be used on a construction project, especially as the vintage of the equipment would likely not correspond to the estimates from a single study. The study by (Rasdorf et al. 2010) outlines procedures for collecting data using PEMS, but this is clearly beyond the scope of the current project.

<u>Evaporative and Refueling Emissions</u>

Evaporative emissions are losses of the volatile components of fuel to a gaseous state, essentially without chemical transformation of the fuel material (EPA 2005e)(EPA 2005e)(EPA 2005e). Increases in ambient or engine temperatures increase the likelihood that fuels will vaporize. Diurnal emissions refer to evaporation caused by higher ambient temperatures during daylight hours. Hot soak and running losses refer to evaporative emissions that occur as a result of a hot engine. Hot soak emissions occur after an engine has been turned off, but before it has cooled to ambient temperature. Running losses occur while a hot engine is running. Permeation losses occur when fuel has soaked through containers or hoses and become exposed to air. Diffusion losses occur when fuel is otherwise exposed to air. These include displacement losses and spillage, which refer to evaporation of fuel that occurs during refueling because of displaced vapors or when spilled fuel evaporates. Crankcase emissions and resting loss occur through the crankcase and fuel tank, respectively, when the temperature is stable.

NONROAD (EPA 2005b)(EPA 2004a) assumes that evaporative emissions are only a concern for gasoline engines. It is argued that evaporative emissions are negligible for

[7] Equipment covered by (Rasdorf et al. 2010) includes backhoes, bulldozers, excavators, generators, motor graders, off-highway trucks, rubber tire loaders, track loaders, and skid-steer loaders.

CNG and LPG engines because these are designed to contain fuel that is in a gaseous state at ambient temperatures and pressures. Diesel on the other hand contains only components that are heavy enough so as not to be volatile at ambient temperatures and pressures. Only gasoline contains components that are usually but not always liquid at ambient temperatures and pressures and therefore likely to change phase(Speight 2007). However, NONROAD accounts for hydrocarbon crankcase emissions from diesel engines (EPA 2004a).

Detailed guidance for estimating evaporative and refueling emissions as done in NONROAD is available (EPA 2005e, EPA 2004c). Since we incorporate evaporative and refueling emissions unaltered from the model output, the reader is referred there.

Exhaust Emissions

EPA published separate NONROAD model guidance for estimating exhaust emissions for spark ignition (EPA 2005b) and compression ignition engines (EPA 2004a). Spark ignition engines include gasoline, CNG and LPG engines. Gasoline engines may use two or four-stroke cycles. Compression ignition engines use diesel oil. Although EPA has published emissions modeling software we adjust fuel consumption to apply variations in the upstream emissions from the various fuel pathways discussed in the GREET model (Argonne National Laboratory 2009)(Argonne National Laboratory 2009)(Argonne National Laboratory 2009).

We estimate emissions for CO_2, CH_4, N_2O and black carbon particulate matter. We estimate black carbon as a fraction of particulate matter smaller than 2.5 microns. NONROAD does not differentiate between organic and elemental carbon particulate matter. We estimate direct N_2O emissions with the GREET model (Argonne National Laboratory 2009). The equipment discussion addresses spark ignition and compression ignition engines separately. The discussion of spark ignition engines focuses primarily on variations among small gasoline engines (<25 hp), since large spark ignition engines vary by fuel type rather than by power rating (EPA 2005b). The first decade of the twenty-first century witnessed a sharp decrease in the sulfur content of diesel fuel from 3,000 ppm to 15 ppm . This process is complete or will be completed early in the 2010s for most fuel used in compression ignition engines of various power ratings. Much of the temporal variation in emissions from diesel fuel results from the phased implementation of new fuel sulfur restrictions.

NONROAD Model Basics

The NONROAD model applies laboratory test results to approximate emissions and fuel consumption under operating conditions. The NONROAD model first estimates *zero-hour steady-state* criteria pollutant emissions and fuel consumption. Zero-hour emissions are not adjusted for normal deterioration of engine performance over its useful life. Steady-state refers to running an engine under a constant load under laboratory conditions without a load adjustment to correct for variations in load during normal use. NONROAD estimates deterioration factors (DF) and transient adjustment factors (TAF) to correct for the zero-hour state and the steady state emissions, respectively. Emissions are estimated in grams per horsepower-hour (hp-hr). Fuel consumption is estimated in pounds per hp-hr. Zero-hour steady-state emissions are estimated for different engine types based on power rating, fuel type and function.

NONROAD provides separate procedures for adjusting particulate matter emissions, gaseous emissions including hydrocarbons, CO, and NO_X, and fuel consumption (EPA 2004a)(EPA 2004a)(EPA 2004a). The formulas are shown in Table 17.

EF_{adj} represents the adjusted emission factors for HC, CO, NO_X, PM, and BSFC. EF_{ss} represents the steady state zero hour emission factors. SPM_{adj} is an adjustment factor that accounts for the impact of variations in fuel sulfur levels on particulate matter levels. Since no deterioration factor is applied to BSFC the adjusted fuel consumption rate is the product of the steady-state fuel consumption rate and the TAF. Deterioration factors are estimated for HC, CO, and NO_X so the adjusted emission factor for each of these is the product of the zero-hour steady-state emission rate, the TAF and the DF. The same procedure is used to estimate adjusted particulate matter emissions, however, reductions in sulfur content over the last decade reduce the volume of sulfate in particulate matter and must also be accounted for. The sulfur adjustment to particulate matter is used unchanged from the NONROAD model, which includes this adjustment. Zero-hour steady-state emissions and fuel use, transient emissions factors, and deterioration factors are reported in Appendix A Tables A1-3 for spark ignition engines and in Appendix B Tables B1-3 for compression ignition engines.

<u>Zero-Hour, Steady-State Emissions and Fuel Use.</u>

The unadjusted tables used in NONROAD track emissions of HC, CO, NO_X, PM and BSFC (EPA 2004a, EPA 2005b). Hydrocarbons are essentially unburned and partially consumed fuel. They include a multiplicity of compounds that are classified by volatility and the presence of oxygen (EPA 2005a)(EPA 2005a)(EPA 2005a). NONROAD does not address oxidation of hydrocarbons to CO_2, although the GREET model addresses this phenomenon. CO is a product of partial combustion that is readily oxidized into CO_2 in the atmosphere and is so modeled in NONROAD (EPA 2004a, EPA 2005b)(EPA 2004a, EPA 2005b)(EPA 2004a, EPA 2005b). The zero-hour steady-state emissions factors apply to unused equipment with zero hours of use run at a constant rate under laboratory conditions.

Table 17. Adjustments to Zero-Hour Steady State Rates.

Brake-Specific Fuel Consumption $EF_{adj(BSFC)} = EF_{ss(BSFC)} * TAF_{(BSFC)}$ Emission Factors for HC, CO, and NO_X $EF_{adj(HC, CO, NOX)} = EF_{ss(HC, CO, NOX)} * TAF_{(HC, CO, NOX)} * DF_{(HC, CO, NOX)}$ Emission Factors for Particulate Matter $EF_{adj(PM)} = EF_{ss(PM)} * TAF_{(PM)} * DF_{(PM)} - S_{Pmadj}$ Where: EF_{adj} is the adjusted emission factor; EF_{ss} is the steady-state [zero-hour] emission factor; TAF is the transient adjustment factor; DF is the deterioration factor; and S_{PMadj} is the sulfur adjustment to particulate matter. Sources: Exhaust and Crankcase Emission Factors for Nonroad Engine Modeling—Compression-Ignition (EPA 2004a). Exhaust Emission Factors for Nonroad Engine Modeling: Spark-Ignition (EPA 2005b).

Transient Adjustment Factors

Most off-road engines operate with variable or transient loads but the emissions testing for the NONROAD model is done with steady-state tests (EPA 2004a, EPA 2005b). At variable loads engine efficiency should vary because the ratio of fuel to air varies (Stone 1992)(Stone 1992)(Stone 1992). TAFs correct for inefficiencies from this type of variability. They are generally stated as a factor of one or greater, although the manual states that they may be less than 1.0 (EPA 2004a). TAFs are multiplied by the four steady-state emission factors and the fuel consumption factor to produce transient factors (EPA 2004a). A TAF of one (1.0) indicates that load variability has no effect on emissions. This assumption is made for small spark ignition engines (<25 hp), Tier four compression ignition engines, large (>25 hp) spark ignition made under Phase 2 standards (2007-8 and later) and equipment that usually runs at a steady state, such as generators, pumps, and compressors (EPA 2004a, EPA 2005b).

Deterioration Factors

Generally engines lose efficiency over their useful life. NONROAD estimates this effect for the four zero-hour emission factors but not for fuel consumption (EPA 2004a, EPA 2005b)(EPA 2004a, EPA 2005b)(EPA 2004a, EPA 2005b). Deterioration-adjusted emissions are modeled as the product of zero-hour emissions and a deterioration factor based on the proportion of the median useful life of an equipment piece expended. The deterioration factor is a function of median life expended up to but not beyond the point where half of the population has been scrapped. The NONROAD model assumes that in order to continue functioning an equipment piece must be maintained to a certain de facto standard so that it is unrealistic that equipment will continue to deteriorate if it is still in service when half the population has been scrapped (EPA 2005d). The deterioration factor is expressed:

$DF = 1 + A * AF^b$ (for $0.0 \leq AF \leq 1.0$)

where A is the maximum proportionate increase in emissions at the end of the median life of the equipment type by fuel type and power rating; AF is the proportion of the median life already expended; and b is a constant that regulates acceleration of emissions. The guidance cautions that there is little PM deterioration data and that PM deterioration estimates are based on HC deterioration data for spark ignition engines (EPA 2005d)(EPA 2005d)(EPA 2005d). If b is equal to 1, deterioration is at a constant rate. If b is less than one the engine experiences a rapid initial increase in emissions which decelerates as the end of the median life approaches. If b is greater than one, the increase in emissions is initially slow but accelerating. The exponential b constant is set to 0.5 for small 4-stroke spark ignition engines and 1.0 for small ($\leq$25hp) 4-stroke gasoline engines and 1.0 for all 2-stroke gasoline and large (>25hp) spark ignition engines (EPA 2005d). The b constant is set equal to 1.0 for all compression ignition engines. Median life is measured as hours of use at full load taken from the Power Systems Research database (EPA 2005d). These values may be converted to median life in years by dividing them by the product of average use stated in hours of use per year and average load stated as a fraction of full load (EPA 2005d).

Adjustments to NONROAD GHG Definitions

Total hydrocarbon (THC) emissions include those emissions that are measureable with a flame ionization detector calibrated with propane (EPA 2005a). This definition excludes oxygenated hydrocarbons such as alcohols and aldehydes, which are similar in reactivity with ozone forming hydrocarbons in the atmosphere. Together hydrocarbons and oxygenated variants are combined into a class called total organic gases (TOG). Because CH_4 is less reactive than other hydrocarbons non-methane classifications are also estimated. These are non-methane hydrocarbons (NMHC) and non-methane organic gases (NMOG), respectively. By definition VOCs are all materials included in the TOG classification, except CH4, ethane, acetone or other compounds that are rare in engine exhaust such as PFCs or HFCs (EPA 2005a). In practice only CH_4 and ethane are discounted by EPA because the other compounds are present in negligible quantities. Differences among these hydrocarbon classifications are based on the mass of the components not carbon weight.

Once in the atmosphere CO and hydrocarbons in the broadest sense, i.e. TOG, are ultimately transformed into CO_2. CH_4 is less reactive than VOCs by more than one order of magnitude (EPA 2005a). Because they survive longer in the atmosphere CH_4 emissions are treated separately from VOC emissions in GHG accounting. Through *photolysis* CH_4 oxidizes to CO (Wayne 1991). CO emissions as modeled by NONROAD (EPA 2004a, EPA 2005b) are assumed to oxidize further from CO to CO_2. The GREET model (Argonne National Laboratory 2009) includes VOC emissions in CO_2 estimates, although CO_2 emissions produced as a direct product of combustion with CO and VOCs are presented as well in the model's output tables. NONROAD does not incorporate VOCs into CO_2 emissions estimates (EPA 2004a, EPA 2005b). The approach used in the GREET model is preferred for application to the NONROAD data because it accounts for the GHG impact of carbon emissions as CO_2 or CH_4 more completely than the approach taken by NONROAD assuming the NONROAD definitions.

It is tempting to use the NONROAD definition for VOCs (EPA 2005a) because it correctly excludes CH_4. However, VOCs as defined in NONROAD do not include ethane because it is less volatile than larger hydrocarbon species. On the other hand the GHG effects of ethane are not readily available in the literature. If we define readily oxidizing VOCs using the NONROAD definition and report estimates for CH_4 we do not address the full GHG impact from carbon fuel because we neglect ethane. However, ethane is a tiny proportion of THC for most construction equipment engines, although it is somewhat higher for LPG and CNG engines. The NONROAD literature allows estimation of ethane in exhaust as the difference of NMOG and VOC emissions by weight for engine types as follows (EPA 2005a) :

- 0.1% for 2-stroke gasoline engines,
- 1.0% for 4-stroke gasoline engines,
- 0.1% for diesel engines,
- 2.4% for LPG engines, and
- 4.5% for CNG engines

NMOG emissions are a not unreasonable alternative to VOC emissions using the NONROAD definitions (EPA 2005a). This definition includes ethane and by doing so includes 100% of the carbon exhaust emissions as CO_2, CO and VOC as NMOG which oxidize to CO_2, and CH_4. However this approach does not take into account the different volatility of ethane from larger hydrocarbons. Yet a third alternative would be to treat ethane as the equivalent of CH_4 based on carbon weight, but no literature was found to justify this approach. Listed in increasing order of conservativeness, i.e. the magnitude of GHG impact reported, the possible approaches are VOCs, NMOG, and ethane as methane equivalent. The first approach would treat ethane as though it were not present. The second approach would treat ethane as a higher hydrocarbon that readily oxidizes into CO_2. The third approach would treat ethane as equivalent to methane based on weight and carbon content, although with little backing from the literature. The second approach was taken because it ascribes a GHG impact to ethane in engine exhaust. To the extent that ethane behaves as CH_4 does in the atmosphere we have slightly underestimated the GHG impact using the NONROAD estimates.

In the NONROAD model CO_2 emissions are estimated as follows (EPA 2004a, EPA 2005b):

$$CO_2 = (BSFC * 453.6 – [T]HC) * [CF / (12/44)]$$

In this formula CO_2 is the mass of CO_2 in grams; BSFC is brake specific fuel consumption in pounds; 453.6 is a factor to convert pounds to grams; HC or THC (in

(EPA 2005a)(EPA 2005a)(EPA 2005a)) is the hydrocarbon mass in grams; CF is the carbon fraction of the fuel; and (12/44) is the carbon fraction of CO_2. For gasoline and diesel the carbon fraction is assumed to be 0.87 in NONROAD (EPA 2004a, EPA 2005b). NONROAD does not present carbon fractions for CNG or LPG. However the assumption that non-methane hydrocarbon emissions from evaporate natural gas suggests a carbon fraction of 0.75 for natural gas because it is defined as pure CH_4 (CF = 12/16). The GREET model uses more empirically derived estimates of 0.724 and 0.820 for CNG and LPG respectively (Argonne National Laboratory 2009). These estimates account for the presence of impurities and higher hydrocarbons, which are verified in the case of natural gas (Speight 2007)(Speight 2007)(Speight 2007). However, we take into account the possibility that EPA adjusted fuel consumption for CNG and LPG engines and follow the NONROAD instructions using 0.87 as the carbon fraction for all engine fuel (EPA 2005b)(EPA 2005b)(EPA 2005b). To the extent that this assumption is incorrect, the carbon content of fuel consumed by CNG and LPG engines is overestimated. Using the NONROAD procedure unaltered in this case is a conservative choice.

However, to account for oxidation of NMOG to CO_2 we add NMOG back to the NONROAD formula for CO_2 emissions stated above. In the GREET model total CO_2 emissions are estimated as the sum of direct CO_2 emissions in grams from combustion, the product of the CO emissions in grams and the ratio of the carbon fraction of CO to the carbon fraction of CO_2 by weight, and the product of the VOC emissions in grams and the average carbon fraction of VOCs to the carbon fraction of CO_2 by weight. CH_4 emissions are the difference between TOG and NMOG.

Nitrous Oxide

The NONROAD model does not estimate N_2O emissions. A study done for the NONROAD program presents N_2O emissions for 10 non-road diesel engines with power ratings from 7 to 850 hp engines used with agricultural and construction equipment (Helmer et al. 2004). Measurements were taken using two types of fuel (2,500 ppm sulfur and 500 ppm sulfur). The reported emissions were in a range between 0.004 and 0.026 grams N_2O per hp-hr. The mean was about 0.010 g/hp-hr and the standard deviation was about 0.006 g/hp-hr. The sample was undoubtedly skewed to the left, with some higher outliers. When the results are stratified by fuel sulfur content, the mean and the standard deviation for the lower sulfur content fuel are reduced to 0.006 and 0.002 respectively. The lower estimate is consistent with GREET model (Argonne National Laboratory 2009) estimates.

Although it is fraught with methodological issues to estimate N_2O emissions from such a small empirical base for non-road engines that vary considerably by power rating, it seems unlikely that we would grossly underestimate N_2O emissions assuming 0.006 g/hp-hr for all diesel engines of all power ratings because by 2010 we are approaching the full implementation of regulations lowering the sulfur content of diesel ultimately to 15 ppm (EPA 2004a). Another justification of this very liberal assumption is that GHG impact is minimal. Although N_2O has a GWP potential 310 times that of CO_2 it is present in diesel exhaust in minute quantities. N_2O content of 0.006 g/hp-hr is equivalent to

1.86 g/hp-hr of CO_2. The 0.006 g/hp-hr is close to estimates used in the GREET model (Argonne National Laboratory 2009) but is not cited by it. The GREET model uses estimates of 2.0 g N_2O per MMBtu of fuel for all fuels in stationary sources and heavy heavy duty trucks and 2.898 g N_2O per MMBtu for medium heavy duty trucks (Argonne National Laboratory 2009). These estimates convert to 0.0051 g N_2O per hp-hr and 0.0074 g N_2O per hp-hr, respectively. Since the GREET model estimates the same N_2O emission rate for all fuels we apply the higher GREET estimates and assume that all fuels produce N_2O exhaust emissions at the rate of 0.0074 g/hp-hr. N_2O emissions are the product of the average load expressed in hp-hr for each application and power rating.

This completes our discussion of the three greenhouse gases modeled by NONROAD (EPA 2004a, EPA 2005b) and the GREET model (Argonne National Laboratory 2009). Our Carbon Footprint model covers CO_2, CH_4, and N_2O. Fluorocarbons are present in engine exhaust in minute quantities. NONROAD does not model them. If they were estimated they would be included with NMOG but not VOC (EPA 2005a)(EPA 2005a)(EPA 2005a). Our model would incorporate these because we define hydrocarbons to include all organic gases. SF_6 is not modeled by NONROAD. HFCs, PFC, and SF6 emissions are not produced in significant quantities in association with transportation fuels (Wang, Huang 1999).

Black Carbon

The capacity for black carbon to contribute to global warming by absorbing light and radiating heat was discussed. PM from combustion consists of sulfates, nitrates, and black and organic carbon. We do not attempt to separate organic carbon into volatile and non-volatile components or organic carbon from ammonium ions. This means that we do not discuss the GWP of brown carbon, which has been characterized as minor but recent findings suggest its impact is not fully appreciated and may be much greater than thought (Andreae, Gelenscér 2006).

We attempt to estimate black carbon emissions from NONROAD PM estimates (EPA 2004a, EPA 2005f). NONROAD defines as particulate matter measurable materials 10 microns (μ) or smaller (PM_{10}). All black carbon particles are 2.5μ or smaller ($PM_{2.5}$) (Battye, Boyer & Pace 2002). The NONROAD model assumes that 97% of diesel PM_{10}, 92% of gasoline PM_{10}, and 100% of CNG and LPG are smaller than 2.5μ. Assuming constant or at least average black carbon emissions we apply speciation factor estimates of $PM_{2.5}$ to produce estimates of black carbon particulate matter (PM_{BC}). The speciation factors are taken from a 2002 report funded by EPA to establish methods of estimating black and organic carbon emissions for inventory purposes (Battye, Boyer & Pace 2002). We estimate PM_{BC} with the following formula:

$$PM_{BC} = PM_{[10]} * SF_{BC}$$

where SF_{BC} is the speciation factor for black carbon. $PM_{2.5}$ is transient, deterioration and sulfate adjusted particulate matter 2.5μ or smaller. This formula shows the basic mechanics by which black carbon emissions are estimated for equipment in the Carbon

Footprint Project. The black carbon speciation factors are 0.43 for diesel-powered non-road equipment and 0.27 for gasoline-powered non-road equipment (Battye, Boyer & Pace 2002)(Battye, Boyer & Pace 2002)(Battye, Boyer & Pace 2002). We apply the generic speciation (0.14) factor to CNG and LPG powered equipment. Application of these speciation factors is complicated by changing levels of sulfur in fossil fuel and increasingly stringent restrictions of sulfur levels over the course of the first decade of the twenty-first century, especially for diesel.

GREET Model – Upstream Emissions

The GREET model (Argonne National Laboratory 2009) provides detailed upstream, or well-to-pump emission factors for a variety of fuel types. We ran the GREET model to compare the processes or pathways by which CNG, LPG, gasoline, and diesel fuel are produced. As modeled in GREET LPG may be produced from natural gas or crude petroleum. A 60 to 40 natural gas to petroleum LPG blend is assumed. CNG has a single pathway. Gasoline is a blended product of petroleum refining. Gasoline blends include a half and half conventional and reformulated gasoline blend, a ten percent ethanol blend and an 85% ethanol blend. Diesel is modeled as low sulfur diesel, biodiesel, and Fischer-Tropsch diesel. The Fischer-Tropsch process can be used to convert coal, natural gas and biomass to diesel oil and other fuels, solvents and waxes (Wang, Huang 1999, Kreutz, Larson & G. Williams 2008, Wu, Wu & Wang 2005)(Wang, Huang 1999, Kreutz, Larson & G. Williams 2008, Wu, Wu & Wang 2005)(Wang, Huang 1999, Kreutz, Larson & G. Williams 2008, Wu, Wu & Wang 2005).

The GREET model (Argonne National Laboratory 2009) includes 81 separate fuel pathways. Feedstocks include petroleum and bituminous tar sands, natural gas, landfill gas, biomass, solar energy, nuclear power, and coal. From petroleum and tar sands conventional, standard and California reformulated gasoline, conventional and low sulfur diesel, LPG and naphtha are produced. Although these products are not used as fuels their extraction is by the same process that fuels are extracted from petroleum, although these are not directly addressed in GREET. GREET also models the processes by which compressed (CNG) and liquefied natural gas (LNG), LPG, methanol, hydrogen and dimethyl ether are produced from natural gas. In GREET, natural gas is also a feedstock for diesel and naphtha produced by the Fischer-Tropsch method.

Fuel cycles have essentially five stages (Gerdes, Skone 2008a, Huo et al. 2008)(Huo et al. 2008, Gerdes, Skone 2008b)(Huo et al. 2008, Gerdes, Skone 2008b). These include:

- Stage 1 – Feedstock extraction, which includes all steps such as drilling and removing petroleum or natural gas or planting, raising, and harvesting vegetable matter for biofuels;
- Stage 2 – Transportation of feedstocks to processing facilities, such as refineries;
- Stage 3 – Processing of feedstocks into finished fuels;
- Stage 4 – Distribution of finished fuels to the tank; and
- Stage 5 – Fuel consumption and fugitive emissions

For biofuels Stage 3 may be usefully split into an extraction phase for the feedstock, such as soybean oil, and a processing phase by which the feedstock is converted to finished fuel (Huo et al. 2008).

Fossil Fuels Modeled in NONROAD

Petroleum is made up of fossilized hydrocarbons of various weights. It is extracted from land and sea-based deposits. Transportation to refineries is by pipeline, ship, truck and rail (Gerdes, Skone 2008a). The refining process consists of a three phase repeating process. Hydrocarbons are separated by weight (Speight 2007). Atmospheric distillation involves heating of crude petroleum under oxygen poor conditions to separate the lighter hydrocarbons including LPG. Vacuum distillation extracts the heavier components under vacuum conditions. Number 2 fuel oil which is equivalent to diesel oil is extracted at this stage. The remainder, or *residuum*, includes the heavy elements such as residual fuel oil, waxes, and asphalt binder. Further processing of residua, often by heating to critical temperatures, causes the remaining heavy hydrocarbons to break into smaller molecules, which may be subjected again to distillation.

Like petroleum, natural gas is extracted from land and sea-based deposits (Speight 2007)(Speight 2007)(Speight 2007). Natural gas may be found in associated deposits--with petroleum--or in non-associated deposits—without petroleum. Wet natural gas has higher concentrations of heavier hydrocarbons, while dry natural gas contains relatively more methane and ethane. Natural gas produced from non-associated deposits tends to be dryer than gas produced from associated deposits (Speight 2007). The wet components of natural gas are referred to as natural gas liquids in the GREET model literature (Wang, Huang 1999). The processing of natural gas involves removal of impurities such as water, H_2S, and CO_2, and separation of natural gas liquids from natural gas. The natural gas liquids are separated into ethane, LPG, and hydrocarbons that are pentane or higher. Natural gas may be compressed as CNG or converted to higher hydrocarbons through gasification and the Fischer-Tropsch process discussed below (Wang, Huang 1999). LPG according to the GREET model default is 60% from natural gas feedstocks and 40% from petroleum feedstocks (Argonne National Laboratory 2009). Because natural gas refining is a simpler process than petroleum refining the energy input for extracting LPG from natural gas is less than from petroleum so that extraction from natural gas is more efficient than from petroleum (Wang, Huang 1999).

The GREET model (Tyner et al. 2010) produces upstream estimates for CNG, LPG, gasoline, and diesel oil from natural gas and/or petroleum feedstocks. The model estimates emissions from natural gas and crude petroleum extraction and feedstock transportation storage and distribution emissions involved in delivering the feedstock to refineries, and fuel-specific refinery emissions. For petroleum-based fuels refining emissions are based on a global petroleum refinery efficiency coefficient, which is the ratio of the energy in finished refinery products to the sum of the energy in the crude, other feedstocks, and process fuels (Wang 2008)(Wang 2008)(Wang 2008). Specific refinery energy efficiencies are calculated based on industry rule of thumb assumptions that 60% of all process fuels are used to produce gasoline, 25% are used to produce diesel, and 15% are used to produce all other products. Gasoline accounts for 47.0% of energy content, diesel for 25.7% and all other products for 27.3%. On this basis fuel-specific refinery intensities are 1.28, 0.97, and 0.55 for gasoline, diesel and other products, respectively (Wang 2008)(Wang 2008)(Wang 2008). On that basis, efficiencies of 87.7%, 90.3%, and 94.3% are estimated for gasoline, diesel, and other petroleum products respectively. The Fuel Cycle does not apportion fuel-specific refinery efficiencies for LPG so GREET apportions upstream emissions for each GHG on an energy basis by adding extraction and transportation emissions for crude petroleum in g/MMBtu to the refinery specific emissions also in g/MMBtu. An energy efficiency of 96.5% is assumed for LPG refined from natural gas liquids (Wang, Huang 1999). CNG processing involves compression of dry natural gas using electric or natural gas-powered compressors with energy efficiency of 97.3% and 93.1% respectively .

Error! Reference source not found. shows upstream GHG emissions from standard petroleum and natural gas-based fuels modeled in NONROAD. Estimates are taken from the GREET model (Argonne National Laboratory 2009). Estimates are for non-oxygenated conventional gasoline, low-sulfur diesel with 15 ppm sulfur content, and LPG and CNG based on default GREET assumptions. LPG is assumed to be 60% from petroleum and 40% from natural gas feedstocks (Argonne National Laboratory 2009)(Argonne National Laboratory 2009)(Argonne National Laboratory 2009). Black carbon estimates in **Error! Reference source not found.** were estimated with the speciation factor for miscellaneous fuel combustion (14%) (Battye, Boyer & Pace 2002) of estimates of particulate matter smaller than 2.5µ from the GREET model (Argonne National Laboratory 2009)(Argonne National Laboratory 2009)(Argonne National Laboratory 2009).

Table 18. Upstream GHG Emissions for Standard Fuels Modeled in NONROAD.

	Conventional Gasoline	Low Sulfur Diesel	LPG	CNG
	g/lb BSFC	g/lb BSFC	g/lb BSFC	g/lb BSFC
CO_2 (w/ C in VOC & CO)	326.721	210.103	184.241	313.894
CH_4	1.994	4.518	2.310	2.118
N_2O	0.005	0.003	0.003	0.005
$PM_{2.5}$: Total	0.073	0.049	0.030	0.070
Black Carbon	0.010	0.007	0.004	0.010

Sources: Estimated from the GREET Model (Argonne National Laboratory 2009) and converted into g/lb BSFC.
Particulate matter speciation, i.e. Black Carbon is estimated from (Battye, Boyer & Pace 2002)(Battye, Boyer & Pace 2002)(Battye, Boyer & Pace 2002).

Biofuels

Biofuels are considered renewable because the CO_2 emission from their combustion represents the release of sequestered carbon from the atmosphere and not fossil carbon such as petroleum, natural gas, or coal. Fossil fuels contribute to global warming by returning carbon to the atmosphere that has remained outside of the carbon cycle for millions of years (Wayne 1991)(Wayne 1991)(Wayne 1991). Biofuels have in common that they are produced from farmed vegetable matter or waste food products and go through a refining process in which the food product is prepared and converted into finished fuel (Huo et al. 2008)(Huo et al. 2008)(Huo et al. 2008). The refining processes include fermentation and gasification with processing into higher hydrocarbons through the Fischer-Tropsch process (Wu, Wu & Wang 2005). These processes are made more efficient by coproduction of steam, electricity or other products.

Under the final EPA National Renewable Fuel Standard Program regulations concerning the inclusion of biofuels in transportation fuels and minimum GHG reduction standards for biofuels apply to off-road equipment (EPA 2010b). Corn and sugar cane-based ethanol, biodiesel from soy and waste grease, oil, and fats meet the new standard. Cellulose-based biofuels meet and often exceed the new standard. The regulation mandates that minimum proportions of fuel produced by refiners to be from cellulosic biofuel (0.004%) biomass-based diesel (1.10%), total advanced biofuel (0.61%), and renewable fuel (8.25%).[8]

Farming Emissions.

The upstream GHG footprint of biofuels includes emissions from farming of feedstocks including machinery, fertilizer and pesticide, and transportation of inputs. The GREET model (Argonne National Laboratory 2009) addresses biofuels produced from corn, corn stover i.e. leaves and stalks, woody and herbaceous biomass generically, bagasse or sugar cane straw, soybeans, and wood residue from forestry operations. **Error! Reference source not found.** shows emissions for ethanol production for each biomass input addressed in the GREET model. The differences among feedstocks reflect differences in the farming process because refining emissions were held constant.

Table 19. Upstream GHG Emissions for Ethanol from Biomass Feedstocks.

	Corn	Woody Biomass	Herbaceous Biomass	Corn Stover	Forest Residue	Bagasse
	g/lb BSFC	g/lb BSFC	g/lb BSFC	g/lb BSFC	g/lb BSFC	g/lb BSFC
CO_2 (w/ C in VOC & CO)	-236.321	-1082.581	-884.942	-828.921	-677.020	-729.703
CH_4	1.260	-0.004	0.088	0.067	0.323	3.840

[8] Proportions are for 2010, except biomass-based diesel, which is combined 2009-2010. These proportions will increase annually through 2022.

N_2O	0.478	0.167	0.486	0.133	0.138	0.304
$PM_{2.5}$: Total	0.226	0.095	0.097	0.096	0.149	5.304
Black Carbon	0.032	0.013	0.014	0.013	0.021	0.743

Sources: Estimated from the GREET Model (Argonne National Laboratory 2009) and converted into g/lb BSFC.
Particulate matter speciation, i.e. Black Carbon is estimated from (Battye, Boyer & Pace 2002)(Battye, Boyer & Pace 2002)(Battye, Boyer & Pace 2002).

There is considerable variation in farming emissions for biofuel feedstocks. **Error! Reference source not found.** shows GHG and black carbon emissions for ethanol produced from the six types of biomass modeled for ethanol production in the GREET model (Argonne National Laboratory 2009). For compatibility with NONROAD all emissions are expressed in grams per pound of fuel. CO_2 emissions are negative in each case which indicates that between the farming process and displacement of fossil fuel consumption through coproduction of fuels and other products, enough carbon is sequestered in the soil and there are sufficient CO_2 savings from electricity or steam coproduced to more than offset the CO_2 emissions associated with farming, transporting, producing, and distributing ethanol. Ethanol production produces the largest CO_2 savings from woody biomass and the smallest from corn. Herbaceous biomass, corn stover, and bagasse are somewhat similar in this respect. Emissions from ethanol production from corn are generally higher than the alternatives except for particulate matter and CH_4 from bagasse and N_2O from herbaceous biomass.

Much of the variation associated with farming of biofuel feedstocks results from emissions from the soil. Perennial plants such as switchgrass tend to fix carbon in the soil while annual plants such as corn tend to release carbon as CO_2 from the soil (Wu, Wu & Wang 2005, Andress 2002). Residual agricultural materials such as corn stover would alternatively be left to decompose returning nutrients so that their use requires additional fertilizer inputs with increased N_2O emissions (Wu, Wang & Huo 2006)(Wu, Wang & Huo 2006)(Wu, Wang & Huo 2006).

Crop choice may also be a factor in farming emissions. Direct N_2O emissions from biomass are a result of fertilizer application and nitrogen that is released as above ground biomass decomposes (Huo et al. 2008). Legumes such as soybeans fix nitrogen in the soil although this effect is not considered by IPCC because of the high level of uncertainty concerning the impact on N_2O emissions (Huo et al. 2008). This reduces the need for application of nitrogen fertilizers to legumes, in contrast to other annual crops such as corn, which do not fix nitrogen in the soil. Corn requires fertilizer inputs of 420g per bushel compared to soybeans 62g per bushel. The total nitrogen left in field after harvest for soybean biomass is 200.7g per bushel compared with 141.6g per bushel for corn. In 2006 IPCC estimated that 0.01 kg of N_2O is released into the atmosphere for every kg of elemental nitrogen as direct emissions with a range of from 0.003 to 0.03 (Huo et al. 2008). Indirect N_2O emissions include volatilization and leaching of nitrates in the soil accounting for 0.00325 kg of N_2O for every kg of elemental nitrogen in the soil, again with considerable uncertainty (0.0025-0.075) (Huo et al. 2008).

The production of biofuels results in varying levels of changes in land use. There is considerable uncertainty as to the extent of these changes (Liska, Perrin 2009). Direct emissions occur as a result of conversion of forest or pastureland to farmland, and are relatively straightforward to estimate. Indirect emissions result from economic shifts due to the increased competition for agricultural resources. Although there is evidence of the relationship, such as a correlation between the lower soybean prices and deforestation in Brazil, it has been argued recently that a consensus as to the magnitude of these effects from a sufficiently broad methodological base does not exist (Liska, Perrin 2009). A study that was partially funded by Argonne National Laboratory used an econometric land use modeling approach to address direct CO_2 emissions from conversion of forests and pastureland to farming (Tyner et al. 2010). The study addresses CO_2 emissions from US ethanol production from corn grown on a global scale due to shifts in land use. The study estimates an effect, and demonstrates that the effect is mitigated somewhat when population and yield increases are accounted for. Corn-based ethanol production is shown to have a smaller well-to-wheels GHG footprint than gasoline (Tyner et al. 2010). Corn is used to model ethanol production. The GREET model only addresses soybeans as a feedstock for biodiesel (Argonne National Laboratory 2009)(Argonne National Laboratory 2009)(Argonne National Laboratory 2009).

Process Emissions.

The other factors in the differences among biofuels emissions are displacement or energy savings from co-products or byproducts and emissions from refining the finished fuels. We compare standard fossil fuels modeled in NONROAD with biomass-based alternatives. The GREET model (Argonne National Laboratory 2009) does not include biomass alternatives for CNG or LPG. Alternatives are discussed for gasoline and diesel. Three processes are considered here including ethanol production, biodiesel production, and Fischer-Tropsch synthesis. Ethanol production is accomplished through the biological fermentation of biomass (Wu, Wu & Wang 2005)(Wu, Wu & Wang 2005)(Wu, Wu & Wang 2005).

Biodiesel production involves the removal of oxygen from fats and oils leaving hydrocarbons of the desired size. These may include seed oils, recycled oils, or animal fats, but typically the feedstock for biodiesel is soybean oil in the United States. Two processes are described as standard (Huo et al. 2008). Transesterification is a reaction of triglyceride with ethanol or methanol to produce methyl esters (biodiesel) and glycerin at a weight ratio of roughly 5:1. Hydrotreating includes two subprocesses. Hydrodeoxygenation involves reaction of hydrogen with fatty acids yielding a paraffin and water. Decarboxylation involves extraction of CO_2 using a lead/hydrogen catalyst. The Supercetane process is a hydrotreating technique that occurs in conjunction with hydrocracking so that large molecules are broken apart while oxygen is removed. This process produces 70-80% middle distillates, but also naphtha, and waxes as well as fuel gas for steam but not electricity production (Huo et al. 2008)(Huo et al. 2008)(Huo et al. 2008).

A second hydrotreating process is a reaction of the bio-feedstock with hydrogen and steam to produce biodiesel with propane as a co-product (Huo et al. 2008)(Huo et al. 2008)(Huo et al. 2008). The Fischer-Tropsch (FT) process is addressed extensively in the GREET model (Argonne National Laboratory 2009) which is a testament to its extreme flexibility. The FT process can be applied to natural gas (Wang, Huang 1999)(Wang, Huang 1999)(Wang, Huang 1999), coal, or biomass (Kreutz, Larson & G. Williams 2008). The FT process involves breaking a feedstock down through cracking and partial oxidation to CO and hydrogen gas. The resulting syngas is then cleansed of its acid components i.e. H_2S, CO_2, and COS. The cleansed syngas is then reassembled into larger hydrocarbons, known as syn-crude, which may be refined into its components. Typically a number of components of different weights are produced including diesel, but also naphtha and potentially gasoline (Wu, Wu & Wang 2005).

Although the GREET model (Argonne National Laboratory 2009)(Argonne National Laboratory 2009)(Argonne National Laboratory 2009) addresses fuel pathways separately much of the supporting literature describes coproduction and other emissions savings measures. Ethanol fermentation is combined with production of electricity through steam and natural gas turbines that use syngas, or other fuels produced through the Fischer-Tropsch process (Wu, Wu & Wang 2005). Biodiesel production may also include coproduction of steam or electricity (Huo et al. 2008).

These include FT diesel, FT naphtha, and FT gasoline, the latter of which is not modeled in GREET as it is not economically viable because of the energy intensity of gasoline blending (Wu, Wu & Wang 2005). FT naphtha can be marketed more profitably as a feedstock for petrochemical processes than as a blendstock for gasoline (Kreutz, Larson & G. Williams 2008).

Again, no biofuel alternatives to CNG and LPG are addressed by the GREET model (Argonne National Laboratory 2009). We evaluate ethanol as an additive and as an alternative to gasoline. Because Fischer-Tropsch gasoline is not commercially viable we do not discuss it as an alternative to conventional or reformulated gasoline (Wu, Wu & Wang 2005). Biogasoline is discussed as a co-product or alternative product for biodiesel through hydrocracking, however the authors acknowledge that biogasoline is less ready for market than biodiesel (Huo et al. 2008). The GREET model does not address either of these two alternative gasoline pathways (Argonne National Laboratory 2009). We evaluate biodiesel and Fischer-Tropsch diesel as alternatives to diesel fuel. To evaluate Fischer-Tropsch synthesis we compare upstream emissions associated with Fischer-Tropsch diesel from biomass, natural gas, and coal feedstocks.

Gasoline and Alternatives.

The GREET model (Argonne National Laboratory 2009) addresses conventional and reformulated gasoline, ethanol, and ethanol blends to run in spark ignition engines. The ethanol used in the model was produced from corn through fermentation. Corn was chosen as feedstock because it represents the most likely source for new ethanol use. It is however a worst case scenario for ethanol production minimizing CO_2 sequestration. We compare GHG and black carbon emissions from production of conventional or unblended gasoline with reformulated gasoline, which is a 10% ethanol mixture. In addition we compare an 85% ethanol/gasoline mixture and 100% ethanol, both of which require dedicated engines. We converted the GREET model output from grams per MMBtu to grams per pound of gasoline equivalent on an energy basis. The modeling results are shown in **Error! Reference source not found.**.

Table 20. Upstream Emissions from Gasoline, Ethanol, and Blends.

	Conventional Gasoline g/lb BSFC	Reformulated Gasoline 10% Ethanol Blend g/lb BSFC	85% Ethanol Gasoline mix (Requires Dedicated Engine) g/lb BSFC	100% Ethanol (Requires Dedicated Engine) g/lb BSFC
CO_2 (w/ C in VOC & CO)	326.723	276.288	-192.660	-380.968
CH_4	1.994	1.991	2.021	2.031
N_2O	0.005	0.055	0.567	0.770
$PM_{2.5}$: Total	0.073	0.091	0.287	0.365
Black Carbon	0.010	0.013	0.040	0.051

Sources: Estimated from the GREET Model (Argonne National Laboratory 2009) and converted into g/lb BSFC.
Particulate matter speciation, i.e. Black Carbon is estimated from (Battye, Boyer & Pace 2002).

Ethanol production as shown in **Error! Reference source not found.** has negative upstream CO_2 emissions of roughly the same rate as positive upstream CO_2 emissions from gasoline refining. This means that carbon sequestration and displacement offset all emissions from ethanol production and roughly the same CO_2 emissions that gasoline production produces. Upstream CH_4 emissions increase slightly from substitution of ethanol for conventional gasoline however N_2O and black carbon emissions increase substantially. Upstream N_2O emissions from corn-based ethanol production are 154 times greater than from gasoline production. At nearly one thousandth the mass of CO_2 sequestrated N_2O emissions offset more than 30% of the benefits of CO_2 sequestration due to the higher global warming potential of N_2O. Upstream black carbon emissions from corn-based ethanol are four times higher than emissions from gasoline production. When substituted for conventional gasoline, reformulated gasoline with 10% ethanol reduces upstream CO_2 emissions by 15%, with a modest increases in N_2O and black carbon. The reduction of upstream GHG emissions from an 85% ethanol blend is greater than for reformulated gasoline. Reformulated gasoline is compatible with existing technology, as is the 85% ethanol blend if the vehicles have flex-fuel technology. However use of gasoline fuel in construction equipment is generally a small component limited to smaller engines. GREET models gasoline use in on-road vehicles, where ethanol shows modest improvements in emissions.

Low Sulfur Diesel and Alternatives.

For 2010 the GREET model addresses low sulfur diesel as the baseline diesel fuel. For compatibility with NONROAD, 15 ppm sulfur content was specified instead of the 11 ppm GREET model default. The diesel alternatives considered were 20% biodiesel, low sulfur diesel mix, and FT diesel from natural gas, coal, and biomass feedstocks. DME was considered but unlike the other fuels DME will not work with standard compression ignition technology and showed CO_2 and CH_4 upstream emissions that were higher than low sulfur diesel.. Best case scenarios were modeled for the FT diesel fuels from all three feedstocks including steam or electricity export and CO_2 sequestration in the case of coal. Both the GREET model and the literature (Kreutz, Larson & G. Williams 2008) are clear that upstream emissions from coal production without CO_2 sequestration are prohibitively high. **Error! Reference source not found.** shows upstream emissions for low sulfur diesel and substitutable alternatives.

FT diesel production from biomass feedstock with electricity export sequesters or displaces all three GHGs, massively in the case of CO_2 and produces little black carbon. Independent of its availability it is the most environmentally friendly alternative that will work in standard compression ignition engines. The 20% biodiesel blend had the next lowest upstream CO_2 emissions of the five diesel pathways modeled. Substitution of 20% of the low sulfur diesel with biodiesel reduced upstream emissions by 92%. If we extrapolate CO_2 emissions to 100% biodiesel the upstream emissions would clearly become negative. Biodiesel as modeled with the GREET model produces less CH_4 than low sulfur diesel but more N_2O and black carbon. Upstream GHG emissions of CO_2 and CH_4 from FT diesel are lower than the baseline when coal is the feedstock but higher when the feedstock is natural gas. All FT diesels are sinks for N_2O. As modeled alternative biomass diesel fuels offer the possibility of massive carbon sequestration and displacement of fossil fuels. FT diesel from coal would reduce CO_2 emissions by 59% and significantly lower the GHG impact of diesel fuel production if substituted for low sulfur diesel.

Table 21. Upstream Emissions from Low Sulfur and Alternative Diesel Fuels.

	Baseline Low Sulfur Diesel	20% Biodiesel/Low Sulfur Diesel Mix	FTD Natural Gas Feedstock steam export	FTD Coal Feedstock w/ CO_2 seq. electricity export	FTD Biomass Feedstock elect export
	g/lb BSFC	g/lb BSFC	g/lb BSFC	g/lb BSFC	g/lb BSFC
CO_2 (w/ C in VOC & CO)	287.966	23.657	291.248	117.017	-3542.944
CH_4	1.944	1.730	3.539	4.353	-2.936
N_2O	0.005	0.041	-0.002	-0.002	-0.023
$PM_{2.5}$: Total	0.145	0.491	0.235	0.262	0.013
Black Carbon	0.020	0.069	0.033	0.037	0.002

Sources: Estimated from the GREET Model (Argonne National Laboratory 2009) and converted into g/lb BSFC.
Particulate matter speciation, i.e. Black Carbon is estimated from (Battye, Boyer & Pace 2002).

Procedure for Building GASCAP Dataset

The following procedure was used to develop the database of construction and related equipment modeled in NONROAD (EPA 2008a) by function, fuel and operating cycle, and power rating. Appendix B shows equipment function, power rating, average load, BSFC, and emissions of CO_2, CH_4, N_2O, and black carbon from upstream and direct emissions. The procedure is as follows:

- Non-recreational equipment was identified from a list of NONROAD source classification codes (SCC) (EPA 2005d). The list was purged of equipment types that are strictly speaking specialty functions such as oil drilling, farming, airport activities, and so on.
- A script was written for NMIM which specified for each type of equipment by functional description, fuel cycle, (SCC) and power rating specifying year of manufacture as 2010, number of machines and hours of operation as one assuming the average of all technology types for the year. Distribution of the hour of operation was even across all twelve calendar months.
- NMIM was run at the county level with Middlesex County, NJ specified with fuel assumptions for 2010 and PM_{10}, $PM_{2.5}$, CO, NMOG, CO_2, NH_3, NO_X, and SO_2 as

the pollutants. This produced an error log that included errors for equipment specifications that were not produced in 2010 and winter equipment for which NONROAD has data for December through February only. The seasonal errors were corrected by distributing an hour of production over the three months of data. The errors for non-existent equipment types were ignored as these produced no records.

- NMIM was run with the corrected script for TOG and NMOG. The two databases were consolidated into a single database with TOG and NMOG variables. Evaporative and recycling emissions were consolidated into exhaust records for NMOG. This step does not exclude CH_4 from fugitive emissions because fugitive emissions from gasoline are unaltered hydrocarbons, none of which are CH_4 (EPA 2005a). Output for hourly emissions for all pollutants and equipment types were converted to grams from short tons.
- Direct emissions of CO_2 were calculated as the sum of CO_2 measured by NONROAD and the product of the combined exhaust and fugitive NMOG emissions and the ratio of carbon fraction for unburned fuel (0.87) and the carbon fraction of CO_2 (12/44). Direct emissions of CH_4 were calculated as the difference between TOG and NMOG. Direct emissions of N_2O were calculated as the product of the emission factor (0.0074), the average power rating for the equipment class (EPA 2005d), and the appropriate load factor for the equipment class (EPA 2004b). Direct emissions of black carbon were calculated as the product of $PM_{2.5}$ and the appropriate speciation factor.
- Adjusted BSFC was calculated as the product of the steady state BSFC, the appropriate TAF, and the average power rating for the class. Steady state BSFC, and the appropriate TAF were taken from the tables in Appendix A for spark ignition engines and Appendix B for compression ignition engines. The BSFCs shown express fuel consumption in grams per pound of fuel. All compression ignition engines already on the Tier 4 standards were assigned a TAF of 1.00. This was done with compression ignition engines 75 hp or smaller for 2010 models. See Table 15.
- Upstream emissions rates for standard fuels were taken from **Error! Reference source not found.** above. **Error! Reference source not found.** shows emission factors GHG and black carbon emission factors for standard fuels including CNG, LPG using the 60%/40% GREET model default ratio for natural gas and petroleum feedstock, conventional gasoline with no oxygenate, and low sulfur diesel. Upstream emission rates were converted to grams of emissions per pound of fuel consumed. Upstream emissions per hour are calculated as the product of the NONROAD BSFC and the GREET upstream emission factors.
- Upstream emissions for equipment types manufactured in 2010 are shown in Appendix C. Comparable data for 1988-2010 is included in GASCAP.

GASCAP Dataset Inputs and Outputs

Equipment inputs include equipment type, vintage, power rating, fuel type, and activity, for each equipment piece. Activity is assumed to be the product duration of equipment use in hours and average load taken from the NONROAD model. These inputs may be macro assisted, however GASCAP will allow the user to override default load assumptions and type in different values. We are exploring ways to automate duration assumptions using macros as well. The equipment outputs include upstream, direct, and total emissions for CO_2, CH_4, N_2O, and black carbon.

REVIEW OF MAINTENANCE AND REHABILITATION PROCEDURES FOR ROADWAYS AND BRIDGES

This section presents assumptions made for the GASCAP model about the lifetime maintenance and repair needs of roads and bridges constructed under New Jersey Department of Transportation (NJDOT) authority. These assumptions will provide the basis for estimating greenhouse gas (GHG) emissions attributable to transportation capital projects following construction. The full module has not been implemented in the current version of GASCAP as we identified various data sources that are needed to fully develop this method. This data is currently being analyzed by a group at NJIT and we are unable to obtain this data within the scope of the current project. We document work done prior to this finding in the section that follows.

To the extent possible, both theory and evidence-based defaults were used to estimate the timing of maintenance and rehabilitation for asphalt and concrete pavement and for different types of bridges. Pavement defaults are taken from the New York State Department of Transportation (NYSDOT) *Comprehensive Pavement Design Model* (NYSDOT 2002)()(). Bridge defaults are taken from the Ohio Department of Transportation (ODOT) On-line Bridge Maintenance Manual Preventive Maintenance/Repair Guidelines for Bridges and Culverts (ODOT 2010), which is a website that lists maintenance and repair issues associated with bridges and the cost and expected service life of bridge repairs. New York State roadways are accepted as surrogates for New Jersey Roadways because of similarities in climate. Uncertainties connected with life-cycle cost analysis (LCCA) are greater with bridges than with pavement LCCA is not common practice for timing of maintenance and rehabilitation of bridges. The purpose of the defaults included in this report is to provide baseline defaults so that pavement and bridge engineers can have an easily modifiable basis from which to input lifetime assumptions into the GASCAP tool.

The balance of this report elaborates the baseline assumptions for the expected lifetime, and maintenance and rehabilitation inputs of a facility over that lifetime. It begins with a review of the literature for LCCA discussing the data requirements, applicability and appropriateness for the GASCAP tool. The following section identifies maintenance and rehabilitation activities that will be included in the life time analysis feature of the GASCAP tool for roadways and bridges. Another section will present the structure of the life time emissions component of the GASCAP tool and a list of repair activities for roadways and bridges. It should be emphasized that maintenance and rehabilitation activities contribute extensively to the service life of a facility. However, this first version of the GASCAP tool will not be capable of adjusting the service life for maintenance and rehabilitation activities.

Prediction of Optimum Timing of Maintenance and Rehabilitation Activities

Economic analysis of life time costs are used as a means of rationalizing the decision-making process between alternative pavement and bridge designs. The life cycles of bridges and roads are quantified using LCCA. In general, these analyses compare costs over the lifetime of a facility from construction or reconstruction to reconstruction or demolition. Costs included are those associated with design, planning, construction, maintenance, rehabilitation and use for both pavement and bridges (Hawk 2003). For completeness, these costs are offset by salvage value, although the offset is minor. Because of the long planned service life of most of these facilities uncertainty associated with future costs of maintenance, rehabilitation, and costs to users, care is needed in interpreting results. One result of this seems to be that analysis of this type is more broadly accepted for pavement planning than bridge planning perhaps due to the longer service lives of bridges.

These analyses are decision-making tools and as such are only for use as a part of the decision-making process. The history of the development of LCCA is outlined in thumbnail in a report to the Federal Highway Administration (Walls III, Smith 1998) and echoed in a report to NJDOT (Ozbay et al. 2003). The concept was outlined by the American Association of State Highway Officials (AASHTO) in 1960, although it was acknowledged that the information base to apply it with acceptable comprehensiveness and reliability did not exist at the time (Ozbay et al. 2003)(Ozbay et al. 2003)(Ozbay et al. 2003). In 1984 the National Cooperative Highway Research Program (NCHRP) and AASHTO reviewed and encouraged the use of LCCA as an economically-based decision support tool (Ozbay et al. 2003). However, it was not until 1991 under the Intermodal Surface Transportation Efficiency Act (ISTEA) that estimation of life cycle costs was required as part of the design and engineering of bridges, tunnels, and pavement projects for metropolitan and state transportation planning (Walls III, Smith 1998, Ozbay et al. 2003). In 1995 the National Highway System (NHS) Designation Act mandated LCCA for NHS projects valued at over $25 million. However, the regulations were relaxed in 1998 under the Transportation Equity Act for the 21st Century (TEA-21) when the mandate to conduct LCCA on NHS projects over $25 million was eliminated (Walls III, Smith 1998, Ozbay et al. 2003). TEA-21 left LCCA a voluntary but recommended component of transportation planning. FWHA policy emphasizes that LCCA is a tool that supports decision-making but the results should not be confused with the expert decisions of engineers (Walls III, Smith 1998, Ozbay et al. 2003).

LCCA is the method of generating lifetime maintenance and rehabilitation plans described in the proposal for the Carbon Footprint Project. The proposal calls for assessment of the longevity of construction materials and carbon emissions associated with different maintenance protocols. Plans also call for use of estimates of vehicle volume to estimate the wear to the facility. LCCA, however, is not feasible at this time because of a lack of available data and historical information about deterioration and maintenance practices at NJDOT. It is also clear that LCCA is not standard practice for maintenance and rehabilitation planning for bridges (Markow, Hyman 2009).

The New York State Department of Transportation (NYSDOT) has produced detailed default expected life expectancy for preventive and remedial maintenance and rehabilitation of pavement. These defaults are used to assemble a default schedule for roadways with asphalt or concrete pavement for inclusion in the GASCAP tool. For bridges the default maintenance and rehabilitation schedule is limited to indentifying the inputs and suggesting a probable sequence of maintenance events, without considering the timing of activities. Maintenance and rehabilitation plans are included as defaults but we intend to build in substantial flexibility to allow GASCAP users to plan maintenance and rehabilitation based on their expertise.

It bares emphasis that LCCA analyses are not generally accepted as a stand-alone basis for decision making among project alternatives. LCCA approaches are useful as a basis for estimating maintenance and rehabilitation inputs because those inputs must be specified as the basis for estimating cost. We classify GHG emissions from maintenance and rehabilitation as downstream emissions, despite the virtual certainty that they will be attributable to NJDOT or its agents, because these emissions are unrealized at the point of construction.

Although LCCA is beyond the scope of what is feasible for the Carbon Footprint analysis, it provides a basis for evaluating alternative approaches to the timing of maintenance and rehabilitation of roadways and bridges. LCCA is economic analysis that compares the costs of alternative pavement and bridge designs, with future costs adjusted with a discount rate to account for opportunity costs. LCCA allows selection of an economically most efficient project.

How LCCA Works

LCCA is a generalized method of estimating discounted present and future costs of constructing, rehabilitating and maintaining that is applied to transportation facilities. It is a response to a perceived need to rationalize the timing of preventive maintenance and rehabilitation (Walls III, Smith 1998). It is assumed that alternatives have the following known or assumed attributes: an expected design life, periodic maintenance treatments to meet that design life, and a set of rehabilitation activities (Walls III, Smith 1998). Design life refers to the time between construction and the end of serviceable life of a design alternative. It is the period of time during which the alternative design can be expected to deteriorate to the point that it is no longer useable or in other words, the point at which it reaches terminal serviceability. LCCA involves comparison of alternative project facility designs over a fixed analysis period. The analysis period should be long enough to reflect differences among design alternatives and should be long enough to accommodate at least one rehabilitation. FWHA guidance recommends a minimum analysis period for pavement of at least 35 years (Walls III, Smith 1998). Analysis periods shorter than 35 years are not discouraged if all alternatives reach terminal serviceability in less than 35 years. Analysis periods for bridges are generally much longer (Hawk 2003). The New Jersey Guidance suggests analysis periods of 25 to 40 years for new pavement, 5 – 15 years for pavement rehabilitation and 75 years or more for bridges, tunnels, and hydraulic systems (Ozbay et al. 2003).

The life cycle cost (LCC) is the net present value of all costs (NPVC) associated with a transportation facility (Ozbay et al. 2003). These costs may be one-time costs such as the construction itself or rehabilitation costs if there is one rehabilitation included in the planned service life of an alternative. There may also be recurring costs such as routine maintenance and rehabilitation at fixed n year intervals (Hawk 2003, Ozbay et al. 2003).

Generally this is expressed

$$NPVC = {}^{T}\sum_{t=0} C_t * (1 + d)^{-t}$$

where C_t is the non-recurring cost of a transportation project in year t and d is the discount rate. Costs that recur at regular intervals are useful in LCCA if the costs are common to all of the alternatives (Ozbay et al. 2003). The purpose of LCCA is to achieve long term economic efficiency in the comparison of alternative investments on a cost minimizing basis (Walls III, Smith 1998).

For bridges and pavements, the LCC is given by the following equation (Hawk 2003):

$$LCC = DC + CC + MC + RC + UC + SV$$

where DC is the design cost; CC is the construction cost; RC is the rehabilitation cost; MC is the maintenance cost; UC is the user cost; and SV is the salvage value of the project. Design and construction costs generally occur before the beginning of the service life of a facility and are in year 0 and therefore are not discounted. Rehabilitation and maintenance costs occur between year 1 and year T – 1 and are discounted. These costs are stated under the assumption that treatments are timely as the cost-effectiveness of most treatments may be severely reduced when applied as an emergency measure on a deteriorated facility (Peshkin, Hoerner & Zimmerman 2004)(Peshkin, Hoerner & Zimmerman 2004)(Peshkin, Hoerner & Zimmerman 2004). User costs are generally complicated and difficult to assess. These include operating costs such as tolls, crash costs and delay costs (time) due to normal operations as facilities deteriorate, and also due to traffic restrictions that arise from repairs (Walls III, Smith 1998). User costs are generally not straightforward to calculate, and are often excluded from the analysis in practice (Ozbay et al. 2003). Their exclusion results in an LCC based solely on costs to the department of transportation. Salvage value is the value of the project at the end of its service life expressed as a negative cost that occurs in year T (Walls III, Smith 1998). On this basis the equation above may be rewritten as

$$LCC = DC + CC + {}^{T}\sum_{t=0} ((MC_t + RC_t) * (1 + d)^{-t}) + SV * (1 + d)^{-T}$$

LCC computation is data intensive and subject to high uncertainty. The uncertainty factor is a result of predicting input parameters far into the future. The New Jersey guidance (Ozbay et al. 2003) recommends sensitivity testing for the discount rate, timing of rehabilitation activities, traffic growth rates, costs associated with construction inputs, and the length of the analysis period. Fluctuation in construction inputs will affect maintenance and rehabilitation costs. Monte Carlo testing is widely recommended as a means to reduce risks from errors by presenting results as probabilities rather than as certainties as would be implied by the use of data points (Hawk 2003, Walls III, Smith 1998, Ozbay et al. 2003).

LCCA Procedure for Pavement

The New York State Comprehensive Pavement Design Manual (NYSDOT 2002) section on LCCA defines department costs as those necessary to provide serviceable pavement over a selected analysis period including current treatment costs, costs, timing, and service lives of future maintenance and rehabilitation activities, the time value of money i.e. the discount rate and the salvage value. Budgetary constraints, non-pavement construction needs, and heavy traffic volumes are also mentioned as considerations in selection of a pavement alternative. The LCCA procedure is made up of the following steps as described in the New Jersey Guidance (Ozbay et al. 2003):

1. Define the project's alternatives.
2. Choose a probabilistic or deterministic approach.
3. Choose the general economic parameters including the discount rate and analysis period.
4. Establish an expenditure stream for each alternative.
5. Compute the NPV for each alternative.
6. Compare and interpret the results and conduct sensitivity analysis.
7. Reevaluate the design strategy if needed.

The New York State Comprehensive Pavement Design Manual (NYSDOT 2002) includes the same steps except step 2. NYSDOT like many other state transportation agencies (Ozbay et al. 2003) uses a deterministic approach, which is less data intensive because it does not include Monte Carlo testing procedures. The first step is to identify alternatives including all appropriate initial alternatives (NYSDOT 2002). Alternatives are based on inspection of facilities to identify distress types and severity, and conditions for use data associated with each treatment based on historical data for New York State. The analysis period should be long enough for one or two rehabilitation treatments and several preventive maintenance treatments. The analysis period should at a minimum cover the maximum expected service life of the initial construction and one rehabilitation treatment. The example presented used a 30 year analysis period for the alternatives considered. A discount rate of four percent is used. Rehabilitation and maintenance treatments are incorporated using the Preliminary Estimating Program (PEP) with regional data within New York State. Sensitivity analysis is performed on treatment service lives, treatment timing, future treatment strategies, and item costs, but not the discount rate.

The procedure described above results in plausible assumptions regarding the service life of rehabilitation and maintenance treatments described below. These estimates are stated as single values, not probabilities. It is not possible through the Carbon Footprint Project whether these values are reliably applicable to New Jersey. Neither is it possible to address the extent that any maintenance or rehabilitation treatment would extend the service life of a roadway in New Jersey with any validity. However, these treatments will make it possible to specify default maintenance and rehabilitation plans for the GASCAP spreadsheet. It is expected that design engineers at NJDOT will be able to use these defaults as a basis for lifetime maintenance and rehabilitation based on their own expertise.

LCCA Procedure for Bridges

LCCA procedures for bridges have greater uncertainty that arises from the longer service lives of bridges. This problem was recognized in NCHRP documentation for a plan to develop LCCA software for bridges in 2003 (Hawk 2003), when it was stated that bridges as a general rule have perpetual service lives. Six years later another NCHRP report (Markow, Hyman 2009) reviewed bridge management practices in the United States and Canada. Based on survey data, most state DOTs use of bridge management system data is for current or near term analysis of bridge condition rather than long term analysis of economic costs.

Standard practice for bridges involves needs assessment based on biennial bridge inspections (Markow, Hyman 2009). The GASCAP spreadsheet will assume this and offer a 75 year default analysis period with biennial inspections which users will be able to supplement with maintenance and rehabilitation treatments based on their expertise.

GASCAP Approach to Lifetime Maintenance and Rehabilitation

The GASCAP tool will allow users to fill in an optional timeline for anticipated maintenance and rehabilitation of newly constructed or reconstructed roadways and bridges. Users will be asked to specify if they want to include a lifetime maintenance and rehabilitation plan, and if so the type of roadway or bridge and what the expected service life of the facility is. More detailed information will be required from the user on the timing and maintenance activities expected to be undertaken. The GASCAP tool will provide a simple framework for entering this information. We hope that after further consultations with NJDOT staff, we may be able to suggest some default maintenance plans. We are also planning meetings with staff at CAIT and NJIT who may be able to provide information or data on maintenance activities. The balance of this section lists maintenance and rehabilitation inputs that will be addressed by GASCAP.
The emissions factors for the materials used in these treatments are readily calculated from the materials page in GASCAP; any emissions factors from the maintenance equipment emissions can also be calculated. The inputs needed by the user will be similar to other components of GASCAP, such as volume of material and hours of equipment use (much of which can be derived from associated bid sheets). The critical difference in how we deal with these items is that the user determines a lifetime maintenance schedule as part of the construction process, although we intend to report the results both in a combined and disaggregated format.

Maintenance and Rehabilitation of Roadways

For roadways and other structures, maintenance and rehabilitation are processes by which remedial steps are taken to counteract wear and distress due to weather, climate and traffic. This section briefly discusses the remedial steps taken to remedy the various types of deterioration for roadways. GASCAP users will be able to select these steps from a menu. Roadway treatments are taken from the NYSDOT Comprehensive Pavement Design Manual (NYSDOT 2002)(NYSDOT 2002)(NYSDOT 2002).

Rigid Pavement Preventive Maintenance

Joint and Crack Filling. This procedure involves cleaning and filling longitudinal and transverse joints, slab cracks, and the pavement/shoulder joint. Expected service life is two years.

Joint and Crack Sealing. This procedure involves cleaning and sealing longitudinal and transverse joints, routing cleaning and sealing slab cracks, and cleaning and filling the pavement/shoulder joint. Expected service life is eight years.

Joint and Crack Sealing with Spall Repair. In this procedure spalls[9] are milled and patched with rapid-setting concrete patching materials. Longitudinal and transverse joints are cleaned and sealed. Slab cracks are routed, cleaned and sealed. The pavement/shoulder joint is cleaned and filled. (See flexible shoulder treatments.) Expected service life is eight years for joint and crack repairs and ten years for spall repair.

Rigid Pavement Corrective Maintenance

Joint and Crack Sealing with Spall Repair and Grinding. In this procedure spalls are milled and patched and joints and cracks are addressed as with joint and crack sealing with spall repair. In addition, rough areas in the concrete are ground. Expected service life is eight years for the joint and crack repairs, ten years for spall repair, and five years for the ground areas.

Joint and Crack Sealing with Spall Repair, Grinding, and Full-Depth Segment Replacement. In this procedure rough areas are ground, spalls are milled and patched and joints and cracks are addressed as with joint and crack sealing with spall repair, and grinding. In addition, one or more of the Portland concrete segments is replaced. Expected service life is eight years for joint and crack repairs, ten years for spall repair, and five years for grinding. Full-depth replacement segments are expected to equal or exceed the remaining life of the existing rigid pavement for as long as thirty years.

[9] Spalling is a process by which chips or flakes are removed from concrete.

Rigid Pavement Rehabilitation

Joint and Crack Sealing with Spall Repair and Full-Depth Segment Replacement. In this procedure spalls are milled and patched and joints and cracks are addressed as with joint and crack sealing with spall repair. In addition, one or more of the original Portland concrete segments is replaced. Expected service life is eight years for joint and crack repairs, and ten years for spall repair. Full-depth replacement segments are expected to equal or exceed the remaining life of the existing rigid pavement for as long as thirty years.

Bonded Concrete Overlay. Under this procedure pavement is scarified[10] to a depth of 0.25 in. by sandblasting, after spalls are milled out. The pavement is cleaned and a 3" Portland concrete bonded overlay is applied. When hard the overlay is sawed and sealed over the existing joints. Asphalt or Portland concrete may be used for the shoulder. Expected service life is 20 years. Required maintenance includes joint and crack resealing every eight years.

Sawed and Sealed Asphalt Concrete Overlay 3". Under this procedure there may be partial full-depth replacement of segments with Portland concrete or asphalt concrete. Spalls are milled and patched with rapid-setting Portland concrete or asphalt concrete. Joints and cracks including the pavement/shoulder joint are cleaned and filled. Faults and wheel ruts are shimmed[11] and the pavement is cleaned. A tack coat is applied to the surface. Asphalt concrete is applied to level the surface followed by two 1.5" lifts that include a binder and surface layers. The rehabilitated pavement is sawed and sealed over the existing transverse joints. Expected service life is 15 years for the 3" asphalt overlay with full length transverse crack sealing every five years as required maintenance. The expected service life for the sawed and sealed joints is eight years. Full depth asphalt concrete repairs will require bump milling every five years. Full depth Portland concrete repairs have an expected service life of 30 years.

Sawed and Sealed Asphalt Concrete Overlay 4". Under this procedure there may be partial full-depth segment replacement of segments with Portland concrete or asphalt concrete. Spalls are milled and patched with rapid-setting Portland concrete or asphalt concrete. Joints and cracks including the pavement/shoulder joint are cleaned and filled. Faults and wheel ruts are shimmed and the pavement is cleaned. A tack coat is applied to the surface. Asphalt concrete is applied to level the surface followed by three lifts. These include a 1.0" first course followed by a 1.5" intermediate course and a 1.5" surface course. Expected service life is 15 years for the 3" asphalt overlay with full length transverse crack sealing every five years as required maintenance. The expected service life for the sawed and sealed joints is eight years. Full depth asphalt concrete repairs will require bump milling every five years. Full depth Portland concrete repairs have an expected service life of 30 years.

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[10] Milled.

[11] Shimming in this context refers to filling faults and wheel ruts to even out the pavement before an overlay is applied.

Asphalt Concrete Overlay (5") Preceded by Cracking and Seating. Under this procedure there may be partial full-depth segment replacement of segments with Portland concrete or asphalt concrete. Non-replaced pavement is stabilized by cracking and seating. Spalls are milled and patched with asphalt concrete. Joints, including the pavement/shoulder joint and cracks are cleaned and filled. Faults and wheel ruts are shimmed. The pavement is cleaned and a tack coat is applied. The surface is then trued and leveled with asphalt concrete. Asphalt concrete is applied to level the surface followed by three lifts. Asphalt concrete is applied to level the surface followed by three lifts. These include a 2.0" initial course followed by a 1.5" intermediate course and a 1.5" surface course. The expected service life of the asphalt overlay is 15 years with required maintenance including full-length sealing of transverse cracks every five years. The service life for full depth repairs is 15 years for asphalt concrete and 30 years for Portland concrete.

Asphalt Concrete Overlay (6") Preceded by Rubblizing. This procedure begins with installation of an edge drain consisting of a "daylighted" crushed stone shoulder. Asphalt patches and overlays are removed, rubblized, and compacted. Depressions are patched with crushed stone. Asphalt concrete is applied to level the surface followed by three lifts. These include a 3.0" base course followed by a 1.5" intermediate course and a 1.5" surface course. No full-depth replacement or spall repair is required. The expected service life is 15 years with required maintenance including full-length sealing of transverse cracks every five years.

Rigid Pavement Reconstruction

Full-Depth Portland Cement or Asphalt Concrete. This procedure includes full removal and replacement of pavement. The service life for full reconstruction is 15 years if the replacement material is asphalt concrete and 30 years if replacement is done with Portland concrete.

Flexible Pavement Preventive Maintenance

Crack Sealing. Under this procedure transverse cracks are routed, cleaned and sealed. Pavement/shoulder joints are cleaned and filled. The expected service life is five years.

Crack Filling. Under this procedure cracks and the pavement/shoulder joint are cleaned and filled. The expected service life is two years.

Single-Course Overlay (1" to 1.5"). For this procedure cracks and the pavement/shoulder joint are cleaned and filled and the pavement is cleaned. A tack coat is applied before an asphalt concrete top course between 1" and 1.5" in depth. The expected service life is eight years. Maintenance consists of full-width transverse crack sealing after the first year and every five years thereafter, and filling of other cracks every two years starting after the second year.

Flexible Pavement Corrective Maintenance

Single-Course Overlay (1" to 1.5"). For this procedure severe cracks are milled and patched with asphalt concrete. Pavement/shoulder joints are cleaned and filled and wheel ruts are shimmed. The pavement is cleaned and a tack coat is applied. The pavement is trued and leveled with asphalt concrete and a surface course is applied between 1" and 1.5". The expected service life is eight years. Maintenance consists of full-width transverse crack sealing after the first year and every five years thereafter, and filling of other cracks every two years starting after the second year.

Hot In-Place Recycle (1" to 1.5"). The pavement is milled to a depth of 1" to 1.5". A tack coat is applied before a surface course consisting of the recycled material is applied as hot mix asphalt concrete between 1" and 1.5". The expected service life is eight years. Maintenance consists of full-width transverse crack sealing after the first year and every five years thereafter, and filling of other cracks every two years starting after the second year.

Cold Milling and Replacement (1" to 1.5"). The pavement is cold milled to a depth of 1" to 1.5". Severe cracks and raveled[12] or stripped areas are patched with asphalt concrete. A tack coat is applied before a surface course of asphalt concrete between 1" and 1.5" is applied. The expected service life is eight years. Maintenance consists of full-width transverse crack sealing after the first year and every five years thereafter, and filling of other cracks every two years starting after the second year.

Flexible Pavement Rehabilitation

Two-Course Overlay (3"). Severe cracks are milled and patched with asphalt concrete and cracks and the pavement/shoulder joint are filled. Wheel ruts are shimmed. The pavement is cleaned and a tack coat is applied. A truing and leveling course is applied followed by a 1.5" intermediate course and a 1.5" binding course. The expected service life is 15 years. Maintenance consists of full-width transverse crack sealing every five years, and filling of other cracks every two years.

Cold Milling with Single-Course Overlay (3"). The pavement is cold milled to a depth of at least 1.5". Severe cracks and raveled or stripped areas are milled and patched. A tack coat is applied followed by a course of asphalt concrete of at least 1.5". A surface course of asphalt concrete is then applied to a depth of 1.5". The milled material is transported to the dump or to a recycling facility. The expected service life is 15 years. Maintenance consists of full-width transverse crack sealing every five years, and filling of other cracks every two years.

Hot In-Place Recycle with Single-Course Overlay (3"). The pavement is milled to a depth of 1.5". A tack coat is applied before an intermediate course consisting of the recycled material is applied as hot mix asphalt concrete to a depth of 1.5". A surface course is applied to a depth of 1.5". The expected service life is 15 years. Maintenance

[12] Raveling refers to loss of aggregate due to deterioration of the binding material.

consists of full-width transverse crack sealing every five years, and filling of other cracks every two years.

Cold In-Place Recycle with Single-Course Overlay (4.5”). The pavement is milled and recycled to a depth of 3”, mixed as warm mix asphalt concrete and reapplied to a depth of 3”. An asphalt concrete top course is applied to a depth of 1.5”. The expected service life is 15 years. Maintenance consists of full-width transverse crack sealing every five years, and filling of other cracks every two years.

Multiple-Course Overlay (≥4”). Under this procedure severe cracks are milled and patched and pavement/shoulder cracks are cleaned and filled with asphalt concrete. Wheel ruts are shimmed. The pavement is cleaned and a tack coat and truing and leveling course are applied. An asphalt concrete strengthening course from 1” to 4” is applied, followed by a 1.5” intermediary course. The surface course is applied to a depth of 1.5”. The expected service life is 15 years. Maintenance consists of full-width transverse crack sealing every five years, and filling of other cracks every two years.

Cold Milling with Multiple-Course Overlay (≥4”). The existing pavement is milled to a depth of at least 1”. Raveled and stripped areas are patched with asphalt concrete and a tack coat is applied. An inlay or strengthening course at least 1” in depth is applied. Multiple lifts are needed if this course is greater than 4” in depth. An intermediate course of 1.5” is applied followed by a 1.5” surface course. The expected service life is 15 years. Maintenance consists of full-width transverse crack sealing every five years, and filling of other cracks every two years.

Cold In-Place Recycle with Multiple-Course Overlay (6”). The pavement is milled and recycled to a depth of 3”, mixed as warm mix asphalt concrete and reapplied to a depth of 3”. A tack coat and a truing and leveling course are applied. An asphalt concrete intermediary course and a top course are applied, both to a depth of 1.5”. The expected service life is 15 years. Maintenance consists of full-width transverse crack sealing every five years, and filling of other cracks every two years.

Flexible Pavement Reconstruction

Asphalt Concrete Pavement Construction above Existing Grade. This procedure involves scarification of the existing pavement and shoulder, construction and compaction of new fill and sub-base, and construction of new pavement and shoulder. This process can only be used where it is acceptable to raise the surface of the new pavement at least 12” above the surface of the old. The expected service life is 15 years. Maintenance consists of full-width transverse crack sealing every five years.

Full-Depth Portland or Asphalt Concrete. This procedure includes full removal and replacement of pavement. The service life for full reconstruction is 15 years if the replacement material is asphalt concrete and 30 years if replacement is done with Portland concrete.

Flexible-over-Rigid Pavement Preventive Maintenance

Joint and/or Crack Sealing. This procedure requires that transverse joints and full-width transverse cracks be routed[13], cleaned and sealed. Cracks in the pavement/shoulder joint are cleaned and filled. The expected service life of this procedure is five years.

Joint and/or Crack Filling. Transverse joints and cracks, and the pavement/shoulder joint are cleaned and sealed. The expected service life is two years.

Single-Course Overlay (1" to 1.5"). See flexible pavement above.

Flexible-over-Rigid Pavement Corrective Maintenance

Mill and Patch Joints and/or Cracks. Severe cracks are patched. A tack coat is applied to the horizontal and vertical faces and asphalt concrete patches are applied. The expected service life is five years.

Single-Course Overlay (1" to 1.5"). See flexible pavement above.

Hot In-Place Recycle (1" to 1.5"). See flexible pavement above.

Cold Milling and Replacement (1" to 1.5"). See flexible pavement above.

Flexible-over-Rigid Rehabilitation

Two-Course Overlay (3"). See flexible pavement above.

Cold Milling with Single-Course Overlay (≥3"). See flexible pavement above.

Hot In-Place Recycle with Single-Course Overlay (3"). See flexible pavement above.

Cold In-Place Recycle with Single-Course Overlay (4.5"). See flexible pavement above.

Multiple-Course Overlay (≥4"). See flexible pavement above.

Cold Milling with Multiple-Course Overlay (≥4"). See flexible pavement above.

Cold In-Place Recycle with Multiple-Course Overlay (6"). See flexible pavement above.

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[13] Routing in this context refers to removal of material from a crack with a router to improve adhesion of filling material.

Remove Flexible Overlay, Crack and Seat with Multiple-Course Overlay (5”). This procedure requires that the existing asphalt concrete overlay be removed. The underlying Portland concrete pavement is cracked and seated. Spalls are milled and patched with asphalt concrete. Joints and cracks are cleaned and filled and faults and wheel ruts are shimmed. After cleaning a tack coat is applied to the pavement, followed by a truing and leveling course. Three courses of asphalt concrete are applied. The initial course is applied to a depth of 2” and the intermediate and surface courses are applied to a depth of 1.5” each. The service life of this procedure is 15 years with full-width transverse crack sealing every five years.

Remove Flexible Overlay, Rubblize with Multiple-Course Overlay (6”). This procedure requires that the existing asphalt concrete overlay be removed. An underdrain is installed in the shoulder or the existing shoulder may be replaced with a daylighted crushed stone shoulder. [14] The underlying Portland concrete pavement is rubblized[15] and compacted. Depressions are patched with crushed stone. Three courses of asphalt concrete are applied. The initial course is applied to a depth of 3” and the intermediate and surface courses are applied to a depth of 1.5” each. The service life of this procedure is 15 years with full-width transverse crack sealing every five years.

Flexible-over-Rigid Reconstruction

Full-Depth Portland cement or Asphalt Concrete. This procedure includes full removal and replacement of pavement. The service life for full reconstruction is 15 years if the replacement material is asphalt concrete and 30 years if replacement is done with Portland concrete.

Rigid or Flexible-over-Rigid Pavement Widening

Portland Cement Concrete. This procedure involves the excavation and removal of the existing shoulder, widening of the embankment and sub-base, and replacement and compaction of the new and disturbed sub-base. Holes are drilled and longitudinal joint ties are installed. Transverse load-transfer devices are placed. The Portland concrete is placed. Longitudinal and transverse joints are constructed, as is the new shoulder. The expected service life of the widened portion of the road is up to 30 years, and should equal or exceed the service life of the original part of the road. Joint sealing is required every eight years.

Flexible or Flexible-over-Rigid Pavement Widening

Asphalt Concrete. This procedure involves the excavation and removal of the existing shoulder, widening of the embankment and sub-base, and replacement and compaction

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[14] A daylighted crushed stone shoulder uses crushed stone to channel water away from the roadway, preferably to an open place, i.e. daylight, where the water will not be able to accumulate.
[15] Rubblization is a process by which concrete is broken up for use as aggregate.

of the new and disturbed sub-base. A tack coat is applied to the edge of the existing pavement. Asphalt concrete is placed and compacted and a longitudinal joint is routed and sealed. A new shoulder is constructed. The expected service life of the widened portion of the road is 15 years. Full width transverse crack sealing is required every five years.

Flexible Shoulder Preventive Maintenance

Pavement/Shoulder Joint and/or Crack Filling. This procedure involves cleaning and filling cracks and the pavement/shoulder joint. The expected service life is two years.

Surface Treatment. The shoulder is cleaned and a single surface treatment is applied. The expected service life is five years.

Flexible Shoulder Corrective Maintenance

Asphalt Concrete Wedging. The shoulder is cleaned and a tack coat is applied. A wedge is created through the application of asphalt concrete adjacent to the pavement. The expected service life is three years.

Surface Treatment. The shoulder is cleaned and a single surface treatment is applied. The expected service life is five years.

Flexible Shoulder Rehabilitation

Single or Multiple-Course Asphalt Overlay. The shoulder is cleaned and a tack coat is applied. A single or multiple course overlay of asphalt concrete is applied. A single course overlay has an expected service life of eight years. A multiple course overlay has an expected service life of 15 years.

Flexible Shoulder Reconstruction. Replacement may be with Portland concrete, asphalt concrete or bituminous-stabilized gravel with an asphalt concrete top course. The taper for a Portland concrete reconstruction is from 9” to 6”. For asphalt concrete reconstruction the shoulder is either 3” or 4”. For a bituminous-stabilized gravel reconstruction the bituminous-stabilized gravel is 3” and the top asphalt concrete course is 1”. A Portland concrete shoulder has an expected service life of 30 years, while an asphalt concrete or bituminous-stabilized gravel with asphalt top course each has 15-year expected service lives.

Maintenance and Rehabilitation of Bridges

Bridges consist of the structural members, structural decks, and wearing courses that support vehicular traffic, as well as curbs, sidewalks, railings and fencing and utility pipes, conduits, lighting equipment and traffic signal hardware (AASHTO 2007). This section takes inputs from the On-line Bridge Maintenance Manual Preventive

Maintenance/Repair Guidelines for Bridges and Culverts (ODOT 2010), referred to as the Ohio guidance throughout the rest of this section. Maintenance and repair of bridges is significantly more complex than for road surfaces. We summarize various basic and common repairs as reported in the Ohio guidance; however, this can vary by specific circumstances. The Ohio guidance estimates costs for repairs in current dollars. We have included these values, however, we must also caution that the costs and expected service life estimates for the repairs listed here are based on data collected by ODOT, which may not be valid for New Jersey. We anticipate that the translation of this information into the GASCAP tool will require a more flexible approach rather than a complete menu of options. We hope that our upcoming meetings with NJDOT maintenance engineers will allow us to refine the bridge maintenance procedures.

Abutments

Abutments provide structural support of bridge ends, bearing devices and backwalks. They are generally made of concrete. The seats are the flat parts of abutments that support the bearing devices. They are the most vulnerable part of these structures to deterioration from moisture and debris buildup. Wall type abutments support the structure from the stream bed. Stub abutments are shorter than the wall type and are built from the bank rather than the stream bed. Piles are normally driven to support stub abutments. Both structures have exposed seats. Routine maintenance includes power washing every year to remove salt and other deicing compounds and sealing the seats and adjacent parts of the faces every five years with silane/siloxane[16] or every 15 years with epoxy/urethane[17]. Integral and semi-integral abutments encase the beam ends. Because these do not have exposed seats the need for preventive maintenance is greatly reduced. Integral abutments totally encase the beam ends which are connected with reinforcing steel. Semi-integral abutments are separated in the upper part from the expansion material.

For stub type abutments leaning/tilting may be addressed by converting the abutment to integral abutments or replacement. The conversion repair is at a cost of $25,000 for each stub type abutment and has a serviceable life of 15 years. Replacement is at a cost of $50,000 for each stub type abutment. This repair has a serviceable life of 40 years. Settlement may be addressed by shimming with concrete, conversion to integral, or replacement. Raising the seat by shimming or with concrete is at a cost of $10,000 for each abutment and has a serviceable life of 15 years. Conversion to integral is at a cost of $20,000 for each stub type abutment. The repair has a serviceable life of 15 years. Replacement is at a cost of $50,000 for each stub type abutment. This repair has a serviceable life of 40 years. Concrete Deterioration is addressed by sealing of expansion joints and removal and patching of deteriorated concrete. Sealing of expansion joints costs approximately $150 per linear foot and has a service life of 15 years. Removal and patching of concrete is at a cost of $45 per square foot and has a service life of 15 years.

[16] Commonly used commercially available concrete sealer.
[17] Commonly used commercially available concrete sealer.

For wall abutments leaning may be addressed by tree cutting on the embankment at a cost of $500 per linear foot, Underpinning with concrete at a cost of $200 per linear foot, or replacement at $800 per linear foot. Service lives for these repairs are 10 years for tree removal, 15 years for underpinning, and 40 years for replacement. For exposed footers, if the abutment is not sitting on piling, underpin[18] with concrete. In any case armor the footer with rock. With concrete underpinning the cost for this repair is $200 per foot, otherwise the cost is $20 per foot. In either case the expected service life of the repair is 15 years. For vertical cracking if the crack is wider than 3/8 inch fill with mortar or quick setting epoxy at a cost of $35 per linear foot. If the crack is less than 3/8 inch wide inject epoxy at a cost of $20 per linear foot. In either case the expected service life of the repair is 20 years. For deteriorated concrete repairs include sealing leaking joints, diverting scuppers, removing and patching unsound concrete at an overall cost of $45 per linear foot. The service life of these repairs is 20 years.

For integral/semi-integral abutments if the crack is wider than 1/4 inch fill with mortar or quick setting epoxy at a cost of $35 per linear foot. If the crack is less than 1/4 inch wide inject epoxy at a cost of $20 per linear foot. In either case the expected service life of the repair is 30 years. For concrete deterioration repairs include placement of underdrains at $100 per linear foot and removal and patching of concrete at $45 per square foot. Underdrains have a serviceable life of 20 years and concrete patching has an expected serviceable life of 15 years.

Approach Slabs

Approach slabs are the structures that connect the bridge to the roadway. They are generally built on disturbed earth that has been removed to place the backwall and abutments and are prone to settlement. Settlement is a problem because without a smooth transition from roadway to the bridge the bridge is susceptible to damage from impact, especially from heavy trucks. Preventive maintenance includes sealing the joint between the backwall and the approach slab with rubberized asphalt, and exclusion of groundhogs from the area.

Scaling repairs may include sealing with silane at a cost of $2 per square foot, which has a serviceable life of five years or overlay with epoxy/sand slurry at a cost of $40 per SY, which has a serviceable life of ten years. Cracking repairs may include filling with epoxy and undersealing[19] at a cost of $5 per linear foot, which has an expected serviceable life of 15 years or replacement of the approach slab at $60 per SY, which has an expected serviceable life of 30 years. Potholes may be repaired by saw cutting and replacing with quick setting concrete at a cost of $15 per SY with an expected service life of 10 years or filled with asphalt concrete at a cost of $2 per square yard and an expected service life of five years. Settlement may be addressed with an asphalt

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[18] Underpinning in this context means that concrete is added to an unstable footer to anchor it and provide stability.
[19] Undersealing is a procedure whereby voids under approach slabs are filled by injection of grout through holes drilled for that purpose.

concrete overlay at $2 per SY with an expected service life of five years or mudjacked[20] with grout or urethane at $15 per SY with an expected service life of 15 years.

Arch Bridges

The Ohio guidance (ODOT 2010) discusses three types of arch bridge including filled spandrel[21] wall arch bridge, the open spandrel arch, and the through arch or rainbow arch bridge. The filled spandrel wall arch bridge has a vertically curved concrete slab and vertical wall on top that form sides for the bridge. Granular material is used to fill the area defined by the arches and walls and support the road bed. Maintenance for these bridges is generally minimal, although the filled area tends to hold water, which can shift the fill material and cause cracking in the wearing surface. Sewer and water lines may fail contributing to problems with moisture. Preventive maintenance includes crack sealing the wearing surface, sealing gutter areas with rubberized asphalt or some other flexible sealer, routine inspection of buried utility pipes, and installation of drains if there is evidence of accumulation of moisture.

Repairs of filled spandrel wall arch bridges include management of wall movement and repair of concrete deterioration. Generally sanitary, storm and water lines should be replaced if they are leaking and the berm area should be kept clear of vegetation. Moisture accumulation can be reduced by replacing the wearing surface at $10 per SY, crack sealing the surface at $2 per SY, Paving full width at $10 per linear foot and sealing the joint between the pavement edge and the wall face at $2 per linear foot. These are all ten-year repairs. Twenty-year repairs include drilling of weep holes at $50 each in the walls and $70 at low points in the arch. Installation of transverse tie rods between the walls at $1,000 each is also a twenty-year repair. Replacement of the walls at $1,500 per linear foot is a fifty-year repair. Deteriorated concrete is repaired by saw cutting and patching at $45 per square foot for a 25-year repair.

Open spandrel arch bridges have vertically curved concrete slabs and vertical columns or arch ribs that support floor beams and the deck slab. Leakage at joints and drainage problems tend to cause damage from corrosion. The principal construction material is concrete. Preventive maintenance measures include sealing of concrete decks, annual cleaning and sealing of expansion joints, management of the drainage system so that drainage that falls onto the arch components is redirected.

Repairs of open spandrel arch bridges include repairs to the wearing surface, floor beam deterioration, column deterioration and arch rib or ring deterioration. Open spandrel arch bridges have a concrete slab wearing surface which is discussed in the section on slab bridges. Floor beam, column, and arch rib deterioration are handled similarly. Floor beam deterioration that does not require replacement of the floor beams and deck may be repaired by patching delaminations and sealing joints at $45 per

[20] Mudjacking involves insertion of a cement-based mixture to support structures undermined by settlement.
[21] According to the Ohio Guidance spandrel bridges are supported by two arches from below. The filled spandrel wall arch bridge deck is supported by aggregate placed in the central area. Open spandrel arch bridges run columns between the arches and the deck for support.

square foot for a 20 year repair. Floor beam and deck replacement costs $80 per square foot and has an expected serviceable life of 40 years. Column or arch rib deterioration that is not severe is corrected by patching and sealing and adjusting drainage. It is not clear what the additional cost of replacing columns is. Bridge reconstruction costs $120 per square foot and has an expected serviceable life of 80 years.

Rainbow arch bridges are supported by two arches that rise above the roadway and hold vertical columns which in turn support floor beams and the deck slab. Construction materials include reinforced concrete and steel. Because of slenderness of the vertical columns both the concrete and reinforcing steel components of reinforced concrete rainbow arch bridges are susceptible to corrosion from deicing materials. It is therefore necessary to have the splash zone cleaned and all its components sealed. Preventive maintenance includes annual power washing of the deck surface, gutters and vertical columns, sealing the concrete decks, sealing the arch within the splash zone with silane/siloxane or epoxy/urethane, and crack sealing the transverse contraction joints of the deck near each end with rubberized asphalt, silicone caulk, or urethane caulk.

Repairs of rainbow arch bridges include repairs to the wearing surface, deck, floor beam deterioration, column deterioration and arch rib or ring deterioration. Repairs of the deck and wearing surface are referred to general guidance for those two issues. As with open spandrel arch bridges, less serious deterioration of the floor beams or arch ribs is treated by patching and sealing joints. Columns are fine structures and therefore difficult to patch, but can be reinforced. The guidance is not clear on the cost or expected life of reinforced columns.

Backwalls

Backwalls are retaining walls at the bridge ends that support approach slabs directly and by holding back the embankment underneath the approach slabs. They are vulnerable to breakage from expanding pavement. Preventive maintenance includes power washing every year to remove deicing agents, sealing the backwall face with silane/siloxane every five years, or epoxy/urethane every 10 years, and installation of asphalt-filled relief joints to absorb the movement of expanding, usually concrete pavement.

Repair issues include delaminations, leaning, and deterioration of the top portion. Delaminations are addressed by patching, and joint sealing at a cost of $45 per linear foot. No estimate of expected service life is included in the guidance. Tilting generally requires replacement of the backwall and adjustment of the beam ends. Simple replacement costs an estimated $600 per linear foot and has an estimated service life of 10 years. Moving the backwall away from the beam ends costs $800 per linear foot and has an estimated service life of 15 years. Conversion to integral abutments costs $1,000 per linear foot and has an estimated service life of 20 years. Repair of deteriorated tops involves bracing, if necessary, removal and replacement of deteriorated concrete, and installation of pavement pressure relief joints.

Beams

The beams covered by the Ohio guidance (ODOT 2010) are made either of steel or pre-stressed concrete. Pre-stressed concrete beams may be box beams or I-beams. Steel beams are subject to rust and more serious corrosion, bending through impact, and physical breaking. Pre-stressed concrete is subject to water damage, spalling, and cracking.

For steel beams rust is managed by repainting. If less than 20% of the surface has lost its paint covering then it may be spot painted at $7.50 per square foot for a ten-year repair, otherwise the piece must be repainted at $5 per square foot for an 18-year repair. Repair of a steel beam that is seriously corroded involves plate over welding at $25 per square foot for a 10 year repair or addition of new steel by welding and grinding of the welds at $50 per square foot for a 30 year repair. Bent members may be heat straightened at $10,000 if less than six inches out of alignment or $5,000 per inch of deflection for a 25 year repair. Nicks and gouges are ground out so that sharp edges are eliminated.

For concrete box beams leaking joints between beams are repaired by removing and replacing asphalt, waterproofing, and unsound grout at $15 per square foot for a 20 year repair. In cases of minor spalling without strand corrosion the concrete may be patched with mortar applied by trowel at a cost of $25 per square foot for a 20 year repair. If the spalling is more severe and there is strand corrosion then the beams must be replaced at a cost of $150 for a 40 year repair. Drip strips may be used to prevent damage from over-the-side drainage on the underside of outside beams at a cost of $5 per linear foot for a 30 year repair. Cracks may be treated with epoxy injection at $10 per linear foot for a permanent repair.

For concrete I-beams cracks in the bottom flange may be treated by epoxy in injection at $10 per linear foot for a 20 year repair. Cracks in cast-in-place closure pour between beam ends may be treated the same way although replacement at $50 per cubic foot may also be necessary for a 20 year repair.

Bearings

Bearings are devices that transfer weight from the superstructure to the substructure, and allow the bridge to expand and contract. They are usually constructed of steel or elastomeric neoprene, or a combination of both. They may be fixed, anchoring the superstructure to the substructure or sliding, rocker, or roller bearings, which allow movement. Preventive maintenance for steel or partial steel and neoprene bearings involves annual power washing, and painting with epoxy paint as needed. Preventive maintenance needs for neoprene bearings are minimal, consisting of an occasional power washing to prevent dirt and debris build-up.

The Ohio guidance (ODOT 2010) lists three repair issues for steel rocker type bearings: out of vertical, rust, and loose bearings. If a steel rocker bearing is out of vertical at 70^o or less the bearing may be reseated and shimmed or the bridge may be jacked for a cost of $200 each and an expected service life of 10 years or the abutment may be converted to integral for a cost of $2,000 per linear foot and an expected service life of 30 years. To manage corrosion expansion joints should be resealed and the bearings should be painted at a cost of $80 per bearing and an expected service life of 15 years for the repair. Loose rocker bearings should be removed, cleaned and reseated and the expansion joint should be replaced or rehabilitated at a cost of $100 per linear foot of expansion joint and $1,500 per bearing. Expected serviceable life is 20 years for the expansion joint repair and 35 years for the rocker bearing repair.

Repair issues for neoprene bearings include cracking, and repair of bearings that are loose or out of position. Cracked bearings may be sealed with silicone at $10 each for a 15 year repair, or replaced for a 40 year repair. Loose or out of position bearings should be reseated with shimming or grinding of the abutment as necessary. Reseating, including any shimming is at a cost of $50 per bearing. If the there is a need to grind abutments or piers there is an additional cost of $200. The expected service life of this repair is 15 years.

Culverts

The Ohio guidance (ODOT 2010) describes culverts as structures that form a hole through an embankment. Corrugated metal pipe arch culverts are galvanized steel structures that are flat on the bottom and circular above that. Box culverts are precast concrete structures with three or four sides. Four-sided box culverts have a concrete bottom, while three-sided box culverts leave the ground exposed. Aluminum box culverts are three-sided corrugated aluminum structures. Three-sided culverts, whether precast concrete or aluminum must be seated on concrete platform at both ends. Generally preventive maintenance of culverts involves improving flow through placement of riprap, keeping the inside clear of debris, and removing trees and saplings as needed. The life of corrugated metal pipe arch culverts may be extended by adding a concrete bottom.

Repairs for corrugated metal pipe arch culverts include correction of corrosion of the bottom platform, loss of shape, cracks at the bolted connections, scour hole at the outlet, and leaning at the headwall. Bottom corrosion may be addressed by laying concrete on the bottom at a cost of $100 per linear foot for a 20 year repair or replacement of the culvert at $1,200 per linear foot for a 35 year repair. Distortion of shape more than 15% may be remediable by installation of a liner plate at $1,000 per linear foot for a 35 year replacement or installation of a plastic liner at $800 per linear foot for a 40 year repair or the culvert may be replaced at $1,200 per linear foot for a 35 year repair. Trees may need to be removed at $0.50 each every 10 years or so. If cracks at the bolted connections involve more than 10% of the culverts length the problem may be addressed by welding rebar to every other corrugation at a cost of $50 each weld for a 10 year repair or the culvert may be replaced for $1,500 per linear foot for a 25 year repair. Scour holes are addressed by placement of dump rock at the outlet. Disintegration or leaning of the headwall requires replacement of the headwall at a cost of $1,500 for a 30 year repair.

Issues addressed for the repair of four-sided precast concrete box culverts include leaking joints, concrete disintegration, and gaps in the joints larger than one inch. Leaking joints may be excavated and the waterproofing replaced at a cost of $500 per linear foot for a 20 year repair or joint may be sealed with expanding polyethylene/urethane caulk or fast setting mortar at $10 per linear foot of joint for a 10 year repair. Deteriorated concrete may be addressed by sealing the joint at a cost of $10 per linear foot of joint and troweling mortar to patch, or gunite may be used for vertical and overhead areas, or a concrete slab may be laid onto the structure. The concrete or mortar repairs all cost $45 per square foot and have expected service lives of 15 years. Large gaps in the joints may be filled with fast setting mortar at a cost of $5 per linear foot of joint for a 10 year repair.

Repairs for aluminum box culverts address leaking around seams and bolts, bulging or sagging of the top, and exposure or undermining footers. Leakage around seams and bolts is addressed by excavating and waterproofing these at a cost of $700 per linear foot. The Ohio guidance (ODOT 2010) does not specify the expected service life of this repair. Repair of bulging or sagging tops involves excavation of the culvert, jacking it back into shape and reseating it at a cost of $900 per linear foot for a 10 year repair or replacement of the culvert at $1,500 per linear foot for a 25 year repair. Undermined footers are underpinned with concrete. Undermined or exposed footers are armored with rock. The undermined footer repair cost is $100 per linear foot. The exposed footer repair is $25 per linear foot. The expected service life of both repairs is 15 years.

Repairs for three-sided precast concrete culverts address leaking from joints, concrete delaminations, and exposure and undermining of footers. Joint leaks may be addressed from the underside by applying expanding urethane at a cost of $5 per linear foot of joint for a 15 year repair or by reapplying the waterproofing membrane at a cost of $200 per linear foot of culvert. Repair of concrete delaminations involves joint sealing and patching with mortar or gunite. Undermined or exposed footers are addressed as with aluminum box culverts above.

Decks

In Ohio most reinforced concrete decks are 8.5 inches thick and sit on steel or concrete I-beams (ODOT 2010). There may or may not be a concrete overlay either 1.25 or 1.75 inches thick or an asphalt overlay 2.25 inches thick. The Ohio guidance (ODOT 2010) does not discuss steel grid decks and timber structures. The common features of reinforced concrete decks are discussed including wearing surfaces, sidewalks, railings, scuppers, drain pipes below the deck, over-the-side drainage, and expansion joints.

Preventive maintenance for concrete decks and concrete overlays includes sweeping with a power broom, and power washing the gutter areas at least once a year to remove deicing compounds and sealing the deck surface with silane or siloxane every five years. Transverse cracks should be filled with high molecular weight methacrylate or a gravity fed silicate solution. Ponding may be addressed by grinding a trough to draw drainage, or the low area may be patched. Delaminations, potholes, scaling and similar problems should be repaired and loose spalls removed. For asphalt overlays cracks should be sealed and more generalized weathering should be chip sealed or milled and filled with new asphalt. Slurry seals may also be used.

Repairs for reinforced concrete decks include scaling, aggregate popouts, cracks including transverse cracks, potholes, and full-depth holes from the top side, and transverse cracks, delaminations, discolorations, and full-depth holes from the bottom side. Popouts and minor scaling or cracks may be addressed by sealing with silane at a cost of $1 per square foot for a five year repair. If scaling is deeper than ½ inch the deck should be milled to a depth of 1.25 inches and replaced with concrete inlay at a cost of $35 per square foot for a 15 year repair. More severe cracks may be treated with a high molecular weight Methacrylate (HMWM) at a cost of $2 per square foot for a 15 year repair, a reactive silicate solution at a cost of $0.50 per square foot for a five year repair, or with gravity fed resin at a cost of $1.50 per square foot for a ten year repair. Repair of potholes by patching involves removal of unsound material, saw cutting if concrete is the patching material and filling with asphalt or fast setting concrete patching material. The asphalt repair costs $15 per square foot and is a temporary repair with a three year expected service life. The concrete repair costs $100 per square foot and has an expected service life of 10 years. If more than 10% of the deck area is unsound it is recommended that the top surface of deck be removed and replaced with a 1.25 inch concrete inlay at a cost of $35 per square foot for a 15 year repair. An asphalt overlay may also be used as a temporary measure at a cost of $15 per square foot for a three to five year repair. Delaminations from under the bridge are not patched but may require that the deck be replaced. Full depth holes and discolorations may be replaced with a full depth concrete patch at a cost of $150 per square foot for a 10 year repair if less than 5% of the deck is missing or less than 10% of the deck is discolored, otherwise the deck should be replaced at a cost of $80 per square foot for a 40 year repair.

Wearing surfaces may be either asphalt or concrete overlays. Repairs for asphalt overlays include cracks, surface raveling and potholes. Isolated cracks and less severe raveling may be treated by sealing with rubberized asphalt at a cost of $0.20 per square foot for a five year repair. If cracks are numerous or run together or if raveling asphalt is no longer bonded to the deck the affected section should be replaced with a waterproofing coat and new asphalt at a cost of $35 per square foot for a 10 year repair. If 15% or more of the wearing surface is covered with potholes they may be saw cut and patched with asphalt at a cost of $15 per square foot for a five year repair, otherwise the asphalt overlay should be replaced. Repairs for concrete overlays include scaling, popouts, cracking, delamination and potholes. Popouts and scaling less than ½ inch deep may be sealed with silane at a cost of $1 per square foot for a five year repair. Deeper scaling should be sounded, saw cut and patched with fast acting concrete patching material at a cost of $35 per square foot for a 15 year repair. Cracks may be treated with a high molecular weight Methacrylate (HMWM) at a cost of $2 per square foot for a 15 year repair or with gravity fed resin at a cost of $1.50 per square foot for a ten year repair. Repair of potholes by patching involves removal of unsound material, saw cutting if concrete is the patching material and filling with asphalt or fast setting concrete patching material. The asphalt repair costs $15 per square foot and is a temporary repair with a three year expected service life. The concrete repair costs $100 per square foot and has an expected service life of 10 years. If more than 10% of the deck area is unsound it is recommended that the overlay be removed and replaced at a cost of $35 per square foot for a 15 year repair or that the deck should be replaced at a cost of $80 per square foot for a 40 year repair.

Sidewalks on bridges are usually reinforced concrete although steel checkerplate is also used. The Ohio guidance (ODOT 2010) only addresses the reinforced concrete type. Preventive maintenance includes sweeping and power washing and sealing as with concrete decks. Cracks are handled as with concrete decks as well. However, care must be taken with sealers to add grit to ensure skid resistance and trip hazards must be addressed. Popouts and scaling of the surface may be corrected by cleaning and sealing with silane at a cost of $2 per square foot for a 10 year repair. Scaling may also be treated with a ¼ inch epoxy overlay at a cost of $35 per square foot for a 15 year repair. Cracks may be addressed with a high molecular weight methacrylate at a cost of $1 per square foot if the crack is less than 1/16 inch wide or by routing out the crack and applying a silicone or urethane caulk at a cost of $2.50 per square foot. Surface delaminations may be addressed by removing the unsound concrete, saw cutting the area and patching with patching material at a cost of $40 per square foot for a 15 year repair. If the deterioration is extensive saw cutting and full depth removal is necessary before recasting at a cost of $80 per square foot for a 30 year repair.

Railings are walls on the sides of a bridge that prevent pedestrians and vehicles from going off the sides. They are usually either reinforced concrete or galvanized steel. Preventive maintenance for reinforced concrete railings includes power washing, especially inside the splash zone and sealing with silane or siloxane every five years. For reinforced concrete railings surface scaling or popouts may be addressed by sealing with silane or siloxane at $2 per square foot for a 10 year repair or epoxy/urethane at $4 per square foot for a 15 year repair. Cracks may be addressed with a high molecular weight methacrylate at a cost of $1 per square foot if the crack is less than 1/16 inch wide or by routing out the crack and applying a silicone or urethane caulk at a cost of $2.50 per square foot. Either is a 10 year repair. Surface delaminations may be addressed by removing the unsound concrete, saw cutting the area and patching with patching material at a cost of $40 per square foot for a 15 year repair or patching with a thin layer of trowel-applied mortar at $10 per square foot for a 10 year repair. If the deterioration is extensive, saw cutting and full depth removal is necessary before recasting at a cost of $80 per square foot or the railing may be replaced at $800 per linear foot. Either is a 30 year repair.

Preventive maintenance of galvanized steel railings involves annual tightening of loose bolts and touching up with zinc paint. For galvanized steel railings if the railing is dented or gouged or anchor bolts become loose or imbedded repairs may include touch up with zinc paint at a cost of $2 per square foot, replacement of guardrail sections at $25 per linear foot, or replacement of tubular backup sections at $80 per linear foot. The zinc paint touch up is a 10 year repair and the replacements are 40 year repairs. Leaning or bent posts may be replaced at a cost of $150 per post for a 40 year repair. Surface rusting may be addressed by cleaning and painting with zinc paint at $3 per square foot for a 10 year repair, cleaning and metalizing at $10 per square foot for a 40 year repair or replacement at $150 per linear foot for a 40 year repair.

Scuppers are openings in the bridge floor that allow water to drain into a system of drainage pipes or as free falling water. Preventive maintenance involves clearing debris annually or more often if needed to maintain flow, repair washouts from free falling water, and to ensure that drainage clears all structural steel by adding pipe. Repairs to scuppers include replacing the bottom portion of pipes that have corroded off and addressing surface corrosion. The repair for corroded off pipe from the bottom is to replace the lost pipe by welding on a new section at a cost of $25 each or by applying a PVC pipe extension of the same size at a cost of $20 each. Either measure is a 30 year repair. Surface corrosion should be addressed by cleaning and painting the affected area at a cost of $5 per square foot for a 15 year repair.

Drain pipes below deck receive water from scuppers and channel it away from the bridge and other places where it is undesirable. Preventive maintenance involves keeping the pipes clear. The Ohio guidance (ODOT 2010) discusses design of more maintenance-free drainage pipe systems using PVC pipe, but that is beyond the scope of this report. Repairs of drain pipes include addressing disconnected pipe joints, rusting through of pipes, and clogged pipes. Disconnected pipe joints are repaired by cleaning out and reconnecting the pipes at a cost of $50 per linear foot for a 10year repair. Rusted through pipes may be repaired by cleaning out the pipe and welding a plate over the hole at a cost of $20 per linear foot for a 15 year repair or replacing the pipe at $10 per linear foot for a 20 year repair. Chronically clogged pipes should have clean outs or the means to disconnect at the ground line installed for a cost of $50 each and a 20 year repair or should be redesigned.

Over-the-side drainage is an issue that arises with bridges with steel railing systems that allow water to drain over the sides of the bridge. The efficiency of this system depends on the location and cleanness of the scuppers. This type of drainage can become problematic when chloride laden water chronically wets reinforced concrete and causes the rebar to corrode, which results in further deterioration of the concrete and may undermine structural integrity. Galvanized steel drip strips may be used to cause water to fall to the ground rather than dripping on the structure. Drip strips are easier to install when a new overlay is installed. A simpler remedy is to seal the sides and 18 inches of the bottom with silane/siloxane or epoxy/urethane sealers. If there is edge deterioration from over-the-edge drainage the problem may be corrected if the top edge of the slab is sound by installing a drip strip at a cost of $15 per linear foot for a 20 year repair. If the top and bottom edge are deteriorated then the deteriorated material should be removed and the edge should be patched at a cost of $50 per square foot for a 20 year repair. If the deterioration is extensive the deck should be removed and recast and a drip strip installed at a cost of $1,000 per linear foot for a 40 year repair. If the pre-stressing strands are corroded through the exterior beams should be replaced and a drip strip installed at a cost of $1,000 per linear foot for a 50 year repair.

According to the Ohio guidance (ODOT 2010) expansion joints permit a bridge to expand and contract with temperature fluctuation, and rotate with the beam ends as traffic load shifts. To function properly expansion joints must be kept clear of non-compressible materials such as stone, dirt, and asphalt. Preventive maintenance involves clearing these materials at least once a year. The types of expansion joints mentioned are polymer modified asphalt, steel sliding plate, steel finger joints, and neoprene compression seals. Replacement of polymer modified asphalt expansion joints costs $30 per linear foot and replacement of strip seal expansion joints costs $40 per linear foot. Replacement of neoprene compression seals costs $15 per linear foot. All three replacements are 15 year repairs. Steel sliding plate joints including plate, assembly, and adjacent part of the deck may be replaced at $200 per linear foot for a 25 year repair.

All repairs to polymer modified asphalt expansion joints involve replacement. Loose steel anchorages for strip seals and neoprene compression seals may be repaired with injections of epoxy at $35 per linear foot if the anchorage is not broken for a 15 year repair or by removing and recasting concrete around the anchorage at a cost of $150 per linear foot for a 20 year repair. Joint leaks and separation failures of neoprene compression seals may be repaired by reinstalling the neoprene seal with new adhesive as an alternative to replacement at a cost of $10 per linear foot for a 10 year repair. Loose sliding plates may be re-welded through drilled holes at a cost of $50 per linear foot for a 15 year repair or replaced with the deck edge. To replace a cracked sliding place a new sliding plate is welded as just described at a cost of $75 per linear foot for a 15 year repair or the entire assembly including part of the deck may be replaced. A loose anchorage in the backwall may be repaired with epoxy injections at $35 per linear foot for a 15 year repair or the top of the backwall may be removed and recast at a cost of $150 per linear foot for a 20 year repair. A gouged assembly may be repaired by grinding and re-welding as necessary for an indefinite repair. Repair of closed joints may involve stabilizing abutments, removing encroaching pavement, replacing the joint, and making the joint integral with the abutment. The Ohio guidance (ODOT 2010) estimates the cost at $1,500 per linear foot and the service life of the repair at 15 years although there is likely considerable variability in both estimates.

Piers

Wall type piers are full height piers rectangular in shape that reach from the ground or stream bed to the beam members for the full width of the bridge. These piers are usually concrete. Single slab bridges require minimal maintenance. Piers with unsealed joints must be power washed annually and sealed with silane or siloxane every five years or with epoxy or urethane every ten years. Capped pile piers are a series of piles, usually steel, driven in a line. The piles are usually H-piles but may also be concrete filled round or round-fluted piles. The piles support a continuous reinforced concrete cap that usually extends the full width of the bridge. The base of steel piles must be encased in concrete at or below the ground or water line. The tee type or hammerhead pier is a concrete structure that has a rectangular stem shaped base capped with an expanding section that supports the load. Cap and column piers consist of multiple concrete columns supporting a separate cap structure. Tee type and cap and column piers are prone to vertical cracks in the cap portion and should be power washed annually and sealed every five years with silane or siloxane or every ten years with epoxy or urethane.

Repairs for wall type piers include removal of unsound concrete and patching to address spalling and vertical cracks at a cost of $25 per square foot for a 20 year repair. Vertical cracks may be filled with epoxy if they are less than 3/8 inch at $10 per linear foot for a 20 year repair, otherwise they may be filled with mortar at a cost of $15 per linear foot for a 15 year repair. Underpinning may also be used to address vertical cracks at a cost of $50 per linear foot for a 15 year repair. For capped pile piers corrosion of steel piling at the water level may be addressed by cleaning and encasing steel in concrete to at least two feet below the ground or water line at $20 per linear foot for a 20 year repair. If H-piling is completely welded through, stiffener plates may be welded on and encased in concrete at a cost of $30 per linear foot for a 20 year repair. Concrete cap deterioration may be repaired by correcting drainage and patching and sealing the affected surfaces at $25 per square foot for a 20 year repair. Cracks in the pier cap may be repaired by injecting epoxy at $5 per linear foot for a 20 year repair. For tee type piers, spalling may be corrected by patching and sealing with epoxy or urethane at $30 per square foot for a 15 year repair. Cantilever cracks in tee type piers may be filled with epoxy if less than 1/8 inch wide at $10 per linear foot for a 20 year repair. Steel bands or post tensioning rods may be installed around the cap at $100 per linear foot for a 20 year repair. For cap and column piers spalling may be corrected by patching and sealing with epoxy urethane at $30 per square foot and expansion joints should be sealed if necessary at $50 per linear foot for a 15 year repair. Cracks in the pier cap may be repaired by injecting epoxy at $10 per square foot for a 20 year repair.

Slab Bridges

Cast in place concrete slab bridges consist of heavily reinforced concrete slabs that lie directly over pier systems. Single slab bridges have thick reinforcing steel in the bottom portion of the slabs while multiple slabs are reinforced on the top and bottom. Preventive maintenance involves sweeping and flushing the deck surface and gutters annually to remove accumulated chlorides found in deicing compounds and sealing the deck surface with silane or siloxane every five years. These procedures and procedures for sealing cracks and slab sides are identical with the preventive maintenance procedures for concrete decks.

Repair issues addressed in the Ohio guidance (ODOT 2010) for slab bridges include edge deterioration, underside discoloration, and exposure and corrosion of reinforcing steel. Edge deterioration may be managed by simply installing a drip strip if the top edge is intact at a cost of $10 per linear foot for a 20 year repair. Otherwise, in addition to installing a drip strip, the edge should be patched at a cost of $25 per linear foot for a 20 year repair or the whole edge should be recast at a cost of $200 per linear foot for a 30 year repair. If the slab discoloration is accompanied by leaking an inexpensive solution is to seal the top side of the slab with high molecular weight methacrylate, silane, or reactive silicates at a cost of $5 per square foot. If the unsound slab area is less than 15% of the total, the next escalation is to replace the affected portions of the slab at a cost of $150 per square foot for a 15 year repair. Otherwise the slab should be replaced at a cost of $200 per square foot for a 40 year repair. If there is exposed reinforcing steel on less than 10% of the slab the unsound material may be removed and recast at a cost of $150 per square foot for a 15 year repair. Otherwise the slab should be replaced.

Stream beds

The Ohio guidance (ODOT 2010) discusses three issues that arise from the evolution of stream beds including debris deposition, migration of the stream bed, and lowering of the stream bed. Generally, the solutions discussed involve removing debris on an as needed basis and stabilizing the stream bed to prevent migration or lowering. The need for these measures is more dependent on extraneous factors than on the decisions of bridge construction and maintenance engineers. It is therefore considered outside of the scope of material covered by the Carbon Footprint Project.

Incorporation of Maintenance and Rehabilitation into the GASCAP Tool

Based on the information above it is possible to provide a list of maintenance and rehabilitation measures for pavement and bridges that users can use to fill out an optional plan for life cycle maintenance of these facilities. We are awaiting information on equipment fuel usage for maintenance activities that is currently being analyzed by a team at NJIT. When available, this will allow us to complete the procedures outlined in this module of GASCAP. Utlimately GASCAP will allow the user to specify the expected service life of pavement or bridge facilities and the routine maintenance, minor repairs, and major rehabilitations that are expected to occur over the life of those facilities, as well as the intervals between each of these inputs. The GASCAP tool will not limit the number of these inputs that can be entered.

FORECASTING CARBON EMISSIONS USING MODELS THAT ACCOUNT FOR INDUCED TRAVEL

Summary

This section summarizes our assessment of the ability to develop methods to forecast the behavioral changes that occur when new transportation capacity is built and the consequent carbon emissions that are generated. The behavioral effects are collectively known as induced travel, that is the net new travel that occurs when either a congested facility has capacity added, or a new facility is built that provides access to land that is relatively undeveloped.

There is a large consensus on the theoretical nature of this effect. Induced travel, expressed in economic terms, represents a relationship between the supply of a good (in this case roads) and the demand for that good (in this case travel). The major cost associated with travel is associated with the value of time. Thus, congestion and total time traveled mitigate the demand response. Any reduction in travel time results in an increase in travel demand, which is a simple expression of an elastic (downward sloping) demand curve (see Figure 3). The traditional view of many traffic engineers and planners was that transportation demand was purely a derived demand that did not respond to changes in costs, or alternatively this implied that the demand curve was inelastic or vertical (see Figure 2).

Our review of the literature confirms this hypothesis. Every study with well specified models of demand demonstrate that there is an association between lane miles of capacity and total vehicle miles of travel (VMT). Some studies go further and demonstrate that this relationship is causal, that is, there is a direct link that expanding capacity leads to more VMT, independent of other changes, such as population growth or increases in average income, that also increase VMT. The net impact from various studies suggests that the induced portion of VMT growth ranges from 15% up to 40% of the total observed growth in VMT.

Part of the growth in VMT is also due to changes in land use that occur over time. Urban economists have long defined a theoretical relationship between access to land and the value of that land. The increase in land value associated with greater access reflects its development potential (see Figure 4). Thus, in the long run we expect to see land use change in direct response to new road capacity, and this leads to further growth in VMT.

The land use effect suggests that one way to forecast and estimate changes in VMT is through an integrated transportation / land use model. These models, however, are both technically complex (i.e., they are often black boxes), have large data requirements (such as parcel level land use data for an entire region), are difficult to estimate, and when estimated are subject to large potential error. While these models can be used for comparative analysis, they are regional in nature and are best for analyzing an entire program of transportation changes. At the facility level, for specific projects, any measurable effect is likely to be buried in the noise of the error term.

An alternative approach is to use empirical econometric models. These typically use aggregate inputs (e.g. at a county-level) to estimate lane-mile elasticities (the responsiveness of VMT to a change in lane-miles of road). Some models have also used an aggregation of specific projects to estimate elasticities, an approach that could be implemented to generate project-specific effects. These models have the ability to forecast VMT into the future, with the main source of error being assumptions on how population, income, or fuel prices might change.

One further complication with estimating carbon emissions is translating net VMT changes into net changes in CO_2. Road capacity additions can change the dynamics of traffic behavior; that is, changes occur in the level of stop-and-go driving and hard accelerations, both of which tend to emit more pollutants than free-flow traffic conditions. New vehicle technology (e.g. hybrid-vehicles) make these effects less important, implying a greater correlation between VMT changes and CO_2 changes, independent of traffic dynamics. EPA's soon to be released MOVES model will be the required regulatory model for conformity analysis and likely will also be used to estimate Greenhouse Gas inventories, however, as yet it does not include adequate modeling of hybrid vehicle dynamics, but will eventually. Approaches have been demonstrated that can integrate a vehicle emissions model (such as MOVES) with a traffic microsimulation model, that can represent the detailed changes in traffic dynamics from a specific project. Using these methods one can back-cast an assumed level of induced travel to determine when any initial reductions in emissions are off-set by growth in traffic. Simulations have found that any initial benefits are lost with relatively small increases in traffic which are assumed to be induced.

Thus, based on our review, we believe there are simple methods that can be applied to forecasting carbon emissions for specific projects and certainly for analyzing the State as a whole. However, these will require various datasets to estimate the necessary econometric models and develop relationships that are valid for New Jersey.

Introduction

The following review consolidates available evidence for the behavioral effects associated with induced travel and considers the viability of developing a method to account for the carbon dioxide (CO_2) emissions of project-level additions to road capacity. Transport planners have long observed that capacity expansions typically do not alleviate congestion in the long run and recent research has empirically established that this occurs. Most transportation modeling systems, however, do not adequately account for these effects and lead to systematic overestimation of congestion reduction benefits. This review will cover these issues, beginning with a discussion of the basic theoretical issues of how changes in road capacity affect behavior, some discussion of why this has been controversial, followed by a review of attempts to model these effects and the applicability of these to project-level forecasts, which could be used for estimating CO_2 emissions.

The controversy surrounding induced travel effects arose from dissatisfaction among environmental activists, transportation planners, regulatory agencies and the general public with the performance of traditional traffic demand forecasting models in terms of their ability to avoid overestimation of short term and long term congestion reduction benefits of transportation investments. Estimates of the magnitude of induced travel effects, reviewed in this appendix, may provide one technique for predicting future growth in demand for travel by mode. It has likewise been demonstrated (Rodier, Johnston 2002)(Timperio et al. 2006)(Timperio et al. 2006) that four step models can be augmented with sufficient feedback steps that can account for induced travel, such that they estimate future transportation demand at more theoretically plausible levels.

Underlying Economic Theory and Behavioral Factors

Travel has been described as a classic case of a normal good (Lee, Klein & Camus 1999, Noland, Lem 2002, Williams, Yamashita 1992). An increase of supply, such as an increase in the capacity of the highway system or an improvement to public transit, reduces the cost of travel, conveyed by the reduction in travel time from reduced congestion, or by allowing greater access by shortening distances (or making trips faster) (DeCorla-Souza 2000). Consumption levels are determined by the supply of opportunities to travel as well as the overall demand for travel, regulated by the cost (primarily time) and individual budget constraints (again, primarily time constraints) (Noland, Lem 2002, Litman 2001)(Litman 2001)(Litman 2001). While there are also cross-elasticities for fuel and maintenance costs (Goodwin 1992, Goodwin 1996, Goodwin, Dargay & Hanly 2004) (Timperio et al. 2004, Train 1998, Cervero 1988)(Timperio et al. 2004, Train 1998, Cervero 1988)the literature suggests that highway users are more sensitive to the price they pay for travel in time (Lee, Klein & Camus 1999, Noland, Lem 2002, Gorham 2009, Fulton et al. 2000), as are riders of transit (Cervero 1990, Kemp 1973) than other costs. Therefore elasticities of demand, by which the amount of travel demanded increases as the price drops may be calculated, although the historical practice of transportation planners has been to treat travel demand as perfectly inelastic, i.e. possessing a vertical demand curve (Noland, Lem 2002).

Figure 2 and Figure 3 graphically illustrates these simple relationships. Much of the confusion over how important induced travel is and whether it exists is due to the assumption of an inelastic demand curve as well as the source of exogenous growth in demand, which confounds any measurement of induced travel effects. Fig. 1 shows how an exogenous increase in supply, represented by the downward shift in the supply curve (from S1 to S2), affects travel demand; with the inelastic demand curve, there is no change in demand (Q1) and any observed changes are attributed to exogenous increases in demand (Q3), for example, from population increases or other economic factors.

Figure 2. Inelastic travel demand and exogenous growth in travel

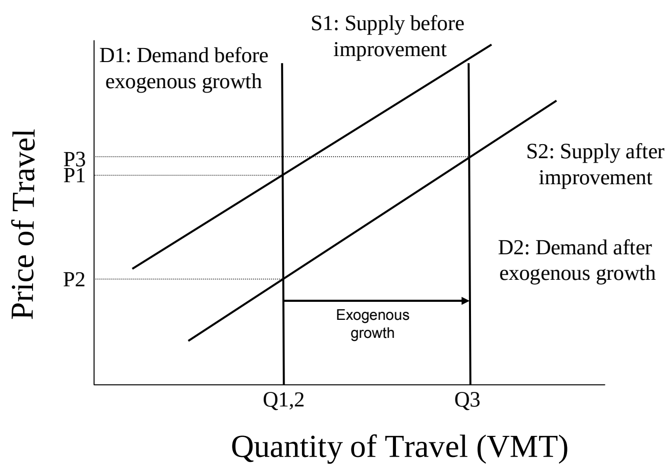
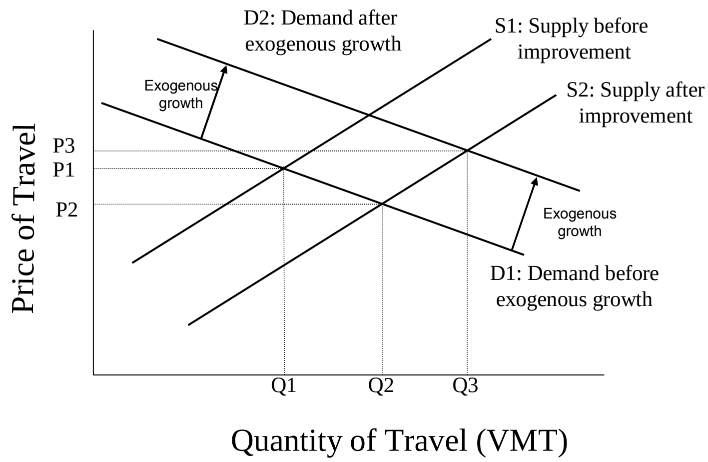


Figure 3, alternatively, shows a downward sloping demand curve which represents an elastic demand response to changes in cost. In this case, any increase in supply (to S2) corresponds to an increase in demand (Q2). While the costs (i.e., the amount of travel delay) may be less than previously (P2 is less than P1), the reduction is less than with an inelastic demand response. Exogenous growth still can reduce this benefit and would do so more rapidly (shifting demand to Q3).

Figure 3. Elastic travel demand and exogenous growth in travel



The time budget literature cited in (Noland, Lem 2002) suggests that the time that people allocate for travel is fairly stable, and has remained stable over time, e.g., (Zahavi, Talvitie 1980) report that daily travel times across a number of countries are fairly consistent. By relating travel time to speed and therefore distance, (Zahavi, Talvitie 1980) imply that demand for travel is elastic, but that they are quite consistent over time in the aggregate (Zahavi, Ryan 1980). As travel times are reduced travel becomes less expensive to consumers and more travel is consumed, up to a given daily limit. (Noland, Lem 2002) acknowledge the theoretical possibility that overall reductions in the generalized cost of travel could lead to increased daily time budgets.

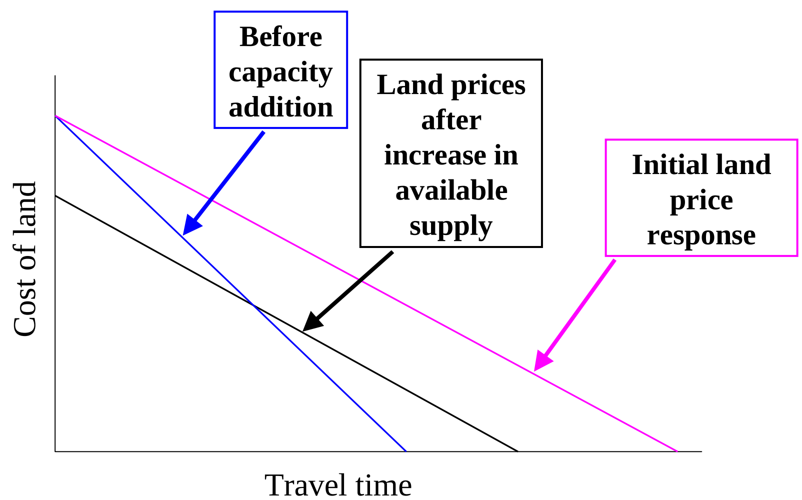
Travel demand elasticities are sensitive to time horizon. Over the short term travelers change their use of the existing transportation system. The immediate to a reduction in congestion are captured in Downs's (Downs 1992)(Frank et al. 2008)(Frank et al. 2008) triple convergence of responses to congestion, which is widely cited in the induced travel literature (Noland, Lem 2002, Gorham 2009, Cervero 2002)(Cervero, Hansen 2002, Cervero 2003). When travel on a highway becomes faster because an increase in capacity reduces congestion the first effect is convergence of travel to peak periods, since previously travelers had shifted to off-peak (or shoulder) periods due to congestion. Another short term reaction includes route shifting, away from parallel routes that are now relatively slower. Finally, (Downs 1992) included shifts away from slower modes, such as public transit. (Noland 2007) also noted that in the short term destinations may change so that trips cover longer distances and trips may also be made more frequently. All these short run effects can occur fairly rapidly.

The demand for travel is a derived demand, which means that the demand for travel is derived from the demand for other goods and services. In other words, travelers travel in order to obtain the benefits of being at work, home, shopping, recreation, or any other of a number of benefits that they value (Gorham 2009). Noland and Cowart (Noland, Cowart 2000) note that transportation planners have resisted incorporation of induced travel effects on grounds that travel demand is derived. However, the overall cost of engaging in activities (i.e., those that generate the derived demand) is a critical component of how new capacity affects travel. Increased road capacity can shape the location of those activities that generate demand for travel. Put another way, this is the fundamental way in which land use can change in response to new accessibility patterns and has long been part of basic theories of urban economics (Noland 2007).

Urban economics describes the bid-rent function between travel costs (or time) and land values (Noland 2007). As travel times decrease to various economic activities, land values increase because consumers make an explicit trade-off between how much they expend on land rent and how much they spend on travel (including time).. In simple models, land values are highest near the most accessible locations and are an inverse function of distance from desirable locations (Chang 2006). This increase is most notable in places at greater distance from the most desirable locations, which previously had little or no value for development. Thus, one can easily explain how increased road capacity can induce new development at the urban edge and also intensify development in the urban core (assuming external costs, such as congestion, do not outweigh the benefits of a central location).

These effects can be shown graphically as in Figure 4. The basic trade-off is displayed by the decline in land value with increasing distance from more accessible locations (typically the center of an urban area). With an increase in road capacity, this line shifts upwards and out, increasing the value of all land. The value of land then shifts to the left due to the increased supply of land reducing the value. In simplified terms, this represents, for example, new housing supply leading to a relative reduction in the price of housing. Alternatively, one can also view increased commercial and retail development of land leading to decreased cost of commercial and retail products, especially if they can take advantage of the increased scale economies offered by the availability of cheaper land. All of these “long term” effects, attributable to new road capacity, further increase total travel, and thus represent the long term induced travel impacts.

Figure 4. Distribution of Benefits of Accessibility Increases



Another issue is the valuation of any benefits associated with new road capacity. Congestion increases the cost of travel in time and reduces the consumer surplus to users of the transportation system. Traffic congestion is a social cost that is external to the drivers who cause it (Arnott, Small 1994). This happens because under conditions of congestion, users of transportation will rationally choose modes and routes that minimize their time cost and are indifferent to how their decisions affect other travelers.

New road capacity can increase consumer surplus by providing more mobility, whether or not it reduces congestion in the long term or not. However, this increased consumer surplus is of lesser value than previously existing travel, since prior to the reduction in congestion, it was suppressed (Litman 2001). This can be quantified via the rule of half, which holds that the benefits of induced units of travel are worth half of what units of previously existing travel are worth and this can be interpreted as a mobility benefit.

An alternative valuation approach incorporates ideas from urban economics as illustrated in Figure 4. Given the change in land accessibility one would expect the benefits of any congestion reduction to be capitalized into land value changes, thus the beneficiary is those who currently own the more accessible land, rather than those who experience increased mobility (Noland 2007). It is widely known that accounting for both benefits in assessment would be double-counting. Noland (Noland 2007)(McFadden, Ruud 1994)(McFadden, Ruud 1994) further notes that the secondary benefit of how the new development changes the supply of housing and commercial development. Therefore a secondary effect is that consumers also capture some of the benefits, although the type of development matters in terms of its impact on environmental costs. A further issue in terms of evaluation of economic effects is the potential to encourage or discourage agglomeration of economic activities. Graham (Graham 2007) suggests that congestion reduction can improve the external productivity gains achievable from firm agglomeration, but does not distinguish road from public transit effects.

One additional consequence of building increased highway capacity is that it can undermine existing public transit. Public transit can be efficient in terms of energy consumption and emissions. However, it derives its ability to compete with private vehicle transportation from the frequency with which it can run, and the fares that are charged. The Downs-Thomson paradox addresses the equilibrium between a congested route and public transit. In a hypothetical illustrative case, Arnott and Small (Arnott, Small 1994) describe a train line in which the operator breaks even by only running trains when they are filled to capacity. As a result the frequency of train runs is a function of total ridership, which determines maximum travel time, including waits. If a parallel congested road has its capacity increased, some travelers will shift away from using the train. As riders shift to the competing roadway the train loses ridership and therefore cuts service (or raises fares). This makes the train less competitive, resulting in further shifts to car usage. Eventually the train is shut down as it is no longer competitive. In the end it is shown that congestion is potentially worse on the parallel road than before the capacity increase. In fact price elasticities for transit are fairly small but elasticities for service frequency can be considerably higher (Cervero 1990, Kemp 1973) lending credibility to the Downs-Thomson paradox.

Theoretically, we can conclude that one would expect to find that increases in road capacity are likely to increase total travel, especially when projects are aimed at congestion reduction. However, even roads that simply provide greater access under conditions of no congestion may facilitate increased development that leads to increased travel. While the theory is straightforward, empirically estimating this effect can be more problematic. In the next section we review recent research that has examined the empirical evidence for these effects. Some of these approaches might also provide a framework for forecasting future impacts.

Empirical Research Evidence and Forecasting Methods

In recent years a number of studies have empirically estimated induced travel, with the aim of demonstrating that a statistically significant relationship can be found between lane miles of road capacity and vehicle miles of travel. These studies typically use aggregate data and multivariate approaches to examine this association. Some go further to examine the endogeneity of traffic growth, that is, whether traffic growth in itself generates the construction of new road facilities. The majority of the empirical analyses has demonstrated that there is a relationship between new roads and extra traffic that is generated, including those analyses that controlled for endogenous effects.

We group our discussion to three basic approaches following the classification of Cervero (Cervero 2002). First, we review those studies that used aggregate cross-sectional time-series data for spatial units. Then we discuss those that examined a cross-section of specific facilities, across time. Finally, we discuss approaches that have used regional travel models and integrated land use/transportation models as a tool for forecasting VMT growth associated with changes in road capacity.

Aggregate Multivariate Regression Models

The majority of studies in this area have estimated multivariate regression models using area-based aggregations (e.g. state, county, or metro area) of both lane miles and VMT using cross-sectional time-series approaches. Exogenous factors, such as income, fuel prices, and population, are typically controlled for. Thus, travel is compared on the aggregate level of facilities by region, producing a demand elasticity for travel.

Regression models typically employ VMT as the dependent variable. VMT provides a continuous variable that captures changes in vehicular travel including travel from new trips, the added distance from longer trips, and route changes, which are generally recognized as increases in travel (Cervero 2002, DeCorla-Souza, Cohen 1998). Barr (Barr 2000) describes VMT as a good summary measure of the number of trips, their spatial distribution, modal choices, and route choices, and a good indicator of energy consumed (and consequent carbon emissions). Although these studies use a direct measure of the dependent variable (Cervero, Hansen 2002, Barr 2000), they do not as directly measure the impact of changes in travel demand on emissions (Rodier et al. 2001), which are generally linked to the flow characteristics of the traffic network as well as the mix of vehicles in the fleet. However, these effects are generally overwhelmed by increased use (Litman 2001, Noland 2007, Noland, Quddus 2006).

Because validation of the hypothesis of induced travel is based on analysis of counterfactuals, demonstration of causality is generally based on several factors. In order for changes in highway capacity to be causal to the quantity of travel demanded the following must be demonstrated:

- There must be correlation between highway capacity and vehicular travel;
- Changes in highway capacity must precede changes in vehicular travel;
- Competing causal factors must be accounted for;
- Endogeneity must be properly controlled for.

The latter condition is the most problematic, but has been tackled by several studies. Much of the analysis that has been done uses cross-sectional time-series (panel) data on spatial units of analysis (i.e., counties, urban areas, or states). Dummy variables are generally used to capture fixed effects of sub regions and time periods to factor out those factors associated with a given region or that may change over time.

Table 22. Estimated Parameter Estimates from Induced Travel Regression Models

Reference	Scale	Fixed Effects		Causality	Elasticities	
		Area	Time		Short Term	Long Term
Models with aggregate data: all with lane mile elasticities						
(Hansen et al. 1993)	Facility	X			0.2 – 0.3	0.3 – 0.4
(Hansen, Huang 1997)	County	X	X	Lag Model	0.21	0.6 – 0.7
(Hansen, Huang 1997)	Metro	X	X	Lag Model	0.19	0.9
(Fulton et al. 2000)	County	X	X	Granger Test	0.2 – 0.6	
(Noland, Cowart 2000)	Metro	X	X	Instrumental Variable Model	0.28	0.90
(Noland 2001)	States	X	X	Distributed Lag Model	0.2 – 0.5	0.7 – 1.0
(Cervero, Hansen 2002)	County			Simultaneous Equations		
VMT dependent	County	X	X	Granger Test	0.59	0.79
LM dependent	County	X	X	Granger Test	0.33	0.66
(Cervero 2003)						
Direct	Facility	X	X	4 element Path model	0.24	0.81
Indirect	Facility	X	X	4 element Path model	0.10	0.39
Models with disaggregate data	Scale	Type of elasticity			Elasticities	
(Strathman et al. 2000)						
Direct	Corridor	Lane Miles			0.29	
Indirect	Corridor	Lane Miles			0.033	
(Barr 2000)	Corridor	Travel Time			-0.3 to -0.5	

A variety of studies have attempted to tackle these issues (see Table 22). The first detailed analysis was conducted by (Hansen et al. 1993) and (Hansen, Huang 1997) who formulated the following functional form, which others have generally followed:

$$\text{Log}\ (VMT_{it}) = \alpha_i + \beta_t + \Sigma_k\ \lambda^k\ \log\ (X_{kit}) + \omega^{L}{}_{l=0}{}^{l}\ \log\ (LM_{it-l}) + \varepsilon_{it}$$

where:

VMT_{it}	represents the VMT in area *i* in time period *t*;
α_i	represents the fixed area effects for area *i*;
β_t	represents the fixed time effects for time period *t*;
X_{kit}	represents the values of a series of confounding variables *k*;
LM_{it-l}	represents some measure of a lane miles increase in region i for lag period *t-l*;
$\lambda^k_{.},\omega^l$	represent coefficients for confounding factors and a lagged estimate of the dependent variable, respectively; and
ε_{it}	is an error term.

The use of the logarithmic form has two advantatges. First, it minimizes any issues of heteroskedasticity, by reducing that might occur by including regions with large variances in size. Second, it allows one to interpret coefficient estimates as elasticities, although this also assumes that elasticities are constant and independent of the existing level of road capacity. In itself this is not an unrealistic assumption, but also as these studies are mainly concerned with identifying a statistically significant effect, the absolute magnitude of the estimated elasticity is less critical.

(Hansen, Huang 1997) estimate travel demand elasticities at the county and metropolitan levels with panel data for 30 urban counties in California, with aggregation assignments to the metropolitan level. (Hansen, Huang 1997) control for area and time fixed effects, population, personal income and fuel price. They report short run elasticities of 0.21 and 0.19 at the county and metropolitan levels respectively and between 0.6 and 0.7 at the county level and 0.9 at the metropolitan level for long run elasticities.

(Fulton et al. 2000) estimate county-level travel demand elasticities for three states and Washington, DC with cross sectional time series data. (Fulton et al. 2000) control for area and time fixed effects and population, population density and employment. A growth model is used to correlate VMT growth with increases in lane miles, enabling a Granger causality test to evaluate precedence of the associated increases of VMT with prior increases in capacity, i.e. lane miles. A growth variable for lane miles is used as an instrument in a second stage to address simultaneity bias with one year and two year lag periods. As a result (Fulton et al. 2000) report short term lane mile elasticities between 0.2 and 0.6, the first successful model to establish a causal linkage.

(Noland, Cowart 2000) estimate travel demand elasticities for freeways and arterial roads at the metropolitan area level. They use an instrumental variable approach, controlling for fixed effects of area and time, controlling for population density, per capita income, proportion urban area, and fuel costs. (Noland, Cowart 2000) estimate a short term elasticity of 0.28 and a long term elasticity of 0.90, however, the instrument selected was found to be weak, questioning any firm conclusions of a causal effect.

(Noland 2001) estimates state level travel demand elasticities with cross sectional time series data, controlling for population, income and fuel cost changes and separately treating facility types based on established road categorization schemes, from rural collector roads to interstate routes. A range of models are estimated including seemingly unrelated regression estimates by road type for short term elasticities, a distributed lag model to estimate long term elasticities, and growth models to address multi-collinearity among the independent variables. As a result travel demand elasticities between 0.2 and 0.5 were estimated for the short term and between 0.7 and 1.0 for the long term. The large variety of models estimated provide a large degree of robustness in the estimates, however none deal explicitly with endogenous effects. (Noland 2001) also produced a short term forecast, of future VMT growth, which might serve as a basis for an aggregate forecast of VMT and carbon emissions using readily available inputs.

(Cervero, Hansen 2002) demonstrate the mutual causality of VMT and lane mile expansion. Using simultaneous equations for supply and demand and instrumental variable regressions, that include political variables as instrument, they find a statistically significant induced travel effect. They also find that increases in VMT lead to more road capacity, i.e., that there is a two-way effect confirming the view that planners have some foresight about where road capacity will be demanded. This latter effect, however, is smaller than the estimated coefficient on lane miles, associated with VMT.

(Liu et al. 2006) estimate a series of models using county-level data from Pennsylvania. They find very high lane-mile elasticities and significance levels, but likely have major problems with multicollinearity in their data. They claim that their lane-mile elasticities are high because they capture reclassification of various road categories, such as rural to urban. They use their models as a means of forecasting statewide VMT, an approach that might be feasible with these sort of models as a way of estimating carbon emissions.

A recent model using data from Switzerland also finds a significant induced travel effect (Weis, Axhausen 2009). Using a pseudo-panel constructed from a series of national travel surveys, an accessibility indicator is constructed as is a generalized cost index. Estimation of a structural equation model shows a statistically significant effect of elasticities for various components of travel demand; for example number of trips, trip distance, and trips per tour are calculated. This is one of the benefits of using this type of data which allows disaggregation of different behavioral components. However, the key conclusion from this study is again that there is a large and statistically significant effect, although it is difficult to strictly compare their elasticities with the other studies listed in Table 22.

As Table 22 demonstrates, all of these models find statistically significant effects and parameter estimates within reasonable ranges. (Cervero, Hansen 2002) and (Cervero 2003) note that all these models used similar methodologies, and suggest that different approaches are needed to more firmly establish the validity of the theoretical effects.

Facility-Specific Studies

Facility-specific studies have examined the impact of specific links or corridors within the transportation network and subsequent growth in VMT. These include growth comparisons and quasi-experimental or matched-pair comparisons. Regression models have also been employed using facility level data as an independent variable.
A matched pair study, conducted by (Mokhtarian et al. 2002) was conducted using California data. This study attempted to match similar roads, with and without a capacity improvement, and confounders were assumed to be controlled for by matching similar road pairs. This type of study would not be able to control for endogeneity, in

that a transportation planning authority made a presumably rational choice to improve one facility but not its comparable mate in a matched pair. Likewise, any network effects associated with the improved road, such as growth on alternative routes, would not be properly captured. It is unsurprising, therefore, that (Mokhtarian et al. 2002) found no significant effect.

(Goodwin 1996) reviewed facility-specific studies (mainly bypasses of town centers in the United Kingdom) connecting distance traveled to fuel cost, highway capacity, and travel time. He found fuel cost elasticities within a range of -0.1 to -0.5. That review estimated an elasticity of traffic relative to highway capacity of 0.11, which approximated a benchmark. (Goodwin 1996) estimated the elasticity of demand for time based on a cross elasticity for the demand for money, particularly as fuel cost as follows: $E_t = E_m * V_t * M$ where E_t is the demand elasticity for time savings, E_m is the demand elasticity for fuel cost savings, V_t is the value placed on time and M is the money value of fuel cost (p.40). This provides a basis from which (Goodwin 1996) calculates demand elasticities with respect to travel time. On this basis generalized observed traffic flows between 10% and 20% higher than a null hypothesis of no induced traffic, with a range between 0% and 40% are predicted. What was found was an average increase of 20% within a range of 9% to 44% of the flow before improvements. Long term increases were even higher. (Goodwin 1996) also noted that growth of peak period flows were relatively higher, suggesting that peak-spreading was diminished, while some alternate routes had lower flow than predicted. (Goodwin 1996) approximated an average travel time elasticity of -0.5 in the short run and -1.0 in the long run based on the literature at that time.

(Cervero 2003) estimates a structured equation model that includes changes in road speed, as the mediating influence on behavioral change, and links new capacity to development activity and VMT. His estimates also account for endogenous effects of how VMT and development activity affect both speeds and increased road capacity. Road capacity is measured using a selection of specific projects, rather than aggregate changes in lane miles as other models have done. He finds statistically significant effects and this suggests a useful approach for linking individual projects to potential increases in carbon emissions.

Cervero’s results are listed in Table 22 and provide both short and long run elasticity estimates. While he claims that he shows smaller effects than other studies, this is not an accurate interpretation of other results. He attributes about 40% of VMT growth to capacity improvements, while (Noland 2001) found at most 28%, with other demographic and economic factors associated with the remainder. Despite this flaw in how Cervero’s model results have been interpreted, the structure is useful for dissecting different sources of growth in VMT (speeds and development effects) and for accounting for endogeneity.

(Cervero 2003) suggests that more sophisticated modeling of travel demand may result in lower elasticity estimates, which could most usefully be used to calibrate long range travel forecasting and urban simulation models such as MEPLAN, TRANUS, and

TRANSIMS. Like (Gorham 2009), (Cervero 2003) is concerned with accuracy of measurement. However, Cervero's (Cervero 2003) concern is more with over than underestimation, because he perceives a political agenda and methodological sloppiness have exaggerated estimates to the detriment of those interests served by development. We discuss these more disaggregate approaches using integrated transport and land use models in the next section.

Disaggregate Data Analysis

(Strathman et al. 2000)(Williams 1977)(Williams 1977) use panel data to estimate a model for 48 urban areas in the United States for the purpose of distinguishing between the direct effects of highway capacity measured as lane miles and the indirect effects factoring out the effects on residential and employment location choices of lane miles on VMT. They select a sample of roughly 12,000 individual respondents from the 1995 Nationwide Personal Transportation Survey (NPTS) and 48 urban areas from the Texas Transportation Institute database. (Strathman et al. 2000) report a direct elasticity of per capita roadway capacity to VMT of 0.29 and an indirect elasticity (representing the secondary effects due to changes in land use) of 0.033. The meaning of the indirect elasticity value is questionable because residential and employment location choices are affected by induced travel effects. It is doubtful that the indirect elasticity would be much help in estimating future effects.

(Barr 2000) also used the NPTS data to estimate short term elasticities. However, his sample was nationwide and included roughly 27,000 households of which 61% were in urbanized areas and 63% had access to public transportation. A model was estimated with VMT as the dependent variable while the independent variables included the inverse of speed, census tract population density, annual and per capita family income, household size, number of workers in households, the median household income of the census tract and an error term. (Barr 2000) estimates travel time elasticities between -0.3 and -0.5.

It is notable that models using both aggregate and disaggregate data, estimated at a variety of levels of spatial aggregation, predict travel demand elasticities in a range of about 0.2 to 0.6 in the short term and 0.6 to 1.0 in the long term. These results show stability in the reliability of travel demand elasticities in that they can be arrived at consistently by more than one method. It is pointed out broadly that the fact of a correlation does not imply causality on the face of it (Noland, Lem 2002, Cervero 2002). The direct lane mile elasticities calculated using both methods appear comparable in magnitude. Although the range of elasticities seems somewhat larger in the aggregate regression models, the small number of studies, the variety of models, and the differences of geographic scale and facility type may have contributed to this. It is not possible to assess what loss of effectiveness there is in choosing a direct measure of the dependent variable, i.e. travel time, over a proxy measure, i.e. lane miles, although the results seem to show considerable consistency.

Disaggregate Regional Travel Demand Models and Land Use Modeling

(Cervero 2002) and (Noland, Lem 2002) note that among transportation planners there is a preference for disaggregate models, as opposed to the aggregate regression models previously discussed. This largely dates to problems with zonal gravity model approaches used in the early years of transportation planning, but disaggregate individual level modeling comes with its own costs and complexities, especially for estimating induced travel effects. Several methods have been used, including the use of four-step travel demand modeling approaches.

Table 23. Estimates using travel demand models.

Model	Method	Scale	Type	Elasticities	
				Short Term	Long Term
(DeCorla-Souza 2000)					
No Feedback	Four step	Facility	Travel Time		-0.7 *
Feedback	Four step	Facility	Travel Time		-1.1 *
(Rodier et al. 2001)					
25 years	MEPLAN	Metro	Lane Miles		0.8
50 years	MEPLAN	Metro	Lane Miles		1.1
* Term uncertain.					

Four step models are the traditional approach to estimating travel demand used to assess specific road and transit projects. Four step models are generally zonal in nature, although there are disaggregate modeling applications that address travel behavior at the person or household level (Frank, Stone 2000). In practice, they generally lack sufficient feedback mechanisms and are widely acknowledged to fail to fully capture induced travel effects. Some areas have implemented more complex activity-based modeling approaches that might better capture some of these effects, but may still not adequately account for the multitude of feedback mechanisms required for a full accounting, in particular feedback to land development effects. Four step models are able to directly calculate time elasticities (DeCorla-Souza 2000) (McDonald 2008)(McDonald 2008)or lane mile elasticities (Rodier et al. 2001).

(Rodier et al. 2001) implement the MEPLAN integrated land use/transport model for metropolitan Sacramento to explicitly examine induced travel effects. MEPLAN, in theory, allows for the full integration of land use and economic effects associated with lane mile increases, as opposed to the typical exogenous assumptions made on how land use may change. They find significant differences associated with forecasts that assume induced travel effects compared to not using sufficient feedback (Rodier et al. 2001) estimate forecasts for 25 and 50 year predictions and assess the sensitivity of criteria pollutants to the corrections of their enhancements by withholding the effects of the enhancements that would not be found in a traditional four step model. At 25 years they project the following differences in increases of emissions between their model and a hypothetical traditional four step model: total organic gases (TOG) 10% vs. -5%, Carbon Monoxide (CO) 12% vs. -2%, Nitrogen Oxides (NOx) 12% vs. -1%, and particulate matter (PM) 8% vs. -8%. At 50 years they project the following differences between their model and a hypothetical model: TOG 9% vs. -7%, CO 13% vs. -4%, NOx 16% vs. -1%, and PM 6% vs. -9%. For every pollutant the traditional model predicted a decrease while induced travel effects suggest a substantial increase. They do not include an estimate for CO_2 emissions, but that can easily be done with this sort of approach.

The MEPLAN modeling framework that (Rodier et al. 2001) includes separate but interactive land and transportation markets. The region is disaggregated spatially and classified by land use type. Discrete choice models predict the location choices based on the attractiveness of each, which is a function of activity-specific input costs including transportation costs based on a transportation network and location-specific disutilities. Through an incremental model, lags provide feedback of transportation costs from one period to the land market model of the next, so that land use is handled dynamically. This application includes eleven industry classifications to match employment with locations; three classifications of household income that incorporates residential location; business consumption of household labor; business activities of households to purchase goods and services; and, consumption of space based on elasticities for seven types of land use. Vacant land and different rents paid for similar land use are also tracked. Exogenous demand by industry and retiring and unemployed households is accounted for.

In addition to the land use components, they also made substantial improvements to the Sacramento regional transportation model, to better incorporate other induced travel effects (beyond the long term land use impacts). These specifically include better feedback from trip generation, distribution, mode choice, and network assignment steps of the model.

(Rodier et al. 2001) report lane mile elasticities of 0.8 projected out 25 years and 1.1 projected out 50 years. Using a simpler model without the intricate feedbacks of (Rodier et al. 2001), (DeCorla-Souza 2000) reports travel time elasticities of -0.7 with feedback withheld and -1.1 with feedback accounted for. (DeCorla-Souza 2000) does not state the time frame in connection with these travel time elasticities, although he notes that they are above a benchmark of -0.4 which represents the average long term household travel time elasticity for personal highway travel.

(Dowling et al. 2005) attempted to develop a full model for estimating how a specific project may induce travel and link this to the emissions from vehicles. This project included a modal emissions model to account for how vehicle dynamics change in response a given project. While this is a useful approach to follow, the main problem with their approach is the large amount of error introduced by any large scale modeling effort. In theory, this would be a problem with any regional travel demand model, including the integrated approach used by (Rodier et al. 2001). Other approaches include those of (Waddell et al. 2007) that implement the UrbanSim location choice model. These types of land use models are dependent on large databases disaggregated to parcel level data and are estimated using discrete choice methods, which can introduce significant levels of uncertainty and error in the results. As an example of the inherent uncertainty of all these approaches, (Rodier, Johnston 2002) found emissions forecasting to be very sensitive to population and employment growth such that it would likely swamp any measurable impact from a specific project, using regional modeling approaches.

Sketch Planning Models

The FHWA has developed at least two simple sketch planning models that presumably account for induced travel effects. These are the SMITE and STEAM models. SMITE was developed as a method to estimate induced travel effects at the corridor level. SMITE uses travel time elasticities, based on (Goodwin 1996) to estimate trips that are diverted to an improved facility. This is represented by $V_i = H_o / (M - (E_d * Sav))$, where V_i is induced VMT, H_o is the initial time savings from an investment, M is the increase in drive time for other drivers due to congestion per added vehicle, E_d is the elasticity of the demand for time, and Sav is the average speed, (DeCorla-Souza, Cohen 2009) (p. 5). The increase in travel time (H_i) is based on the induced VMT and the initial congestion level: $H_i = V_i * M$ so that $V_i = H_i / M$. Because E_d is negative and average speed is positive, the congestion term in the denominator after the induced effects set in is $M - (E_d * Sav)$ and should be greater than the initial congestion term M. Users input initial conditions on the freeway and the arterials including initial VMT, and the proportional freeway and arterial shares of VMT. SMITE calculates initial, arterial and freeway VMT and diverted and induced VMT for the arterials, the freeway, and the corridor as a whole, for low, moderate, and high congestion levels. SMITE also calculates changes in average speed based on the improvement, and thus potentially offers a way to calculate emissions.

STEAM is the second generation of sketch planning tool designed by FHWA for the purpose of conducting cost benefit analysis on transportation planning alternatives at the corridor level (DeCorla-Souza, Hunt 1999). It replaces SPASM, a spreadsheet application. STEAM performs cost benefit analyses, including assessment of global warming impacts based on CO_2 emissions, as well as criteria pollutants: HC, CO, NOx, and PM. STEAM improves on SPASM, its predecessor, by addressing VMT rather than volume measurements. It accepts output from four-step modeling applications after the traffic assignment step. It can accommodate travel demand forecasts but does not incorporate induced travel effects.

STEAM has four components including a user interface and a network analysis model, which holds the parameters of a traffic grid including highway traffic volumes, the lengths, capacities, and related information about facility links, including distance based on minimized time costs (DeCorla-Souza, Hunt 1999). Another component implements trip table analysis and estimates costs and benefits through comparison of base and improved case scenarios, including emissions. The fourth component provides a summary. STEAM handles multiple modes including private auto, carpool, bus, walking to light rail, and driving to light rail for home-based purposes including work, school, non-work, as well as non home-based trips and truck travel. Motor vehicle speed is calculated based on average weekday traffic-to-capacity ratios (AWDTC) (DeCorla-Souza, Hunt 1999), p.6). Non-highway passenger travel is based on passenger count data. STEAM uses a trip based approach to estimate emissions, by which for each trip the emissions based on hot-stabilized VMT is added to the increased emissions that result from a cold start, i.e. the difference between start and hot-stabilized emissions for a proportion of all trips. That proportion has a default but is adjustable. CO_2 and other greenhouse gas emission estimates are based on fuel consumption (DeCorla-Souza, Hunt 1999)(Guo, Bhat & Copperman 2007)(Guo, Bhat & Copperman 2007). While this model has significant detail, it is not designed to explicitly examine the effects associated with induced travel.

Forecasting and Estimating CO_2 Emissions

The key objective here is to determine whether any of these approaches can provide a simple and valid means of estimating project specific CO_2 emissions. While integrated land use / transportation models offer a very detailed method, they suffer from significant potential errors that make assessment of emissions associated with a single project (within a large region) prone to being drowned out by other regional impacts (this was a problem with (Dowling et al. 2005). (Rodier et al. 2001) manage to develop estimates, but these are typically for a package of lane mile additions throughout a region.

Aggregate econometric methods offer some potential as being a simplified method for estimating CO_2 emissions. (Noland 2001) demonstrated this in his state-level study, providing a short term forecast of VMT growth and the effect on CO_2 emissions. (Liu et al. 2006) attempt a similar approach using county-level data for Pennsylvania, but do not calculate emissions. Both (Noland 2001) and (Liu et al. 2006) are based on state and county level aggregations, respectively, which do not necessarily translate to a project level assessment. However, the elasticities generated from these studies (or a similar study for New Jersey) can provide a means for estimating increases in facility specific VMT associated with changes in lane miles. The method developed by (Cervero 2003) provides one option for using facility-specific lane mile changes to estimate VMT growth.

Data necessary to estimate these models is typically readily available or can be supplied by DOT. In addition to data on VMT and lane miles (perhaps disaggregated to facility type), various demographic and income data is also used, as well as fuel prices. Much of the demographic data is highly correlated, so in practice it is often impossible to use more than total population and income within most models. The advantage of these approaches is the simplicity of the data inputs and the clarity of the models; as opposed to large scale regional models which have many uncertainties.

The key benefit of these approaches is nicely summed up by (Goodwin 1992) who said: “demand elasticities are, in general, rather crude and approximate measures of aggregate responses in a market. They do, however, have the great attractions of being empirically estimable, reasonably easily understood, tested by experience, and directly usable for policy assessment. (p. 155)" They are desirable planning tools because they show relationships in a way that is useful for prediction.

While these methods offer an approach for estimating VMT growth, conversion to CO_2 emissions potentially adds additional complexity. The fuel efficiency of the vehicle is directly linked to CO_2 emissions, for a given fuel type. Most vehicles use gasoline, frequently with a 10% ethanol blend. Diesel vehicles tend to be more fuel efficient, but represent a relatively small share of personal vehicles. Emissions estimation models, specifically those developed by EPA (the Mobile6 model and the soon to be released MOVES model) account for the characteristics of the vehicles in the fleet in calculating emissions.

The Mobile6 model separates the driving process into three stages, including cold starts in which engines run inefficiently until they become hot-stabilized and operate at peak efficiency, warm starts, and hot-stabilized, with separate profiles for each (Barth et al. 1996)(Barth et al. 1996, Frank et al. 2007)(Barth et al. 1996, Frank et al. 2007). Emissions are estimated based on average speeds and distance traveled. Adjustments are made to correct for fuel type, ambient temperature, and acceleration/deceleration, but the effects of acceleration and deceleration are underestimated (Barth et al. 1996). Thus a key deficiency of these models is that they do not adequately account for how changes in the road network may change the dynamics of vehicle acceleration and the levels of stop and go driving, both of which tend to lead to reduced vehicle efficiency and consequently more CO_2 emissions.

Several approaches have been developed to better estimate the microscopic emissions associated with vehicle operation. These include the Comprehensive Modal Emissions Model (CMEM) developed at the University of California, Riverside (Barth et al. 1999). This model provides a method to link second-by-second operation of the vehicle to instantaneous emissions. In practice these can be integrated with a microscopic traffic simulation model (e.g. VISSIM, Paramics, Transims).

This has been done by (Stathopoulos, Noland 2003) and (Noland, Quddus 2006) to specifically examine how much induced travel negates the short-term emissions reductions from congestion reduction projects. In the short term, these models demonstrate how reducing stop-and-go traffic, excess idling, and hard accelerations will reduce vehicle emissions (especially criteria pollutants). This effect is demonstrated in both studies. These studies then assume various levels of induced travel, which in theory would occur in response to a congestion reduction, and find that emissions tend to rapidly increase to initial levels. While there is variation based on the assumptions used, in general, the levels of traffic generated that negate the emissions benefit are well within the expected range suggested by induced travel studies. This effect tends to be larger for criteria pollutants than for CO_2 emissions, but it still occurs in most instances for the latter. (Noland, Quddus 2006) further show that as vehicle technology has improved, the short term improvements have diminished, implying a greater correlation between VMT and emissions, as opposed to the effects from accelerations and stop-and-go driving conditions. New hybrid vehicles tend to also be more efficient in urban driving conditions than in free-flow high-speed conditions; primarily due to the ability to rely on battery power at lower speeds.

The CMEM model is relatively dated and was based on a limited dataset of vehicle, and thus is not appropriate for actual measurement. The overall technique of simulated back-casting of induced travel impacts, however, offers a simple approach for evaluating CO_2 emissions, without explicitly specifying any demand model. This method could be used with the new MOVES model combined with a traffic micro-simulation.

The MOVES model (released in Jan 2009) will estimate the full range of GHG emissions. In addition to CO_2 this includes nitrous oxide (N_2O), and methane (CH_4) (Koupal et al. 2002). MOVES will allow classification of separate classes of motor vehicles and off-road equipment. It will allow estimation based on operating mode bins that capture discrete operating modes of vehicles. Operating modes for motor vehicles include cold and warm starts and hot-stabilized running as with MOBILE, but have been expanded to handle extended idling, upstream energy use associated with fuel use by a source, and emissions associated with manufacture and disposal. The intent is to capture full life cycle emissions. MOVES is designed to handle combustion emissions from running and start exhaust, and extended idle, hydrocarbon emissions from hot soak, diurnal, resting loss, as well as running and refueling loss. It is also designed to handle effects from brake and tire wear. Analysis can be done at a high level of aggregation or macroscale, which is a county level analysis, a mesoscale, which is appropriate for local analyses and is at the facility link level of resolution, or at a microscale for estimating emissions in specific corridors or facilities. These levels have decreasing time resolutions as well. MOVES incorporates a four step procedure and a set of utilities referred to as data generators that are essentially after processors (Koupal et al. 2002). Currently, the MOVES model does not include sufficient detail on the characteristics of hybrid vehicles and thus this limits the ability to consider the interaction of new technologies with flow improvement projects. However, eventually the vehicle database will presumably include this capability.

Conclusions

This review has focused on establishing the basic theoretical features of how traffic is induced in response to new road capacity. Basic economic theory provides a fundamental relationship between road supply and demand with travel time of individuals being the price that is determined at equilibrium. We further show how basic urban economic theory implies that long-run effects can be captured by changes in land use and consequently new development that occurs in response to increased accessibility. Thus this leads us to conclude that theoretically there is no question of how reducing congestion through new road projects, or even building new roads that access undeveloped land, will result in increased vehicle travel.

Our review of empirical studies finds conclusive evidence of this theoretical relationship. We also examined whether any of the empirical methods might be suitable for forecasting and estimates of CO_2 emissions. Some models have been used for this purpose and in theory a model could be developed for New Jersey with suitable data. These can use either county-level aggregations of changes in road capacity, or even facility-level changes, if a suitable time-series is available. The key uncertainty is how forecasts of population, income, and fuel prices may affect future VMT, but for a comparative analysis, one can examine alternative scenarios.

The other approach frequently advocated is the use of integrated transport/land use models. These tend to be very data intensive, and while some models are based on a strong theoretical basis, the implementation is both difficult, costly, and potentially prone to error, especially if examining the impacts from only one project.

Calculating emissions from VMT will ultimately be done with the MOVES model set to be released by EPA in January 2009. This model is being developed such that facility-specific impacts can be evaluated. The model can also be integrated with a traffic microsimulation model. This latter approach provides a way to evaluate the changes in vehicle dynamics and the details of how vehicle flow may change. While MOVES does not provide second-by-second emissions, as do experimental models such as CMEM, it is an improvement over Mobile6. Back-casting approaches can then be used to examine different assumptions on how traffic levels may grow in response to specific changes in the traffic network.

CONCLUSIONS AND FURTHER RESEARCH NEEDS

This report documents the development of the GASCAP spreadsheet software for analyzing the life-cycle greenhouse gas emissions from transportation capital projects. Over the course of this project we have identified additional research needs and further work to fully develop this as a tool that NJDOT can use to assess and compare different projects. Each of these key areas is outlined below.

Materials module

The current materials module is based on over 1000 bid-sheet items plus detailed calculations for asphalt and concrete, allowing variations in production processes to be modeled. Despite this, our case studies found various gaps in our coverage of bid sheet items. Feedback from NJDOT staff is necessary on this module to help find missing components. In addition, various electronic and landscaping items (700 and 800s in the bid-sheets) were not included but could be added with additional effort. Other minor materials could also be included.

Equipment module

The main shortcoming of GASCAP is that it is necessary for users to use informed judgment about the mix of equipment and the duration of its use for each project. There is no current information on equipment activity for specific projects. While we expect that contractors and NJDOT engineers likely can assess these needs, ideally the data should be compiled and connected with specific project types, particularly those that occur on a frequent basis. Information on fuel consumption associated with a sample of projects may allow us to develop models that estimate fuel consumption for projects and allow us to allocate these to equipment. Another project currently being completed by a NJDOT contractor should be available in August 2011 and will provide a starting point for this analysis (see also discussion under life-cycle maintenance).

Life-cycle maintenance

An original objective was to develop an approach that could evaluate how maintenance over the life of a project could reduce overall greenhouse gas emissions. Unfortunately we were unable to find standard procedures or reports that document best practices used by NJDOT. We were able to find some reports from other states and the current software contains an uncompleted module that lays out a framework for a life-cycle maintenance approach. This was not completed, as a critical input was to coordinate this component with another project being completed by a NJDOT contract that is not expected to be ready until August 2011. When this data is available, it should provide an opportunity to estimate fuel consumption for a variety of maintenance activities with some additional effort applying the NONROAD model. These data could also be used to estimate GHG emissions from construction activities.

Once this module is completed, it will be incumbent upon NJDOT staff to provide feedback so that the defined maintenance procedures are compatible with NJDOT practice.

Staging module

GASCAP currently includes a module that allows the user to input information on how the project will be staged. This module could be significantly upgraded by providing estimates of how traffic is delayed or diverted during road closures. Estimates of the increase in GHG emissions from this traffic would be beneficial for making decisions on how best to stage a project to minimize GHG emissions. This will also require a more detailed mapping algorithm for calculating alternative routes, than is currently used by GASCAP for estimating transportation distances for project materials to the site.

Lighting module

Additional lighting technologies are rapidly coming on line. We will need to update the available technologies in the lighting (and staging) modules of GASCAP.

Rail module

The approach used in GASCAP to estimate rail construction emissions is somewhat limited using average emission estimates based on a small sample of studies, especially for station and platform construction, bridges, and tunneling. This could be improved, pending data availability, by a bottom-up approach that decomposes the individual components in rail construction projects. NJ Transit bid-sheet data is very limited and further work would need to include additional input from NJ Transit on the detailed inputs to their capital projects.

Emissions coverage

GASCAP currently does not include estimates for SF_6 a GHG which is associated with production of electrical equipment. GASCAP could also be upgraded to include estimates of other criteria pollutants (NO_X, VOC, and particulates) allowing it to be used for assessing localized pollutant impacts.

Updating procedures

Research into life-cycle GHG emissions is continually evolving, as technology changes and as new information is obtained. For example, recent evidence suggests that natural gas usage may have larger life-cycle emissions than previously thought due to leakage from shale formations currently being exploited. EPA and ANL are continually providing updates to their models (NONROAD, MOVES, and GREET). As a result, procedures are needed to allow the user to easily update GASCAP with inputs from these models for future years.

Future technologies

Various future technologies can be investigated for their practical feasibility and to provide options for evaluating them in GASCAP. For example, various "green" pavements, including those with increased reflectivity (see Appendix D) might be feasible to use. Other technologies on the horizon include concrete that is able to absorb greater quantities of CO_2. Further discussion with NJDOT staff as to the applicability of these technologies in New Jersey is warranted and consideration of ways to implement these in GASCAP could be analyzed.

Induced travel module

DEP staff have expressed a desire for a method that can evaluate the impact of alternative projects on travel behavior. This is a useful endeavor and as part of this project we have provided a review of potential approaches to develop sketch-planning methods that would be able to estimate induced travel and the emissions associated with it. This would be a larger undertaking requiring extensive data collection, and would require significant resources to fully implement.

Training, testing and feedback

NJDOT and NJ Transit staff need to be trained on the use of GASCAP. As developed, the software is very user friendly, so we do not anticipate that training is a major task. However, obtaining feedback from staff after they have tested the capabilities of GASCAP is essential. We expect that this will provide useful information on the usability of the software and any major omissions or assumptions that need to be corrected.

APPENDIX A. SPARK IGNITION ENGINES

Table 24. Steady State Emissions from Spark Ignition Engines

Emissions and BSFC for Class III Handheld Small Spark Ignition Engines (< 20cc)							
Engine Tech Type			Steady State				
	HP Min hp-hr	HP Max hp-hr	HC g/hp-hr	CO g/hp-hr	NOx g/hp-hr	PM g/hp-hr	BSFC lb/hp-hr
G2H3 (gas 2-stroke handheld Class III baseline)	0	1	261.000	718.870	0.970	7.700	1.365
G2H31 (Phase 1)	0	1	219.990	480.310	0.780	7.700	1.184
G2H3C1 (Phase 1 with catalyst)	0	1	219.990	480.310	0.780	7.700	1.184
G2H32 (Phase 2)	0	1	33.070	283.370	0.910	7.700	0.822
G2H3C2 (Phase 2 with catalysts)	0	1	26.870	141.690	1.490	7.700	0.822

Emissions and BSFC for Class IV Handheld Small Spark Ignition Engines ($20cc and <50cc)							
Engine Tech Type			Steady State				
	HP Min hp-hr	HP Max hp-hr	HC g/hp-hr	CO g/hp-hr	NOx g/hp-hr	PM g/hp-hr	BSFC lb/hp-hr
G2H4 (gas 2-stroke handheld Class IV baseline)	1	3	261.000	718.870	0.940	7.700	1.365
G2H41 (Phase 1)	1	3	179.720	407.380	0.510	7.700	1.184
G2H4C1 (Phase 1 with catalyst)	1	3	179.720	407.380	0.510	7.700	1.184
G4H41 (Phase 1 4-stroke)	1	3	22.370	533.420	1.790	0.060	0.847
G2H42 (Phase 2)	1	3	33.070	283.370	0.910	7.700	0.822
G2H4C2 (Phase 2 with catalysts)	1	3	26.870	141.690	1.490	7.700	0.822
G4H42 (Phase 2 4-stroke)	1	3	25.830	432.510	1.130	0.060	0.847

Emissions and BSFCs for Class V Handheld Small Spark Ignition Engines (>50cc)							
Engine Tech Type			Steady State				
	HP Min hp-hr	HP Max hp-hr	HC g/hp-hr	CO g/hp-hr	NOx g/hp-hr	PM g/hp-hr	BSFC lb/hp-hr
G2H5 (gas 2-stroke handheld Class V baseline)	3	6	159.580	519.020	0.970	7.700	0.921
G2H51 (Phase 1)	3	6	120.060	351.020	1.820	7.700	0.870
G2H5C1 (Phase 1 with catalyst)	3	6	120.060	351.020	1.820	7.700	0.870
G2H52 (Phase 2)	3	6	47.980	283.370	0.910	7.700	0.608
G2H5C2 (Phase 2 with catalysts)	3	6	40.150	141.690	1.490	7.700	0.608

Table 22. Steady State Emissions from Spark Ignition Engines – continued

Emissions and BSFCs for Class I Nonhandheld Small Spark Ignition Engines (< 225cc)							
Engine Tech Type			Steady State				
	HP Min hp-hr	HP Max hp-hr	HC g/hp-hr	CO g/hp-hr	NOx g/hp-hr	PM g/hp-hr	BSFC lb/hp-hr
G2N1 (gas 2-stroke nonhandheld Class I baseline)	3	6	207.9200	485.8100	0.2900	7.7000	0.870
G4N1S (gas side-valved 4-stroke nonhandheld Class I baseline)	3	6	38.9900	430.8400	2.0000	0.0600	1.365
G4N1O (gas overhead-valved 4-stroke nonhandheld Class I baseline)	3	6	13.390	408.840	1.800	0.060	0.991
G2N11 (2-stroke Phase 1)	3	6	120.060	449.660	4.000	7.700	0.870
G4N1S1 (Phase 1 side-valved 4-stroke)	3	6	8.400	353.690	3.600	0.060	0.921
G4N1O1 (Phase 1 overhead valved 4-stroke)	3	6	8.400	351.160	3.240	0.060	0.781
G4N1SC1 (Phase 1 side-valved 4-stroke with catalyst)	3	6	8.400	353.690	3.600	0.060	0.921
G4N1S2 (Phase 2 side-valved)	3	6	7.930	353.690	2.370	0.060	0.921
G4N1O2 (Phase 2 overhead valved)	3	6	6.130	351.160	1.830	0.060	0.781
Emissions and BSFC for Class II Nonhandheld Small Spark Ignition Engines (≥ 225cc)							
Engine Tech Type			Steady State				
	HP Min hp-hr	HP Max hp-hr	HC g/hp-hr	CO g/hp-hr	NOx g/hp-hr	PM g/hp-hr	BSFC lb/hp-hr
G2N2 (gas 2-stroke nonhandheld Class II baseline)	6	25	207.920	485.810	0.290	7.700	0.870
G4N2S (gas side-valved 4-stroke nonhandheld Class II baseline)	6	25	9.660	430.840	2.060	0.060	0.937
G4N2O (gas overhead-valved 4-stroke nonhandheld Class II baseline)	6	25	5.200	408.840	3.500	0.060	0.937
G4N2S1 (Phase 1 side-valved 4-stroke)	6	25	5.500	387.020	4.500	0.060	0.868
G4N2O1 (Phase 1 overhead valved 4-stroke)	6	25	5.200	352.570	3.500	0.060	0.740
G4N2S2 (Phase 2 side-valved)	6	25	5.500	387.020	4.500	0.060	0.868
G4N2O2 (Phase 2 overhead valved)	6	25	4.160	352.570	2.770	0.060	0.740

Table 22. Steady State Emissions from Spark Ignition Engines – continued

Emission Factors and BSFC for Spark-Ignition Engines > 25 HP							
Engine Tech Type			Steady State				
	HP Min hp-hr	HP Max hp-hr	HC g/hp-hr	CO g/hp-hr	NOx g/hp-hr	PM g/hp-hr	BSFC lb/hp-hr
Uncontrolled							
G4GT25 (gas 4-stroke baseline)	25	3000	3.8500	107.2300	8.4300	0.0600	0.605
LGT25 (LPG baseline)	25	3000	1.6800	28.2300	11.9900	0.0500	0.507
NGT25 (CNG baseline)	25	3000	24.6400	28.2300	11.9900	0.0500	0.507
Phase 1							
G4GT251 (gas 4-stroke)	25	3000	0.5900	29.8600	1.5100	0.0600	0.484
LGT251 (LPG)	25	3000	0.2500	24.4900	2.1000	0.0500	0.406
NGT251 (CNG)	25	3000	3.6900	24.4900	2.1000	0.0500	0.406
Phase 2							
G4GT252 (gas 4-stroke)	25	3000	0.2700	11.9400	0.6900	0.0600	0.484
LGT252 (LPG)	25	3000	0.1000	3.9200	0.8500	0.0500	0.406
NGT252 (CNG)	25	3000	1.5700	3.9200	0.8900	0.0500	0.406

Source: Tables 1-6 in Exhaust Emission Factors for Nonroad Engine Modeling: Spark-Ignition (EPA 2005b)(EPA 2005b)(EPA 2005b).

Table 25. Transient Activity Factors for Spark Ignition Engines

Emissions and BSFC for Class III Handheld Small Spark Ignition Engines (< 20cc)							
Engine Tech Type			TAF				
	HP Min hp-hr	HP Max hp-hr	HC	CO	NOx	PM	BSFC
G2H3 (gas 2-stroke handheld Class III baseline)	0	1	1.00	1.00	1.00	1.00	1.00
G2H31 (Phase 1)	0	1	1.00	1.00	1.00	1.00	1.00
G2H3C1 (Phase 1 with catalyst)	0	1	1.00	1.00	1.00	1.00	1.00
G2H32 (Phase 2)	0	1	1.00	1.00	1.00	1.00	1.00
G2H3C2 (Phase 2 with catalysts)	0	1	1.00	1.00	1.00	1.00	1.00
Emissions and BSFC for Class IV Handheld Small Spark Ignition Engines (≥20cc and <50cc)							
Engine Tech Type			TAF				
	HP Min hp-hr	HP Max hp-hr	HC	CO	NOx	PM	BSFC
G2H4 (gas 2-stroke handheld Class IV baseline)	1	3	1.00	1.00	1.00	1.00	1.00
G2H41 (Phase 1)	1	3	1.00	1.00	1.00	1.00	1.00
G2H4C1 (Phase 1 with catalyst)	1	3	1.00	1.00	1.00	1.00	1.00
G4H41 (Phase 1 4-stroke)	1	3	1.00	1.00	1.00	1.00	1.00
G2H42 (Phase 2)	1	3	1.00	1.00	1.00	1.00	1.00
G2H4C2 (Phase 2 with catalysts)	1	3	1.00	1.00	1.00	1.00	1.00
G4H42 (Phase 2 4-stroke)	1	3	1.00	1.00	1.00	1.00	1.00
Emissions and BSFCs for Class V Handheld Small Spark Ignition Engines (>50cc)							
Engine Tech Type			TAF				
	HP Min hp-hr	HP Max hp-hr	HC	CO	NOx	PM	BSFC
G2H5 (gas 2-stroke handheld Class V baseline)	3	6	1.00	1.00	1.00	1.00	1.00
G2H51 (Phase 1)	3	6	1.00	1.00	1.00	1.00	1.00
G2H5C1 (Phase 1 with catalyst)	3	6	1.00	1.00	1.00	1.00	1.00
G2H52 (Phase 2)	3	6	1.00	1.00	1.00	1.00	1.00
G2H5C2 (Phase 2 with catalysts)	3	6	1.00	1.00	1.00	1.00	1.00

Source: Explanation of non-use of TAFs for small Spark Ignition engines and Table 20 in Exhaust Emission Factors for Nonroad Engine Modeling: Spark-Ignition (EPA 2005b).

Table 23. Transient Activity Factors for Spark Ignition Engines – continued.

Emissions and BSFCs for Class I Nonhandheld Small Spark Ignition Engines (< 225cc)							
Engine Tech Type		TAF					
	HP Min hp-hr	HP Max hp-hr	HC	CO	NOx	PM	BSFC
G2N1 (gas 2-stroke nonhandheld Class I baseline)	3	6	1.00	1.00	1.00	1.00	1.00
G4N1S (gas side-valved 4-stroke nonhandheld Class I baseline)	3	6	1.00	1.00	1.00	1.00	1.00
G4N1O (gas overhead-valved 4-stroke nonhandheld Class I baseline)	3	6	1.00	1.00	1.00	1.00	1.00
G2N11 (2-stroke Phase 1)	3	6	1.00	1.00	1.00	1.00	1.00
G4N1S1 (Phase 1 side-valved 4-stroke)	3	6	1.00	1.00	1.00	1.00	1.00
G4N1O1 (Phase 1 overhead valved 4-stroke)	3	6	1.00	1.00	1.00	1.00	1.00
G4N1SC1 (Phase 1 side-valved 4-stroke with catalyst)	3	6	1.00	1.00	1.00	1.00	1.00
G4N1S2 (Phase 2 side-valved)	3	6	1.00	1.00	1.00	1.00	1.00
G4N1O2 (Phase 2 overhead valved)	3	6	1.00	1.00	1.00	1.00	1.00

Emissions and BSFC for Class II Nonhandheld Small Spark Ignition Engines (≥ 225cc)							
Engine Tech Type			TAF				
	HP Min hp-hr	HP Max hp-hr	HC	CO	NOx	PM	BSFC
G2N2 (gas 2-stroke nonhandheld Class II baseline)	6	25	1.00	1.00	1.00	1.00	1.00
G4N2S (gas side-valved 4-stroke nonhandheld Class II baseline)	6	25	1.00	1.00	1.00	1.00	1.00
G4N2O (gas overhead-valved 4-stroke nonhandheld Class II baseline)	6	25	1.00	1.00	1.00	1.00	1.00
G4N2S1 (Phase 1 side-valved 4-stroke)	6	25	1.00	1.00	1.00	1.00	1.00
G4N2O1 (Phase 1 overhead valved 4-stroke)	6	25	1.00	1.00	1.00	1.00	1.00
G4N2S2 (Phase 2 side-valved)	6	25	1.00	1.00	1.00	1.00	1.00
G4N2O2 (Phase 2 overhead valved)	6	25	1.00	1.00	1.00	1.00	1.00
Source: Explanation of non-use of TAFs for small Spark Ignition engines and Table 20 in Exhaust Emission Factors for Nonroad Engine Modeling: Spark-Ignition (EPA 2005b).							

Table 23. Transient Activity Factors for Spark Ignition Engines – continued.

Emission Factors and BSFC for Spark-Ignition Engines > 25 HP							
Engine Tech Type			TAF *				
	HP Min hp-hr	HP Max hp-hr	HC	CO	NOx	PM	BSFC
Uncontrolled							
G4GT25 (gas 4-stroke baseline)	25	3000	1.30	1.45	1.00	1.00	1.00
LGT25 (LPG baseline)	25	3000	1.30	1.45	1.00	1.00	1.00
NGT25 (CNG baseline)	25	3000	1.30	1.45	1.00	1.00	1.00
Phase 1							
G4GT251 (gas 4-stroke)	25	3000	1.70	1.70	1.40	1.00	1.00
LGT251 (LPG)	25	3000	2.90	1.45	1.50	1.00	1.00
NGT251 (CNG)	25	3000	2.90	1.45	1.50	1.00	1.00
Phase 2							
G4GT252 (gas 4-stroke)	25	3000	1.00	1.00	1.00	1.00	1.00
LGT252 (LPG)	25	3000	1.00	1.00	1.00	1.00	1.00
NGT252 (CNG)	25	3000	1.00	1.00	1.00	1.00	1.00
		* do not apply to generator sets, pumps, or air compressors					

Source: Explanation of non-use of TAFs for small Spark Ignition engines and Table 20 in Exhaust Emission Factors for Nonroad Engine Modeling: Spark-Ignition (EPA 2005b).

Table 26. Deterioration Factors for Spark Ignition Engines.

Emissions and BSFC for Class III Handheld Small Spark Ignition Engines (< 20cc)								
Engine Tech Type			Deterioration Factors A					b
	HP Min hp-hr	HP Max hp-hr	HC	CO	NOx	PM	BSFC	
G2H3 (gas 2-stroke handheld Class III baseline)	0	1	0.2	0.2	0.000	0.000	0.000	1.000
G2H31 (Phase 1)	0	1	0.24	0.24	0.000	0.000	0.000	1.000
G2H3C1 (Phase 1 with catalyst)	0	1	0.24	0.24	0.000	0.000	0.000	1.000
G2H32 (Phase 2)	0	1	0.24	0.24	0.000	0.000	0.000	1.000
G2H3C2 (Phase 2 with catalysts)	0	1	0.24	0.24	0.000	0.000	0.000	1.000

Emissions and BSFC for Class IV Handheld Small Spark Ignition Engines (≥20cc and <50cc)								
Engine Tech Type			Deterioration Factors A					b
	HP Min hp-hr	HP Max hp-hr	HC	CO	NOx	PM	BSFC	
G2H4 (gas 2-stroke handheld Class IV baseline)	1	3	0.2	0.2	0.000	0.000	0.000	1.000
G2H41 (Phase 1)	1	3	0.29	0.24	0.000	0.000	0.000	1.000
G2H4C1 (Phase 1 with catalyst)	1	3	0.29	0.24	0.000	0.000	0.000	1.000
G4H41 (Phase 1 4-stroke)	1	3	1.1	0.9	-0.600	1.100	0.000	1.000
G2H42 (Phase 2)	1	3	0.29	0.24	0.000	0.000	0.000	1.000
G2H4C2 (Phase 2 with catalysts)	1	3	0.29	0.24	0.000	0.000	0.000	1.000
G4H42 (Phase 2 4-stroke)	1	3	1.1	0.9	-0.600	1.100	0.000	0.500

Emissions and BSFCs for Class V Handheld Small Spark Ignition Engines (>50cc)								
Engine Tech Type			Deterioration Factors A					b
	HP Min hp-hr	HP Max hp-hr	HC	CO	NOx	PM	BSF C	
G2H5 (gas 2-stroke handheld Class V baseline)	3	6	0.2	0.2	-0.031	0.000	0.000	1.000
G2H51 (Phase 1)	3	6	0.266	0.231	0.000	0.000	0.000	1.000
G2H5C1 (Phase 1 with catalyst)	3	6	0.266	0.231	0.000	0.000	0.000	1.000
G2H52 (Phase 2)	3	6	0.266	0.231	0.000	0.000	0.000	1.000
G2H5C2 (Phase 2 with catalysts)	3	6	0.266	0.231	0.000	0.000	0.000	1.000

Source: Tables 1-5,7 - Nonroad Spark-Ignition Engine Emission Deterioration Factors (EPA 2005f).

Table 24. Deterioration Factors for Spark Ignition Engines- continued.

Emissions and BSFCs for Class I Non-handheld Small Spark Ignition Engines (< 225cc)								
Engine Tech Type			Deterioration Factors		A			b
	HP Min hp-hr	HP Max hp-hr	HC	CO	NOx	PM	BSFC	
G2N1 (gas 2-stroke nonhandheld Class I baseline)	3	6	0.201	0.199	0.000	0.000	0.000	1.000
G4N1S (gas side-valved 4-stroke nonhandheld Class I baseline)	3	6	1.1	0.9	-0.600	1.100	0.000	0.500
G4N1O (gas overhead-valved 4-stroke nonhandheld Class I baseline)	3	6	1.1	0.9	-0.600	1.100	0.000	0.500
G2N11 (2-stroke Phase 1)	3	6	0.266	0.231	0.000	0.000	0.000	0.500
G4N1S1 (Phase 1 side-valved 4-stroke)	3	6	5.103	1.109	-0.330	5.103	0.000	0.500
G4N1O1 (Phase 1 overhead valved 4-stroke)	3	6	1.753	1.051	-0.300	1.753	0.000	0.500
G4N1SC1 (Phase 1 side-valved 4-stroke with catalyst)	3	6	5.103	1.109	-0.330	5.103	0.000	0.500
G4N1S2 (Phase 2 side-valved)	3	6	5.103	1.109	-0.330	5.103	0.000	0.500
G4N1O2 (Phase 2 overhead valved)	3	6	1.753	1.051	-0.300	1.753	0.000	0.500

Emissions and BSFC for Class II Non-handheld Small Spark Ignition Engines (≥ 225cc)								
Engine Tech Type			Deterioration Factors		A			b
	HP Min hp-hr	HP Max hp-hr	HC	CO	NOx	PM	BSFC	
G2N2 (gas 2-stroke nonhandheld Class II baseline)	6	25	0.201	0.199	0.000	0.000	0.000	1.000
G4N2S (gas side-valved 4-stroke nonhandheld Class II baseline)	6	25	1.1	0.9	-0.600	1.100	0.000	0.500
G4N2O (gas overhead-valved 4-stroke nonhandheld Class II baseline)	6	25	1.1	0.9	-0.600	1.100	0.000	0.500
G4N2S1 (Phase 1 side-valved 4-stroke)	6	25	1.935	0.887	-0.274	1.935	0.000	0.500
G4N2O1 (Phase 1 overhead valved 4-stroke)	6	25	1.095	1.307	-0.599	1.095	0.000	0.500
G4N2S2 (Phase 2 side-valved)	6	25	1.935	0.887	-0.274	1.935	0.000	0.500
G4N2O2 (Phase 2 overhead valved)	6	25	1.095	1.307	-0.599	1.095	0.000	0.500

Source: Tables 1-5 and 7 - Nonroad Spark-Ignition Engine Emission Deterioration Factors (EPA 2005f).

Table 24. Deterioration Factors for Spark Ignition Engines- continued.

Emission Factors and BSFC for Spark-Ignition Engines > 25 HP								
Engine Tech Type			Deterioration Factors			A		b
	HP Min hp-hr	HP Max hp-hr	HC	CO	NOx	PM	BSFC	
Uncontrolled								
G4GT25 (gas 4-stroke baseline)	25	3000	1.1	0.9	-0.600	1.100	0.000	0.500
LGT25 (LPG baseline)	25	3000	1.1	0.9	-0.600	1.100	0.000	0.500
NGT25 (CNG baseline)	25	3000	1.1	0.9	-0.600	1.100	0.000	0.500
Phase 1								
G4GT251 (gas 4-stroke)	25	3000	1.1	0.9	-0.600	1.100	0.000	0.500
LGT251 (LPG)	25	3000	1.1	0.9	-0.600	1.100	0.000	0.500
NGT251 (CNG)	25	3000	1.1	0.9	-0.600	1.100	0.000	0.500
Phase 2								
G4GT252 (gas 4-stroke)	25	3000	1.1	0.9	-0.600	1.100	0.000	0.500
LGT252 (LPG)	25	3000	1.1	0.9	-0.600	1.100	0.000	0.500
NGT252 (CNG)	25	3000	1.1	0.9	-0.600	1.100	0.000	0.500

Source: Tables 1-5 and 7 - Nonroad Spark-Ignition Engine Emission Deterioration Factors (EPA 2005f).

APPENDIX B. COMPRESSION IGNITION ENGINES

Table 27. Zero-Hour, Steady-State Emissions from Compression Ignition Engines.

Power Rating	Technology Type	BSFC lb/hp-hr	Emission Factors (g/hp-hr)			
			HC	CO	NO_X	PM
<= 11 hp	Base	0.408	1.5	5.0	10.0	1.0
	Tier 0	0.408	1.5	5.0	10.0	1.0
	Tier 1	0.408	0.7628	4.1127	5.2298	0.4474
	Tier 2	0.408	0.5508	4.1127	4.3	0.50
	Tier 4A	0.408	0.5508	4.1127	4.3	0.28
	Tier 4B	0.408	0.5508	4.1127	4.3	0.28
>11 to 16 hp	Base	0.408	1.7	5.0	8.5	0.9
	Tier 0	0.408	1.7	5.0	8.5	0.9
	Tier 1	0.408	0.4380	2.1610	4.4399	0.2665
	Tier 2	0.408	0.4380	2.1610	4.4399	0.2665
	Tier 4A	0.408	0.4380	2.1610	4.4399	0.28
	Tier 4B	0.408	0.4380	2.1610	4.4399	0.28
>16 to 25 hp	Base	0.408	1.7	5.0	8.5	0.9
	Tier 0	0.408	1.7	5.0	8.5	0.9
	Tier 1	0.408	0.4380	2.1610	4.4399	0.2665
	Tier 2	0.408	0.4380	2.1610	4.4399	0.2665
	Tier 4A	0.408	0.4380	2.1610	4.4399	0.28
	Tier 4B	0.408	0.4380	2.1610	4.4399	0.28
>25 to 50 hp	Base	0.408	1.8	5.0	6.9	0.8
	Tier 0	0.408	1.8	5.0	6.9	0.8
	Tier 1	0.408	0.2789	1.5323	4.7279	0.3389
	Tier 2	0.408	0.2789	1.5323	4.7279	0.3389
	Tier 4A	0.408	0.2789	1.5323	4.7279	0.20
	Tier 4B	0.408	0.1314	0.153	3.0000	0.0184
>50 to 75 hp	Base	0.408	X	X	X	X
	Tier 0	0.408	0.99	3.49	6.9	0.722
	Tier 1	0.408	0.5213	2.3655	5.5988	0.4730
	Tier 2	0.408	0.3672	2.3655	4.7	0.24
	Tier 4A	0.408	0.1638	2.3655	3.0	0.20
	Tier 4	0.408	0.1314	0.237	3.00	0.0184
Source: Table A2 in Exhaust and Crankcase Emission Factors for Nonroad Engine Modeling--Compression-Ignition (EPA 2004a).						

Table 25. Zero-Hour, Steady-State Emissions from Compression Ignition Engines – continued.

Power Rating	Technology Type	BSFC lb/hp-hr	Emission Factors (g/hp-hr)			
			HC	CO	NO_X	PM
>75 to 100 hp	Base	0.408	X	X	X	X
	Tier 0	0.408	0.99	3.49	6.9	0.722
	Tier 1	0.408	0.5213	2.3655	5.5988	0.4730
	Tier 2	0.408	0.3672	2.3655	4.7	0.24
	Tier 3B	0.408	0.1836	2.3655	3.0000	0.30
	Tier 4	0.408	0.1314	0.237	3.00	0.0092
	Tier 4N	0.408	0.1314	0.237	0.276	0.0092
>100 to 175 hp	Base	0.367	X	X	X	X
	Tier 0	0.367	0.68	2.70	8.38	0.402
	Tier 1	0.367	0.3384	0.8667	5.6523	0.2799
	Tier 2	0.367	0.3384	0.8667	4.1	0.18
	Tier 3	0.367	0.1836	0.8667	2.5	0.22
	Tier 4	0.367	0.1314	0.087	2.5	0.0092
	Tier 4N	0.367	0.1314	0.087	0.276	0.0092
>175 to 300 hp	Base	0.367	X	X	X	X
	Tier 0	0.367	0.68	2.70	8.38	0.402
	Tier 1	0.367	0.3085	0.7475	5.5772	0.2521
	Tier 2	0.367	0.3085	0.7475	4.0	0.1316
	Tier 3	0.367	0.1836	0.7475	2.5	0.15
	Tier 4	0.367	0.1314	0.075	2.50	0.0092
	Tier 4N	0.367	0.1314	0.075	0.276	0.0092
>300 to 600 hp	Base	0.367	X	X	X	X
	Tier 0	0.367	0.68	2.70	8.38	0.402
	Tier 1	0.367	0.2025	1.3060	6.0153	0.2008
	Tier 2	0.367	0.1669	0.8425	4.3351	0.1316
	Tier 3	0.367	0.1669	0.8425	2.5	0.15
	Tier 4	0.367	0.1314	0.084	2.50	0.0092
	Tier 4N	0.367	0.1314	0.084	0.276	0.0092
Source: Table A2 in Exhaust and Crankcase Emission Factors for Nonroad Engine Modeling--Compression-Ignition (EPA 2004a)(EPA 2004a)(EPA 2004a).						

Table 25. Zero-Hour, Steady-State Emissions from Compression Ignition Engines – continued.

Power Rating	Technology Type	BSFC lb/hp-hr	Emission Factors (g/hp-hr)			
			HC	CO	NO_X	PM
>600 to 750	Base	0.367	X	X	X	X
	Tier 0	0.367	0.68	2.70	8.38	0.402
	Tier 1	0.367	0.1473	1.3272	5.8215	0.2201
	Tier 2	0.367	0.1669	1.3272	4.1	0.1316
	Tier 3	0.367	0.1669	1.3272	2.5	0.15
	Tier 4	0.367	0.1314	0.133	2.50	0.0092
	Tier 4N	0.367	0.1314	0.133	0.276	0.0092
>750 hp (except generators)	Base	0.367	X	X	X	X
	Tier 0	0.367	0.68	2.70	8.38	0.402
	Tier 1	0.367	0.2861	0.7642	6.1525	0.1934
	Tier 2	0.367	0.1669	1.3272	4.1	0.1316
	Tier 4	0.367	0.2815	0.076	2.392	0.069
	Tier 4N	0.367	0.1314	0.076	2.392	0.0276
Generator Sets >750 to 1200 hp	Base	0.367	X	X	X	X
	Tier 0	0.367	0.68	2.70	8.38	0.402
	Tier 1	0.367	0.2861	0.7642	6.1525	0.1934
	Tier 2	0.367	0.1669	0.7642	4.1	0.1316
	Tier 4	0.367	0.2815	0.076	2.392	0.069
	Tier 4N	0.367	0.1314	0.076	0.460	0.0184
Generator Sets >1200 hp	Base	0.367	X	X	X	X
	Tier 0	0.367	0.68	2.70	8.38	0.402
	Tier 1	0.367	0.2861	0.7642	6.1525	0.1934
	Tier 2	0.367	0.1669	0.7642	4.1	0.1316
	Tier 4	0.367	0.2815	0.076	0.460	0.069
	Tier 4N	0.367	0.1314	0.076	0.460	0.0184
Source: Table A2 in Exhaust and Crankcase Emission Factors for Nonroad Engine Modeling--Compression-Ignition (EPA 2004a).						

Table 28. Transient Activity Factors for Compression Ignition Engines.

SCC	Cycle	TAF Assignment	HC Base-T3	CO Base-T3	NOx Base, T0-T2	 Tier 3	PM Base, T0-T2	 Tier 3	BSFC Base-T3	All Tier 4
2270005010	AgTractor	Hi LF	1.05	1.53	0.95	1.04	1.23	1.47	1.01	1.00
2270005015	AgTractor	Hi LF	1.05	1.53	0.95	1.04	1.23	1.47	1.01	1.00
2270005020	AgTractor	Hi LF	1.05	1.53	0.95	1.04	1.23	1.47	1.01	1.00
2270005025	AgTractor	Hi LF	1.05	1.53	0.95	1.04	1.23	1.47	1.01	1.00
2270005030	AgTractor	Hi LF	1.05	1.53	0.95	1.04	1.23	1.47	1.01	1.00
2270005035	AgTractor	Hi LF	1.05	1.53	0.95	1.04	1.23	1.47	1.01	1.00
2270005040	AgTractor	Hi LF	1.05	1.53	0.95	1.04	1.23	1.47	1.01	1.00
2270005045	AgTractor	Hi LF	1.05	1.53	0.95	1.04	1.23	1.47	1.01	1.00
2270005055	AgTractor	Hi LF	1.05	1.53	0.95	1.04	1.23	1.47	1.01	1.00
2270002003	Crawler	Hi LF	1.05	1.53	0.95	1.04	1.23	1.47	1.01	1.00
2270002015	Crawler	Hi LF	1.05	1.53	0.95	1.04	1.23	1.47	1.01	1.00
2270002018	Crawler	Hi LF	1.05	1.53	0.95	1.04	1.23	1.47	1.01	1.00
2270002021	Crawler	Hi LF	1.05	1.53	0.95	1.04	1.23	1.47	1.01	1.00
2270002024	Crawler	Hi LF	1.05	1.53	0.95	1.04	1.23	1.47	1.01	1.00
2270002030	Crawler	Hi LF	1.05	1.53	0.95	1.04	1.23	1.47	1.01	1.00
2270002039	Crawler	Hi LF	1.05	1.53	0.95	1.04	1.23	1.47	1.01	1.00
2270002048	Crawler	Hi LF	1.05	1.53	0.95	1.04	1.23	1.47	1.01	1.00
2270002051	Crawler	Hi LF	1.05	1.53	0.95	1.04	1.23	1.47	1.01	1.00
2270002063	Crawler	Hi LF	1.05	1.53	0.95	1.04	1.23	1.47	1.01	1.00
2270002069	Crawler	Hi LF	1.05	1.53	0.95	1.04	1.23	1.47	1.01	1.00
2270002075	Crawler	Hi LF	1.05	1.53	0.95	1.04	1.23	1.47	1.01	1.00
2270002081	Crawler	Hi LF	1.05	1.53	0.95	1.04	1.23	1.47	1.01	1.00
2270003070	Crawler	Hi LF	1.05	1.53	0.95	1.04	1.23	1.47	1.01	1.00
2270002036	Excavator	Hi LF	1.05	1.53	0.95	1.04	1.23	1.47	1.01	1.00
2270002057	RTLoader	Hi LF	1.05	1.53	0.95	1.04	1.23	1.47	1.01	1.00
2270002060	RTLoader	Hi LF	1.05	1.53	0.95	1.04	1.23	1.47	1.01	1.00
2270003020	RTLoader	Hi LF	1.05	1.53	0.95	1.04	1.23	1.47	1.01	1.00
2270007005	RTLoader	Hi LF	1.05	1.53	0.95	1.04	1.23	1.47	1.01	1.00
2270007010	RTLoader	Hi LF	1.05	1.53	0.95	1.04	1.23	1.47	1.01	1.00
2270007015	RTLoader	Hi LF	1.05	1.53	0.95	1.04	1.23	1.47	1.01	1.00
2270008005	RTLoader	Hi LF	1.05	1.53	0.95	1.04	1.23	1.47	1.01	1.00
2270006025	ArcWelder	Lo LF	2.29	2.57	1.10	1.21	1.97	2.37	1.18	1.00
2270001000	Backhoe	Lo LF	2.29	2.57	1.10	1.21	1.97	2.37	1.18	1.00
2270001060	Backhoe	Lo LF	2.29	2.57	1.10	1.21	1.97	2.37	1.18	1.00
2270002066	Backhoe	Lo LF	2.29	2.57	1.10	1.21	1.97	2.37	1.18	1.00
2270002078	Backhoe	Lo LF	2.29	2.57	1.10	1.21	1.97	2.37	1.18	1.00

Source: Table A3 in Exhaust and Crankcase Emission Factors for Nonroad Engine Modeling--Compression-Ignition (EPA 2004a).

Table 26. Transient Activity Factors for Compression Ignition Engines – continued.

SCC	Cycle	TAF Assignment	HC Base-T3	CO Base-T3	NOx Base, T0-T2	NOx Tier 3	PM Base, T0-T2	PM Tier 3	BSFC Base-T3	All Tier 4
2270003010	Backhoe	Lo LF	2.29	2.57	1.10	1.21	1.97	2.37	1.18	1.00
2270003050	Backhoe	Lo LF	2.29	2.57	1.10	1.21	1.97	2.37	1.18	1.00
2270009010	Backhoe	Lo LF	2.29	2.57	1.10	1.21	1.97	2.37	1.18	1.00
2285002015	Backhoe	Lo LF	2.29	2.57	1.10	1.21	1.97	2.37	1.18	1.00
2270002072	SSLoader	Lo LF	2.29	2.57	1.10	1.21	1.97	2.37	1.18	1.00
2270001020	None	None	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2270001030	None	None	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2270001040	None	None	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2270001050	None	None	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2270002006	None	None	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2270002009	None	None	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2270002027	None	None	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2270002033	None	None	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2270002042	None	None	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2270002045	None	None	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2270002054	None	None	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2270003030	None	None	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2270003040	None	None	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2270003060	None	None	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2270004000	None	None	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2270004010	None	None	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2270004011	None	None	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2270004015	None	None	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2270004016	None	None	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2270004020	None	None	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2270004021	None	None	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2270004025	None	None	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2270004026	None	None	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2270004030	None	None	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2270004031	None	None	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2270004035	None	None	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2270004036	None	None	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2270004040	None	None	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2270004041	None	None	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2270004045	None	None	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2270004046	None	None	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2270004050	None	None	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2270004051	None	None	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Source: Table A3 in Exhaust and Crankcase Emission Factors for Nonroad Engine Modeling--Compression-Ignition (EPA 2004a)

Table 26. Transient Activity Factors for Compression Ignition Engines – continued.

SCC	Cycle	TAF Assignment	HC Base-T3	CO Base-T3	NOx Base, T0-T2	 Tier 3	PM Base, T0-T2	 Tier 3	BSFC Base-T3	All Tier 4
2270005060	None	None	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2270006000	None	None	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2270006005	None	None	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2270006010	None	None	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2270006015	None	None	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2270006020	None	None	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2270006030	None	None	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2270010010	None	None	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2282020005	None	None	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2282020010	None	None	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2282020015	None	None	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2282020025	None	None	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2270004055	None	None	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2270004056	None	None	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2270004060	None	None	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2270004061	None	None	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2270004065	None	None	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2270004066	None	None	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2270004071	None	None	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2270004075	None	None	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2270004076	None	None	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2270005050	None	None	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Source: Table A3 in Exhaust and Crankcase Emission Factors for Nonroad Engine Modeling--Compression-Ignition (EPA 2004a).

Table 29. Compression Ignition Deterioration Factors.

Pollutant	Relative Deterioration Factor (A) (% increase/%useful life)				b
	Base/ Tier 0	Tier 1	Tier 2	Tier 3 or later	
HC	0.047	0.036	0.034	0.027	1.0
CO	0.185	0.101	0.101	0.151	1.0
NO_X	0.024	0.024	0.009	0.008	1.0
PM	0.473	0.473	0.473	0.473	1.0

Source: Table A4 in Exhaust and Crankcase Emission Factors for Nonroad Engine Modeling--Compression-Ignition (EPA 2004a).

APPENDIX C. PROJECT MODEL RESULTS

Table 30. Direct Emissions – 2010

SCC	description	Power Class hp	Direct CO_2 g/hr	Direct CH_4 g/hr	Direct N_2O g/hr	Direct PM_{BC} g/hr
2260002006	Tampers/Rammers	6	2,476.695	0.975	0.015	4.406
2260002009	Plate Compactors	3	1,683.123	0.329	0.007	1.638
2260002021	Paving Equipment	3	1,925.909	0.406	0.008	1.980
2260002027	Signal Boards/Light Plants	3	2,574.970	0.683	0.012	3.136
2260002039	Concrete/Industrial Saws	3	2,398.820	0.638	0.011	2.930
2260002039	Concrete/Industrial Saws	6	4,389.878	1.894	0.026	8.559
2260002054	Crushing/Proc. Equipment	3	2,616.114	0.660	0.011	3.029
2260003030	Sweepers/Scrubbers	3	1,589.317	0.391	0.007	1.794
2260003040	Other General Industrial Equipment	3	1,983.063	0.476	0.008	2.186
2260004016	Rotary Tillers < 6 HP (com)	1	763.717	0.106	0.003	0.772
2260004016	Rotary Tillers < 6 HP (com)	3	1,567.311	0.294	0.007	1.645
2260004021	Chain Saws < 6 HP (com)	3	2,156.144	0.637	0.011	2.925
2260004021	Chain Saws < 6 HP (com)	6	2,807.277	1.469	0.020	6.637
2260004026	Trimmers/Edgers/Brush Cutter (com)	3	1,866.523	0.422	0.009	2.202
2260004026	Trimmers/Edgers/Brush Cutter (com)	6	3,035.285	1.418	0.022	6.408
2260004031	Leafblowers/Vacuums (com)	3	2,107.730	0.440	0.010	2.290
2260004031	Leafblowers/Vacuums (com)	6	3,417.786	1.518	0.024	6.860
2260004036	Snowblowers (com)	3	2,076.411	1.362	0.008	1.236
2260004036	Snowblowers (com)	6	3,026.760	2.185	0.012	1.983
2260004071	Commercial Turf Equipment (com)	3	3,383.486	0.590	0.013	3.094
2260005035	Sprayers	1	1,470.766	0.169	0.004	1.185
2260005035	Sprayers	3	2,830.162	0.526	0.012	2.818
2260006005	Generator Sets	1	1,205.549	0.177	0.004	1.171
2260006005	Generator Sets	3	1,957.582	0.393	0.008	1.998
2260006010	Pumps	1	1,373.781	0.279	0.005	1.622
2260006010	Pumps	3	2,257.702	0.594	0.010	2.730
2260006010	Pumps	40	19,033.997	0.069	0.194	51.474
2260006010	Pumps	75	27,548.233	0.097	0.281	73.542
2260006015	Air Compressors	3	2,204.305	0.533	0.009	2.449
2260007005	Chain Saws > 6 HP	11	4,709.340	2.554	0.035	11.543
2265002003	Pavers	6	5,574.750	6.804	0.026	0.452
2265002003	Pavers	11	7,871.572	4.299	0.046	0.173
2265002003	Pavers	16	10,306.663	5.788	0.061	0.232
2265002003	Pavers	25	24,317.302	8.395	0.102	0.337
2265002003	Pavers	40	15,232.510	0.561	0.155	0.326
2265002003	Pavers	75	29,940.127	1.047	0.305	0.628
2265002006	Tampers/Rammers	11	5,620.046	2.324	0.031	0.093

SCC	description	Power Class hp	Direct CO_2 g/hr	Direct CH_4 g/hr	Direct N_2O g/hr	Direct PM_{BC} g/hr
2265002009	Plate Compactors	6	4,118.166	3.410	0.018	0.226
2265002009	Plate Compactors	11	6,036.148	2.558	0.033	0.103
2265002009	Plate Compactors	16	8,806.693	3.941	0.052	0.158
2265002015	Rollers	11	10,219.348	4.250	0.041	0.171
2265002015	Rollers	16	16,789.417	7.076	0.068	0.284
2265002015	Rollers	25	21,508.825	7.838	0.088	0.315
2265002015	Rollers	40	16,631.872	0.640	0.169	0.363
2265002015	Rollers	75	27,598.923	0.982	0.279	0.580
2265002015	Rollers	100	37,264.889	1.342	0.381	0.793
2265002021	Paving Equipment	6	4,960.045	4.407	0.022	0.293
2265002021	Paving Equipment	11	9,553.547	2.910	0.037	0.117
2265002021	Paving Equipment	16	14,684.479	4.521	0.058	0.181
2265002021	Paving Equipment	25	21,871.801	6.161	0.087	0.247
2265002021	Paving Equipment	40	15,763.137	0.543	0.160	0.328
2265002021	Paving Equipment	75	28,423.782	0.962	0.288	0.586
2265002024	Surfacing Equipment	6	4,328.487	4.747	0.019	0.315
2265002024	Surfacing Equipment	11	9,001.856	2.996	0.032	0.120
2265002024	Surfacing Equipment	16	15,481.016	5.244	0.057	0.211
2265002024	Surfacing Equipment	25	18,833.844	5.609	0.069	0.225
2265002024	Surfacing Equipment	40	10,904.304	0.394	0.110	0.230
2265002024	Surfacing Equipment	75	23,797.020	0.819	0.239	0.492
2265002027	Signal Boards/Light Plants	6	5,685.000	6.706	0.027	0.445
2265002027	Signal Boards/Light Plants	11	10,389.876	4.033	0.044	0.162
2265002027	Signal Boards/Light Plants	25	22,263.115	7.723	0.096	0.310
2265002030	Trenchers	3	3,645.526	3.848	0.015	0.255
2265002030	Trenchers	6	5,460.339	6.684	0.025	0.444
2265002030	Trenchers	11	10,581.490	4.118	0.043	0.165
2265002030	Trenchers	16	15,873.080	6.231	0.066	0.250
2265002030	Trenchers	25	22,574.934	7.810	0.094	0.313
2265002030	Trenchers	40	14,392.999	0.531	0.147	0.309
2265002030	Trenchers	75	29,731.882	1.037	0.301	0.621
2265002030	Trenchers	100	38,203.188	1.344	0.391	0.805
2265002033	Bore/Drill Rigs	1	1,565.979	0.979	0.005	0.065
2265002033	Bore/Drill Rigs	3	3,463.481	2.403	0.013	0.160
2265002033	Bore/Drill Rigs	6	7,128.198	5.232	0.028	0.347
2265002033	Bore/Drill Rigs	11	11,651.317	3.860	0.051	0.155
2265002033	Bore/Drill Rigs	16	20,979.811	7.055	0.094	0.283
2265002033	Bore/Drill Rigs	25	27,798.630	8.548	0.125	0.343
2265002033	Bore/Drill Rigs	40	17,920.727	0.619	0.184	0.375
2265002033	Bore/Drill Rigs	75	35,017.011	1.198	0.359	0.730

SCC	description	Power Class hp	Direct CO_2 g/hr	Direct CH_4 g/hr	Direct N_2O g/hr	Direct PM_{BC} g/hr
2265002033	Bore/Drill Rigs	175	67,417.118	2.306	0.690	1.405
2265002039	Concrete/Industrial Saws	11	11,278.183	5.424	0.049	0.218
2265002039	Concrete/Industrial Saws	16	19,143.094	9.328	0.085	0.374
2265002039	Concrete/Industrial Saws	25	25,180.685	10.523	0.112	0.422
2265002039	Concrete/Industrial Saws	40	19,617.005	0.787	0.201	0.438
2265002039	Concrete/Industrial Saws	75	37,089.858	1.362	0.380	0.796
2265002042	Cement & Mortar Mixers	3	3,717.627	2.055	0.013	0.136
2265002042	Cement & Mortar Mixers	6	6,411.048	3.712	0.023	0.246
2265002042	Cement & Mortar Mixers	11	9,384.209	2.541	0.037	0.102
2265002042	Cement & Mortar Mixers	16	14,960.727	4.103	0.059	0.165
2265002042	Cement & Mortar Mixers	25	19,638.702	5.017	0.078	0.201
2265002045	Cranes	11	7,960.464	2.463	0.028	0.099
2265002045	Cranes	16	13,682.285	4.317	0.049	0.173
2265002045	Cranes	25	17,607.810	4.939	0.063	0.198
2265002045	Cranes	40	12,822.746	0.454	0.129	0.268
2265002045	Cranes	75	23,925.158	0.814	0.240	0.492
2265002045	Cranes	175	39,920.125	1.359	0.401	0.821
2265002054	Crushing/Proc. Equipment	6	6,765.045	6.558	0.027	0.435
2265002054	Crushing/Proc. Equipment	11	12,448.877	5.027	0.056	0.202
2265002054	Crushing/Proc. Equipment	16	22,003.804	9.006	0.101	0.362
2265002054	Crushing/Proc. Equipment	75	38,326.222	1.337	0.393	0.806
2265002057	Rough Terrain Forklift	25	25,995.645	8.850	0.107	0.355
2265002057	Rough Terrain Forklift	40	13,303.457	0.489	0.135	0.285
2265002057	Rough Terrain Forklift	75	30,229.717	1.056	0.307	0.633
2265002057	Rough Terrain Forklift	100	36,456.792	1.282	0.373	0.768
2265002057	Rough Terrain Forklift	175	51,969.177	1.816	0.528	1.088
2265002060	Rubber Tire Loaders	40	19,047.559	0.731	0.194	0.416
2265002060	Rubber Tire Loaders	75	36,240.278	1.298	0.370	0.768
2265002060	Rubber Tire Loaders	175	58,168.321	2.083	0.594	1.233
2265002066	Tractors/Loaders/Backhoes	11	10,665.864	4.078	0.038	0.164
2265002066	Tractors/Loaders/Backhoes	25	18,654.385	6.179	0.068	0.248
2265002066	Tractors/Loaders/Backhoes	40	10,607.298	0.409	0.107	0.230
2265002066	Tractors/Loaders/Backhoes	75	21,302.431	0.768	0.217	0.452
2265002066	Tractors/Loaders/Backhoes	100	27,695.598	1.008	0.284	0.593
2265002072	Skid Steer Loaders	16	14,320.439	5.949	0.068	0.239
2265002072	Skid Steer Loaders	25	20,003.157	6.090	0.079	0.244
2265002072	Skid Steer Loaders	40	13,528.180	0.481	0.137	0.285
2265002072	Skid Steer Loaders	75	23,284.250	0.790	0.234	0.478
2265002072	Skid Steer Loaders	100	33,269.935	1.146	0.339	0.694
2265002078	Dumpers/Tenders	6	3,720.514	2.480	0.015	0.165

SCC	description	Power Class hp	Direct CO_2 g/hr	Direct CH_4 g/hr	Direct N_2O g/hr	Direct PM_{BC} g/hr
2265002078	Dumpers/Tenders	11	7,899.443	1.809	0.026	0.073
2265002078	Dumpers/Tenders	16	11,292.725	2.608	0.037	0.105
2265002078	Dumpers/Tenders	25	16,944.762	3.676	0.057	0.148
2265002078	Dumpers/Tenders	75	20,095.754	0.669	0.200	0.407
2265002081	Other Construction Equipment	25	17,653.175	4.920	0.064	0.197
2265002081	Other Construction Equipment	175	44,545.739	1.513	0.448	0.915
2265003010	Aerial Lifts	11	6,926.658	2.352	0.027	0.094
2265003010	Aerial Lifts	16	10,190.520	4.192	0.049	0.168
2265003010	Aerial Lifts	25	20,118.519	5.468	0.072	0.219
2265003010	Aerial Lifts	40	10,601.118	0.371	0.106	0.220
2265003010	Aerial Lifts	75	20,324.563	0.687	0.204	0.416
2265003010	Aerial Lifts	175	37,856.426	1.280	0.380	0.775
2265003020	Forklifts	40	8,265.899	0.281	0.080	0.167
2265003020	Forklifts	50	10,167.073	0.352	0.100	0.208
2265003020	Forklifts	75	13,870.582	0.489	0.139	0.289
2265003020	Forklifts	100	19,393.155	0.693	0.198	0.410
2265003020	Forklifts	175	31,100.912	1.126	0.321	0.667
2265003020	Forklifts	300	46,053.615	1.680	0.479	0.995
2265003030	Sweepers/Scrubbers	6	6,551.514	7.298	0.025	0.484
2265003030	Sweepers/Scrubbers	11	12,209.846	5.320	0.052	0.214
2265003030	Sweepers/Scrubbers	16	18,256.193	8.017	0.078	0.322
2265003030	Sweepers/Scrubbers	25	22,343.067	8.484	0.096	0.341
2265003030	Sweepers/Scrubbers	40	16,427.602	0.631	0.168	0.359
2265003030	Sweepers/Scrubbers	50	23,680.182	0.910	0.242	0.518
2265003030	Sweepers/Scrubbers	75	32,615.819	1.169	0.333	0.692
2265003030	Sweepers/Scrubbers	100	45,879.816	1.660	0.473	0.983
2265003030	Sweepers/Scrubbers	175	77,213.809	2.767	0.788	1.638
2265003030	Sweepers/Scrubbers	600	211,562.230	7.582	2.159	4.487
2265003040	Other General Industrial Eqp	6	5,064.937	5.117	0.017	0.340
2265003040	Other General Industrial Eqp	11	9,626.296	3.769	0.036	0.151
2265003040	Other General Industrial Eqp	16	14,242.359	5.627	0.054	0.226
2265003040	Other General Industrial Eqp	25	19,041.547	6.526	0.073	0.262
2265003040	Other General Industrial Eqp	40	11,916.646	0.456	0.120	0.259
2265003040	Other General Industrial Eqp	75	24,156.633	0.858	0.244	0.507
2265003040	Other General Industrial Eqp	100	31,364.103	1.127	0.320	0.665
2265003040	Other General Industrial Eqp	175	53,800.543	1.915	0.543	1.131
2265003040	Other General Industrial Eqp	300	77,139.637	2.746	0.779	1.622
2265003050	Other Material Handling Eqp	3	3,622.242	2.838	0.012	0.188
2265003050	Other Material Handling Eqp	25	18,732.690	5.605	0.071	0.225
2265003050	Other Material Handling Eqp	75	24,781.006	0.840	0.247	0.506

SCC	description	Power Class hp	Direct CO_2 g/hr	Direct CH_4 g/hr	Direct N_2O g/hr	Direct PM_{BC} g/hr
2265003050	Other Material Handling Eqp	100	33,326.261	1.146	0.337	0.691
2265003060	AC\Refrigeration	11	8,821.249	2.941	0.031	0.118
2265003060	AC\Refrigeration	16	12,630.842	4.248	0.044	0.171
2265003060	AC\Refrigeration	25	17,296.790	5.125	0.061	0.206
2265004011	Lawn mowers (Com)	3	1,681.251	1.213	0.006	0.081
2265004011	Lawn mowers (Com)	6	2,327.699	1.950	0.010	0.129
2265004011	Lawn mowers (Com)	11	2,919.008	1.249	0.015	0.050
2265004016	Rotary Tillers < 6 HP (com)	6	2,909.536	2.227	0.014	0.148
2265004026	Trimmers/Edgers/Brush Cutter (com)	6	4,166.065	4.167	0.022	0.277
2265004026	Trimmers/Edgers/Brush Cutter (com)	11	8,567.677	4.596	0.053	0.184
2265004026	Trimmers/Edgers/Brush Cutter (com)	16	17,082.958	9.309	0.108	0.374
2265004026	Trimmers/Edgers/Brush Cutter (com)	25	19,144.454	10.473	0.121	0.420
2265004031	Leafblowers/Vacuums (com)	6	4,919.403	4.435	0.024	0.294
2265004031	Leafblowers/Vacuums (com)	11	9,401.982	4.988	0.058	0.200
2265004031	Leafblowers/Vacuums (com)	16	15,532.254	8.534	0.099	0.343
2265004031	Leafblowers/Vacuums (com)	25	22,525.502	12.621	0.146	0.507
2265004031	Leafblowers/Vacuums (com)	40	20,627.222	0.782	0.216	0.454
2265004031	Leafblowers/Vacuums (com)	75	40,704.986	1.465	0.426	0.877
2265004031	Leafblowers/Vacuums (com)	175	80,308.390	2.891	0.840	1.731
2265004036	Snowblowers (com)	11	5,158.948	4.092	0.023	0.069
2265004036	Snowblowers (com)	16	7,180.315	5.923	0.033	0.100
2265004041	Rear Engine Riding Mowers (com)	6	3,687.006	3.525	0.014	0.234
2265004041	Rear Engine Riding Mowers (com)	11	6,280.569	2.122	0.026	0.085
2265004041	Rear Engine Riding Mowers (com)	16	7,841.605	2.923	0.035	0.117
2265004041	Rear Engine Riding Mowers (com)	25	10,627.757	4.091	0.051	0.164
2265004046	Front Mowers (com)	11	7,310.456	2.721	0.038	0.109
2265004046	Front Mowers (com)	16	12,091.699	4.582	0.065	0.184
2265004046	Front Mowers (com)	25	15,037.054	5.329	0.082	0.214
2265004046	Front Mowers (com)	40	14,904.323	0.518	0.155	0.316
2265004051	Shredders < 6 HP (com)	3	3,559.210	2.743	0.018	0.182
2265004051	Shredders < 6 HP (com)	6	5,439.278	4.442	0.029	0.295
2265004056	Lawn & Garden Tractors (com)	6	5,169.756	4.544	0.016	0.302
2265004056	Lawn & Garden Tractors (com)	11	7,185.166	2.613	0.032	0.105
2265004056	Lawn & Garden Tractors (com)	16	9,165.269	3.653	0.044	0.147
2265004056	Lawn & Garden Tractors (com)	25	11,870.220	4.941	0.060	0.198
2265004066	Chippers/Stump Grinders (com)	6	5,242.828	6.007	0.020	0.399
2265004066	Chippers/Stump Grinders (com)	11	12,445.996	5.864	0.057	0.235
2265004066	Chippers/Stump Grinders (com)	16	17,210.206	9.176	0.088	0.368
2265004066	Chippers/Stump Grinders (com)	25	26,369.888	10.336	0.116	0.415
2265004066	Chippers/Stump Grinders (com)	40	19,796.534	0.767	0.203	0.435

SCC	description	Power Class hp	Direct CO_2 g/hr	Direct CH_4 g/hr	Direct N_2O g/hr	Direct PM_{BC} g/hr
2265004066	Chippers/Stump Grinders (com)	75	34,272.031	1.235	0.351	0.730
2265004066	Chippers/Stump Grinders (com)	100	44,787.789	1.626	0.462	0.961
2265004066	Chippers/Stump Grinders (com)	175	67,098.307	2.418	0.687	1.429
2265004071	Commercial Turf Equipment (com)	6	6,340.090	4.287	0.023	0.285
2265004071	Commercial Turf Equipment (com)	11	9,916.324	3.330	0.039	0.134
2265004071	Commercial Turf Equipment (com)	16	13,420.177	5.312	0.062	0.213
2265004071	Commercial Turf Equipment (com)	25	20,826.655	7.339	0.086	0.295
2265004071	Commercial Turf Equipment (com)	40	11,772.380	0.463	0.121	0.261
2265004071	Commercial Turf Equipment (com)	75	25,386.776	0.937	0.265	0.552
2265004076	Other Lawn & Garden Eqp. (com)	1	3,093.222	0.593	0.004	0.039
2265004076	Other Lawn & Garden Eqp. (com)	3	4,126.817	1.518	0.010	0.101
2265004076	Other Lawn & Garden Eqp. (com)	6	5,958.432	3.157	0.021	0.210
2265004076	Other Lawn & Garden Eqp. (com)	11	9,792.366	2.343	0.035	0.094
2265004076	Other Lawn & Garden Eqp. (com)	16	14,498.411	4.436	0.067	0.178
2265004076	Other Lawn & Garden Eqp. (com)	25	21,515.428	5.342	0.086	0.214
2265004076	Other Lawn & Garden Eqp. (com)	40	14,996.715	0.517	0.155	0.315
2265004076	Other Lawn & Garden Eqp. (com)	75	27,184.323	0.946	0.283	0.576
2265004076	Other Lawn & Garden Eqp. (com)	100	35,320.281	1.233	0.369	0.751
2265004076	Other Lawn & Garden Eqp. (com)	175	46,303.801	1.620	0.485	0.987
2265005010	2-Wheel Tractors	11	8,375.850	3.263	0.038	0.131
2265005010	2-Wheel Tractors	16	12,501.134	5.648	0.065	0.227
2265005015	Agricultural Tractors	25	22,931.064	8.163	0.094	0.328
2265005015	Agricultural Tractors	40	13,777.495	0.522	0.140	0.298
2265005015	Agricultural Tractors	100	36,439.477	1.316	0.377	0.781
2265005015	Agricultural Tractors	175	55,265.298	2.003	0.574	1.189
2265005030	Agricultural Mowers	6	6,021.493	3.960	0.021	0.263
2265005030	Agricultural Mowers	11	7,328.971	2.464	0.033	0.099
2265005030	Agricultural Mowers	16	10,970.228	4.282	0.057	0.172
2265005030	Agricultural Mowers	25	12,444.424	4.384	0.064	0.176
2265005035	Sprayers	6	5,149.606	3.463	0.021	0.230
2265005035	Sprayers	11	9,989.426	2.762	0.039	0.111
2265005035	Sprayers	16	14,762.777	4.999	0.071	0.201
2265005035	Sprayers	25	23,719.988	6.377	0.099	0.256
2265005035	Sprayers	40	15,733.346	0.535	0.160	0.326
2265005035	Sprayers	75	29,551.749	0.996	0.298	0.607
2265005035	Sprayers	100	42,250.848	1.444	0.432	0.880
2265005035	Sprayers	175	61,593.642	2.093	0.627	1.275
2265005040	Tillers > 6 HP	11	6,576.025	2.392	0.039	0.096
2265005040	Tillers > 6 HP	16	12,748.400	4.708	0.078	0.189
2265005045	Swathers	100	30,526.965	1.028	0.308	0.626

SCC	description	Power Class hp	Direct CO_2 g/hr	Direct CH_4 g/hr	Direct N_2O g/hr	Direct PM_{BC} g/hr
2265005045	Swathers	175	46,514.413	1.567	0.469	0.955
2265005055	Other Agricultural Equipment	6	3,854.790	3.468	0.020	0.230
2265005055	Other Agricultural Equipment	11	9,662.033	2.710	0.037	0.109
2265005055	Other Agricultural Equipment	16	12,738.693	4.184	0.057	0.168
2265005055	Other Agricultural Equipment	25	19,642.859	5.063	0.076	0.203
2265005055	Other Agricultural Equipment	40	12,977.623	0.440	0.131	0.267
2265005055	Other Agricultural Equipment	75	25,175.663	0.848	0.254	0.517
2265005055	Other Agricultural Equipment	100	35,069.028	1.197	0.358	0.729
2265005055	Other Agricultural Equipment	175	66,213.846	2.275	0.681	1.386
2265005055	Other Agricultural Equipment	300	90,387.778	3.128	0.937	1.906
2265005060	Irrigation Sets	6	4,253.864	6.304	0.021	0.418
2265005060	Irrigation Sets	11	7,000.064	4.241	0.040	0.170
2265005060	Irrigation Sets	75	26,366.517	0.942	0.265	0.554
2265005060	Irrigation Sets	100	35,009.790	1.267	0.356	0.744
2265005060	Irrigation Sets	175	52,737.164	1.902	0.535	1.118
2265005060	Irrigation Sets	300	91,993.011	3.318	0.933	1.950
2265006005	Generator Sets	6	4,930.709	4.190	0.023	0.278
2265006005	Generator Sets	11	10,730.701	3.304	0.044	0.133
2265006005	Generator Sets	16	17,232.011	5.373	0.072	0.216
2265006005	Generator Sets	25	24,647.508	7.081	0.104	0.284
2265006010	Pumps	6	5,038.377	5.205	0.024	0.345
2265006010	Pumps	11	10,472.212	3.580	0.043	0.144
2265006010	Pumps	16	15,404.489	6.359	0.076	0.255
2265006010	Pumps	25	22,124.413	7.022	0.094	0.282
2265006010	Pumps	40	16,000.494	0.566	0.163	0.337
2265006010	Pumps	50	23,035.697	0.815	0.235	0.486
2265006010	Pumps	75	30,249.386	1.040	0.309	0.631
2265006010	Pumps	100	40,237.824	1.395	0.415	0.847
2265006010	Pumps	175	57,174.964	1.980	0.589	1.201
2265006015	Air Compressors	6	4,927.678	5.686	0.021	0.377
2265006015	Air Compressors	11	10,261.461	3.924	0.041	0.157
2265006015	Air Compressors	16	12,634.133	5.388	0.056	0.216
2265006015	Air Compressors	25	19,221.099	6.437	0.077	0.258
2265006015	Air Compressors	40	13,119.109	0.477	0.131	0.277
2265006015	Air Compressors	75	24,777.711	0.867	0.252	0.519
2265006015	Air Compressors	100	33,005.881	1.166	0.339	0.698
2265006015	Air Compressors	175	53,183.881	1.883	0.547	1.127
2265006025	Welders	6	6,707.062	8.014	0.030	0.532
2265006025	Welders	11	8,565.532	4.502	0.047	0.181
2265006025	Welders	16	13,374.118	7.584	0.079	0.304

SCC	description	Power Class hp	Direct CO_2 g/hr	Direct CH_4 g/hr	Direct N_2O g/hr	Direct PM_{BC} g/hr
2265006025	Welders	25	22,341.590	7.655	0.092	0.307
2265006025	Welders	75	31,736.381	1.104	0.320	0.660
2265006025	Welders	100	39,539.631	1.389	0.403	0.830
2265006025	Welders	175	63,907.981	2.256	0.654	1.349
2265006030	Pressure Washers	3	4,230.604	3.964	0.019	0.263
2265006030	Pressure Washers	6	6,180.351	5.878	0.030	0.390
2265006030	Pressure Washers	11	12,598.949	4.429	0.057	0.178
2265006030	Pressure Washers	16	17,324.576	6.873	0.089	0.276
2265006030	Pressure Washers	25	25,544.853	8.279	0.118	0.332
2265006030	Pressure Washers	40	22,412.169	0.780	0.230	0.471
2265006030	Pressure Washers	75	39,960.708	1.387	0.415	0.845
2265007010	Shredders > 6 HP	11	8,264.174	3.246	0.048	0.130
2265007010	Shredders > 6 HP	16	12,241.567	5.046	0.075	0.203
2265007010	Shredders > 6 HP	25	19,150.032	7.651	0.122	0.307
2265007015	Forest Eqp - Feller/Bunch/Skidder	6	5,519.528	7.286	0.028	0.484
2265007015	Forest Eqp - Feller/Bunch/Skidder	11	8,025.368	4.344	0.047	0.174
2267002003	Pavers	40	11,560.737	0.186	0.155	0.153
2267002003	Pavers	75	22,724.488	0.348	0.305	0.295
2267002015	Rollers	40	12,594.279	0.213	0.169	0.170
2267002015	Rollers	75	20,782.872	0.326	0.279	0.272
2267002015	Rollers	100	28,390.108	0.445	0.381	0.372
2267002021	Paving Equipment	40	11,913.215	0.180	0.160	0.154
2267002021	Paving Equipment	75	21,482.858	0.319	0.288	0.275
2267002024	Surfacing Equipment	40	8,174.756	0.131	0.110	0.108
2267002024	Surfacing Equipment	75	17,841.664	0.272	0.239	0.231
2267002030	Trenchers	40	10,923.495	0.176	0.147	0.145
2267002030	Trenchers	75	22,462.349	0.344	0.301	0.292
2267002030	Trenchers	100	29,129.315	0.446	0.391	0.378
2267002033	Bore/Drill Rigs	40	13,680.888	0.206	0.184	0.176
2267002033	Bore/Drill Rigs	75	26,734.183	0.398	0.359	0.343
2267002033	Bore/Drill Rigs	175	51,472.171	0.765	0.690	0.660
2267002039	Concrete/Industrial Saws	40	14,970.897	0.261	0.201	0.206
2267002039	Concrete/Industrial Saws	75	28,306.463	0.452	0.380	0.374
2267002045	Cranes	40	9,593.882	0.151	0.129	0.126
2267002045	Cranes	75	17,901.749	0.270	0.240	0.231
2267002045	Cranes	175	29,870.772	0.451	0.401	0.385
2267002054	Crushing/Proc. Equipment	75	29,322.624	0.444	0.393	0.379
2267002057	Rough Terrain Forklift	40	10,079.428	0.162	0.135	0.134
2267002057	Rough Terrain Forklift	75	22,904.590	0.351	0.307	0.297
2267002057	Rough Terrain Forklift	100	27,805.253	0.426	0.373	0.361

SCC	description	Power Class hp	Direct CO_2 g/hr	Direct CH_4 g/hr	Direct N_2O g/hr	Direct PM_{BC} g/hr
2267002057	Rough Terrain Forklift	175	39,379.141	0.603	0.528	0.511
2267002060	Rubber Tire Loaders	40	14,492.970	0.243	0.194	0.195
2267002060	Rubber Tire Loaders	75	27,575.770	0.431	0.370	0.361
2267002060	Rubber Tire Loaders	175	44,262.225	0.692	0.594	0.579
2267002066	Tractors/Loaders/Backhoes	40	7,944.393	0.136	0.107	0.108
2267002066	Tractors/Loaders/Backhoes	75	16,153.528	0.255	0.217	0.212
2267002066	Tractors/Loaders/Backhoes	100	21,185.007	0.335	0.284	0.279
2267002072	Skid Steer Loaders	40	10,217.022	0.160	0.137	0.134
2267002072	Skid Steer Loaders	75	17,464.547	0.263	0.234	0.225
2267002072	Skid Steer Loaders	100	25,278.460	0.381	0.339	0.326
2267002081	Other Construction Equipment	175	33,366.232	0.502	0.448	0.430
2267003010	Aerial Lifts	40	7,922.949	0.123	0.106	0.103
2267003010	Aerial Lifts	75	15,196.170	0.228	0.204	0.196
2267003010	Aerial Lifts	175	28,296.192	0.425	0.380	0.364
2267003020	Forklifts	40	5,534.569	0.086	0.074	0.072
2267003020	Forklifts	50	7,519.005	0.117	0.101	0.098
2267003020	Forklifts	75	9,629.248	0.150	0.129	0.126
2267003020	Forklifts	100	13,212.450	0.206	0.177	0.173
2267003020	Forklifts	175	21,764.277	0.340	0.292	0.285
2267003020	Forklifts	300	35,716.551	0.558	0.479	0.467
2267003030	Sweepers/Scrubbers	40	12,142.770	0.204	0.163	0.164
2267003030	Sweepers/Scrubbers	50	18,410.059	0.309	0.247	0.248
2267003030	Sweepers/Scrubbers	75	24,814.280	0.388	0.333	0.325
2267003030	Sweepers/Scrubbers	100	35,253.077	0.551	0.473	0.461
2267003030	Sweepers/Scrubbers	175	58,755.189	0.919	0.788	0.769
2267003030	Sweepers/Scrubbers	600	160,989.584	2.517	2.159	2.107
2267003040	Other General Industrial Eqp	40	8,973.191	0.151	0.120	0.121
2267003040	Other General Industrial Eqp	75	18,160.798	0.285	0.244	0.238
2267003040	Other General Industrial Eqp	100	23,833.047	0.374	0.320	0.312
2267003040	Other General Industrial Eqp	175	40,516.279	0.636	0.543	0.531
2267003040	Other General Industrial Eqp	300	58,093.114	0.912	0.779	0.762
2267003050	Other Material Handling Eqp	75	15,672.446	0.237	0.210	0.202
2267003050	Other Material Handling Eqp	100	25,146.100	0.381	0.337	0.325
2267004066	Chippers/Stump Grinders (com)	40	15,104.258	0.255	0.203	0.204
2267004066	Chippers/Stump Grinders (com)	75	26,150.551	0.410	0.351	0.343
2267004066	Chippers/Stump Grinders (com)	100	34,425.533	0.540	0.462	0.451
2267004066	Chippers/Stump Grinders (com)	175	51,208.066	0.803	0.687	0.671
2267005055	Other Agricultural Equipment	175	46,728.177	0.695	0.627	0.599
2267006005	Generator Sets	40	11,374.579	0.170	0.153	0.146
2267006005	Generator Sets	50	17,253.174	0.259	0.231	0.222

SCC	description	Power Class hp	Direct CO_2 g/hr	Direct CH_4 g/hr	Direct N_2O g/hr	Direct PM_{BC} g/hr
2267006005	Generator Sets	75	23,600.689	0.351	0.317	0.303
2267006005	Generator Sets	100	30,492.106	0.453	0.409	0.391
2267006005	Generator Sets	175	52,070.729	0.774	0.698	0.668
2267006005	Generator Sets	300	89,885.788	1.337	1.206	1.152
2267006005	Generator Sets	600	139,555.746	2.075	1.872	1.789
2267006010	Pumps	40	12,162.268	0.188	0.163	0.158
2267006010	Pumps	50	17,510.664	0.270	0.235	0.228
2267006010	Pumps	75	21,697.989	0.325	0.291	0.279
2267006010	Pumps	100	30,929.124	0.463	0.415	0.398
2267006010	Pumps	175	43,890.875	0.657	0.589	0.564
2267006015	Air Compressors	40	9,784.336	0.158	0.131	0.130
2267006015	Air Compressors	75	18,762.376	0.288	0.252	0.244
2267006015	Air Compressors	100	25,237.902	0.387	0.339	0.328
2267006015	Air Compressors	175	40,750.079	0.625	0.547	0.529
2267006025	Welders	75	23,870.759	0.367	0.320	0.310
2267006025	Welders	100	30,011.965	0.461	0.403	0.390
2267006025	Welders	175	48,769.545	0.749	0.654	0.634
2267006030	Pressure Washers	40	17,139.610	0.259	0.230	0.221
2267006030	Pressure Washers	75	30,949.876	0.460	0.415	0.397
2268002081	Other Construction Equipment	175	24,197.638	78.271	0.373	0.358
2268003020	Forklifts	50	6,911.440	23.199	0.107	0.104
2268003030	Sweepers/Scrubbers	300	64,746.033	217.605	0.998	0.974
2268003040	Other General Industrial Eqp	100	25,528.040	86.117	0.394	0.385
2268003060	AC\Refrigeration	50	10,593.897	36.958	0.163	0.162
2268003060	AC\Refrigeration	75	16,340.157	53.953	0.252	0.244
2268006005	Generator Sets	40	10,359.435	33.359	0.160	0.153
2268006005	Generator Sets	50	15,563.704	50.117	0.240	0.230
2268006005	Generator Sets	75	19,734.157	63.065	0.304	0.291
2268006005	Generator Sets	100	31,152.154	99.553	0.480	0.459
2268006005	Generator Sets	175	48,258.000	154.218	0.744	0.711
2268006005	Generator Sets	300	78,296.727	250.214	1.207	1.153
2268006005	Generator Sets	600	128,186.972	409.649	1.976	1.888
2268006010	Pumps	40	10,598.505	35.184	0.163	0.159
2268006010	Pumps	75	17,227.171	55.428	0.266	0.254
2268006010	Pumps	175	57,976.066	186.537	0.894	0.856
2268006010	Pumps	300	81,497.699	262.218	1.256	1.204
2268006010	Pumps	600	140,235.749	451.206	2.161	2.071
2268006015	Air Compressors	75	13,978.646	46.087	0.215	0.209
2268006015	Air Compressors	175	39,785.294	131.170	0.613	0.594
2268006020	Gas Compressors	40	11,167.952	57.355	0.173	0.206

SCC	description	Power Class hp	Direct CO_2 g/hr	Direct CH_4 g/hr	Direct N_2O g/hr	Direct PM_{BC} g/hr
2268006020	Gas Compressors	50	18,372.344	94.354	0.285	0.339
2268006020	Gas Compressors	75	28,021.479	143.908	0.434	0.517
2268006020	Gas Compressors	100	37,037.048	190.210	0.574	0.684
2268006020	Gas Compressors	175	59,251.196	304.294	0.918	1.094
2268006020	Gas Compressors	300	98,319.052	504.931	1.523	1.815
2268006020	Gas Compressors	600	163,214.693	838.215	2.528	3.013
2270002003	Pavers	25	7,703.616	0.091	0.096	1.571
2270002003	Pavers	40	11,537.282	0.087	0.143	1.704
2270002003	Pavers	50	15,948.208	0.120	0.198	2.356
2270002003	Pavers	75	22,145.314	0.107	0.275	3.138
2270002003	Pavers	100	30,478.772	0.159	0.378	9.676
2270002003	Pavers	175	42,633.746	0.247	0.588	9.512
2270002003	Pavers	300	70,032.116	0.406	0.965	9.916
2270002003	Pavers	600	122,546.923	0.634	1.689	17.009
2270002006	Tampers/Rammers	6	1,066.331	0.016	0.013	0.208
2270002009	Plate Compactors	6	1,253.453	0.019	0.016	0.245
2270002009	Plate Compactors	11	2,171.766	0.032	0.027	0.425
2270002009	Plate Compactors	16	3,610.187	0.043	0.045	0.707
2270002009	Plate Compactors	25	5,166.478	0.062	0.065	1.011
2270002015	Rollers	6	1,912.953	0.028	0.024	0.388
2270002015	Rollers	11	3,058.677	0.045	0.038	0.620
2270002015	Rollers	16	4,766.390	0.057	0.059	0.966
2270002015	Rollers	25	6,922.699	0.082	0.086	1.402
2270002015	Rollers	40	11,438.780	0.086	0.142	1.679
2270002015	Rollers	50	16,113.568	0.122	0.200	2.365
2270002015	Rollers	75	21,364.518	0.103	0.265	3.016
2270002015	Rollers	100	29,813.977	0.155	0.370	9.431
2270002015	Rollers	175	41,873.588	0.242	0.577	9.304
2270002015	Rollers	300	68,733.517	0.398	0.947	9.689
2270002015	Rollers	600	133,189.771	0.690	1.836	18.431
2270002018	Scrapers	75	23,214.619	0.112	0.288	3.307
2270002018	Scrapers	175	50,932.443	0.295	0.702	11.433
2270002018	Scrapers	300	78,204.117	0.453	1.078	11.148
2270002018	Scrapers	600	133,822.819	0.693	1.845	18.659
2270002018	Scrapers	750	217,791.519	1.128	3.002	30.367
2270002018	Scrapers	1000	240,723.011	1.247	3.318	21.935
2270002021	Paving Equipment	6	1,625.200	0.024	0.020	0.324
2270002021	Paving Equipment	11	2,567.951	0.038	0.032	0.513
2270002021	Paving Equipment	16	5,170.921	0.061	0.064	1.032
2270002021	Paving Equipment	25	6,936.771	0.082	0.086	1.385

SCC	description	Power Class hp	Direct CO_2 g/hr	Direct CH_4 g/hr	Direct N_2O g/hr	Direct PM_{BC} g/hr
2270002021	Paving Equipment	40	11,896.075	0.090	0.148	1.720
2270002021	Paving Equipment	75	21,473.571	0.104	0.267	3.006
2270002021	Paving Equipment	100	29,275.776	0.153	0.363	9.186
2270002021	Paving Equipment	175	41,588.543	0.241	0.573	9.155
2270002021	Paving Equipment	300	72,914.513	0.422	1.005	10.176
2270002021	Paving Equipment	600	145,700.699	0.754	2.008	20.026
2270002024	Surfacing Equipment	11	2,356.888	0.035	0.029	0.467
2270002024	Surfacing Equipment	16	4,678.449	0.055	0.058	0.928
2270002024	Surfacing Equipment	25	7,619.197	0.090	0.095	1.511
2270002024	Surfacing Equipment	40	11,146.907	0.084	0.138	1.601
2270002024	Surfacing Equipment	50	15,793.428	0.119	0.196	2.268
2270002024	Surfacing Equipment	75	19,320.897	0.094	0.240	2.695
2270002024	Surfacing Equipment	100	28,456.228	0.148	0.353	8.897
2270002024	Surfacing Equipment	175	40,068.148	0.232	0.552	8.784
2270002024	Surfacing Equipment	300	73,801.438	0.427	1.017	10.254
2270002024	Surfacing Equipment	600	156,026.586	0.807	2.151	21.380
2270002024	Surfacing Equipment	750	225,994.842	1.169	3.115	30.967
2270002024	Surfacing Equipment	1000	284,117.011	1.471	3.916	25.392
2270002024	Surfacing Equipment	2000	489,048.706	2.531	6.741	43.706
2270002027	Signal Boards/Light Plants	6	1,371.004	0.020	0.017	0.270
2270002027	Signal Boards/Light Plants	11	1,973.989	0.029	0.025	0.388
2270002027	Signal Boards/Light Plants	16	3,485.783	0.042	0.044	0.685
2270002027	Signal Boards/Light Plants	25	5,631.083	0.067	0.071	1.107
2270002027	Signal Boards/Light Plants	40	7,697.314	0.059	0.096	1.096
2270002027	Signal Boards/Light Plants	50	10,713.278	0.081	0.134	1.525
2270002027	Signal Boards/Light Plants	75	15,048.937	0.074	0.189	2.099
2270002027	Signal Boards/Light Plants	100	22,594.121	0.113	0.283	4.745
2270002027	Signal Boards/Light Plants	175	35,966.348	0.199	0.501	5.003
2270002027	Signal Boards/Light Plants	300	49,325.303	0.273	0.687	4.086
2270002030	Trenchers	11	3,377.037	0.050	0.042	0.672
2270002030	Trenchers	16	5,452.329	0.065	0.068	1.085
2270002030	Trenchers	25	7,598.083	0.090	0.094	1.512
2270002030	Trenchers	40	11,994.566	0.090	0.149	1.728
2270002030	Trenchers	50	15,846.224	0.120	0.197	2.283
2270002030	Trenchers	75	21,462.944	0.104	0.266	3.000
2270002030	Trenchers	100	30,513.892	0.159	0.379	9.558
2270002030	Trenchers	175	42,538.789	0.246	0.586	9.346
2270002030	Trenchers	300	79,344.461	0.459	1.094	11.050
2270002030	Trenchers	600	131,320.700	0.680	1.810	18.023
2270002030	Trenchers	750	234,926.728	1.216	3.238	32.243

SCC	description	Power Class hp	Direct CO_2 g/hr	Direct CH_4 g/hr	Direct N_2O g/hr	Direct PM_{BC} g/hr
2270002030	Trenchers	2000	475,111.949	2.459	6.549	42.536
2270002033	Bore/Drill Rigs	11	2,031.110	0.030	0.025	0.397
2270002033	Bore/Drill Rigs	16	3,681.279	0.044	0.046	0.720
2270002033	Bore/Drill Rigs	25	5,961.124	0.071	0.075	1.165
2270002033	Bore/Drill Rigs	40	7,991.808	0.061	0.100	1.131
2270002033	Bore/Drill Rigs	50	11,406.380	0.087	0.143	1.614
2270002033	Bore/Drill Rigs	75	15,701.325	0.077	0.197	2.183
2270002033	Bore/Drill Rigs	100	21,609.154	0.108	0.271	4.524
2270002033	Bore/Drill Rigs	175	30,097.560	0.167	0.419	4.171
2270002033	Bore/Drill Rigs	300	54,623.153	0.302	0.761	4.505
2270002033	Bore/Drill Rigs	600	102,098.701	0.534	1.423	8.340
2270002033	Bore/Drill Rigs	750	157,680.333	0.824	2.197	12.880
2270002033	Bore/Drill Rigs	1000	198,442.299	1.038	2.765	13.051
2270002033	Bore/Drill Rigs	1200	239,774.568	1.254	3.341	15.769
2270002033	Bore/Drill Rigs	2000	342,535.355	1.792	4.773	22.527
2270002036	Excavators	6	2,110.651	0.031	0.026	0.443
2270002036	Excavators	11	2,802.589	0.042	0.035	0.588
2270002036	Excavators	16	4,622.175	0.055	0.057	0.969
2270002036	Excavators	25	7,576.989	0.090	0.094	1.589
2270002036	Excavators	40	11,625.269	0.088	0.144	1.767
2270002036	Excavators	50	16,099.448	0.122	0.200	2.447
2270002036	Excavators	75	21,561.420	0.105	0.268	3.104
2270002036	Excavators	100	32,244.487	0.168	0.400	10.398
2270002036	Excavators	175	43,584.047	0.253	0.601	9.899
2270002036	Excavators	300	73,896.426	0.428	1.019	10.668
2270002036	Excavators	600	130,053.961	0.674	1.793	18.292
2270002036	Excavators	750	227,864.158	1.181	3.141	32.048
2270002036	Excavators	1000	279,999.822	1.451	3.860	25.760
2270002036	Excavators	1200	380,089.605	1.970	5.239	34.969
2270002036	Excavators	2000	559,998.740	2.903	7.719	51.521
2270002036	Excavators	3000	744,342.482	3.859	10.260	68.481
2270002039	Concrete/Industrial Saws	11	3,517.743	0.052	0.044	0.699
2270002039	Concrete/Industrial Saws	25	7,077.477	0.084	0.088	1.406
2270002039	Concrete/Industrial Saws	40	11,586.501	0.087	0.144	1.667
2270002039	Concrete/Industrial Saws	50	15,195.465	0.115	0.189	2.187
2270002039	Concrete/Industrial Saws	75	20,347.969	0.098	0.253	2.841
2270002039	Concrete/Industrial Saws	100	28,656.666	0.149	0.356	8.970
2270002039	Concrete/Industrial Saws	175	38,294.354	0.222	0.528	8.406
2270002039	Concrete/Industrial Saws	300	76,493.702	0.443	1.054	10.643
2270002042	Cement & Mortar Mixers	6	1,519.017	0.023	0.019	0.292

SCC	description	Power Class hp	Direct CO_2 g/hr	Direct CH_4 g/hr	Direct N_2O g/hr	Direct PM_{BC} g/hr
2270002042	Cement & Mortar Mixers	11	2,051.935	0.031	0.026	0.395
2270002042	Cement & Mortar Mixers	16	3,320.768	0.040	0.042	0.639
2270002042	Cement & Mortar Mixers	25	5,351.814	0.064	0.067	1.030
2270002042	Cement & Mortar Mixers	40	8,321.831	0.063	0.104	1.159
2270002042	Cement & Mortar Mixers	75	15,120.033	0.074	0.190	2.084
2270002042	Cement & Mortar Mixers	100	21,187.769	0.105	0.266	4.399
2270002042	Cement & Mortar Mixers	175	29,435.345	0.163	0.410	4.037
2270002042	Cement & Mortar Mixers	300	57,797.332	0.320	0.805	4.711
2270002042	Cement & Mortar Mixers	600	91,868.002	0.480	1.280	7.444
2270002042	Cement & Mortar Mixers	750	160,923.394	0.841	2.242	13.040
2270002045	Cranes	40	10,002.485	0.076	0.125	1.477
2270002045	Cranes	50	10,586.377	0.081	0.133	1.563
2270002045	Cranes	75	16,247.125	0.079	0.204	2.312
2270002045	Cranes	100	22,375.832	0.112	0.280	4.793
2270002045	Cranes	175	33,157.565	0.184	0.462	4.726
2270002045	Cranes	300	54,280.647	0.301	0.756	4.623
2270002045	Cranes	600	94,083.179	0.492	1.311	7.854
2270002045	Cranes	750	152,770.848	0.799	2.129	12.753
2270002045	Cranes	1000	201,593.025	1.055	2.809	13.571
2270002045	Cranes	1200	244,570.063	1.280	3.408	16.465
2270002048	Graders	50	16,989.427	0.128	0.211	2.547
2270002048	Graders	75	20,942.444	0.101	0.260	2.992
2270002048	Graders	100	29,620.467	0.155	0.368	9.480
2270002048	Graders	175	44,597.585	0.258	0.615	10.043
2270002048	Graders	300	73,231.245	0.424	1.009	10.475
2270002048	Graders	600	108,262.322	0.561	1.492	15.131
2270002048	Graders	750	237,556.101	1.230	3.275	33.201
2270002051	Off-highway Trucks	175	50,837.498	0.295	0.701	11.961
2270002051	Off-highway Trucks	300	77,380.623	0.449	1.067	11.605
2270002051	Off-highway Trucks	600	132,999.346	0.690	1.833	19.203
2270002051	Off-highway Trucks	750	217,949.933	1.131	3.004	31.469
2270002051	Off-highway Trucks	1000	274,931.778	1.427	3.790	26.042
2270002051	Off-highway Trucks	1200	365,202.545	1.896	5.034	34.593
2270002051	Off-highway Trucks	2000	566,017.263	2.939	7.802	53.614
2270002051	Off-highway Trucks	3000	767,781.026	3.986	10.583	72.726
2270002054	Crushing/Proc. Equipment	25	5,184.250	0.062	0.065	1.054
2270002054	Crushing/Proc. Equipment	40	8,149.204	0.062	0.102	1.200
2270002054	Crushing/Proc. Equipment	50	11,576.428	0.088	0.145	1.704
2270002054	Crushing/Proc. Equipment	75	15,419.556	0.075	0.193	2.191
2270002054	Crushing/Proc. Equipment	100	22,589.060	0.113	0.283	4.832

SCC	description	Power Class hp	Direct CO_2 g/hr	Direct CH_4 g/hr	Direct N_2O g/hr	Direct PM_{BC} g/hr
2270002054	Crushing/Proc. Equipment	175	30,211.769	0.168	0.421	4.298
2270002054	Crushing/Proc. Equipment	300	55,102.691	0.306	0.768	4.683
2270002054	Crushing/Proc. Equipment	600	96,640.615	0.506	1.347	8.056
2270002054	Crushing/Proc. Equipment	750	152,154.183	0.796	2.120	12.684
2270002054	Crushing/Proc. Equipment	1000	210,088.152	1.100	2.927	14.121
2270002057	Rough Terrain Forklifts	16	4,748.803	0.056	0.059	0.952
2270002057	Rough Terrain Forklifts	25	7,897.082	0.094	0.098	1.583
2270002057	Rough Terrain Forklifts	40	11,734.253	0.089	0.146	1.704
2270002057	Rough Terrain Forklifts	50	15,849.688	0.120	0.197	2.301
2270002057	Rough Terrain Forklifts	75	21,603.706	0.105	0.268	3.032
2270002057	Rough Terrain Forklifts	100	30,109.397	0.157	0.374	9.470
2270002057	Rough Terrain Forklifts	175	39,909.759	0.231	0.550	8.809
2270002057	Rough Terrain Forklifts	300	72,566.105	0.420	1.000	10.157
2270002057	Rough Terrain Forklifts	600	109,624.499	0.567	1.511	15.097
2270002060	Rubber Tire Loaders	25	8,030.757	0.095	0.100	1.627
2270002060	Rubber Tire Loaders	40	12,093.081	0.091	0.150	1.775
2270002060	Rubber Tire Loaders	50	15,983.362	0.121	0.198	2.346
2270002060	Rubber Tire Loaders	75	21,702.152	0.105	0.269	3.064
2270002060	Rubber Tire Loaders	100	30,067.178	0.157	0.373	9.512
2270002060	Rubber Tire Loaders	175	43,172.260	0.250	0.595	9.593
2270002060	Rubber Tire Loaders	300	72,851.156	0.422	1.004	10.271
2270002060	Rubber Tire Loaders	600	132,841.034	0.688	1.831	18.384
2270002060	Rubber Tire Loaders	750	219,248.145	1.135	3.022	30.342
2270002060	Rubber Tire Loaders	1000	274,393.386	1.422	3.782	24.795
2270002060	Rubber Tire Loaders	1200	342,714.287	1.774	4.724	30.968
2270002060	Rubber Tire Loaders	2000	591,356.446	3.063	8.151	53.436
2270002060	Rubber Tire Loaders	3000	710,450.539	3.680	9.793	64.197
2270002066	Tractors/Loaders/Backhoes	16	2,265.630	0.023	0.024	0.376
2270002066	Tractors/Loaders/Backhoes	25	3,329.747	0.034	0.035	0.553
2270002066	Tractors/Loaders/Backhoes	40	4,748.871	0.031	0.050	0.569
2270002066	Tractors/Loaders/Backhoes	50	6,757.160	0.044	0.072	0.810
2270002066	Tractors/Loaders/Backhoes	75	9,129.140	0.038	0.097	1.071
2270002066	Tractors/Loaders/Backhoes	100	12,742.038	0.126	0.135	5.467
2270002066	Tractors/Loaders/Backhoes	175	15,882.886	0.174	0.188	5.031
2270002066	Tractors/Loaders/Backhoes	300	26,318.020	0.288	0.311	5.466
2270002069	Crawler Tractor/Dozers	75	20,393.672	0.099	0.253	2.909
2270002069	Crawler Tractor/Dozers	100	30,904.358	0.161	0.384	9.877
2270002069	Crawler Tractor/Dozers	175	43,108.893	0.250	0.594	9.691
2270002069	Crawler Tractor/Dozers	300	74,593.309	0.432	1.028	10.650
2270002069	Crawler Tractor/Dozers	600	134,710.110	0.698	1.857	18.803

SCC	description	Power Class hp	Direct CO_2 g/hr	Direct CH_4 g/hr	Direct N_2O g/hr	Direct PM_{BC} g/hr
2270002069	Crawler Tractor/Dozers	750	223,936.225	1.160	3.087	31.258
2270002069	Crawler Tractor/Dozers	1000	292,352.654	1.515	4.030	26.671
2270002069	Crawler Tractor/Dozers	1200	337,329.915	1.748	4.650	30.774
2270002069	Crawler Tractor/Dozers	2000	466,560.191	2.418	6.431	42.564
2270002072	Skid Steer Loaders	11	1,388.648	0.018	0.015	0.228
2270002072	Skid Steer Loaders	16	2,261.245	0.023	0.024	0.371
2270002072	Skid Steer Loaders	25	2,967.249	0.030	0.032	0.486
2270002072	Skid Steer Loaders	40	5,111.351	0.033	0.054	0.605
2270002072	Skid Steer Loaders	50	6,568.612	0.042	0.070	0.777
2270002072	Skid Steer Loaders	75	8,429.070	0.035	0.090	0.982
2270002072	Skid Steer Loaders	100	12,329.857	0.122	0.131	5.255
2270002072	Skid Steer Loaders	175	15,172.363	0.166	0.179	4.771
2270002075	Off-Highway Tractors	300	91,856.236	0.532	1.266	13.038
2270002075	Off-Highway Tractors	600	129,959.434	0.673	1.791	18.068
2270002075	Off-Highway Tractors	750	214,117.023	1.109	2.951	29.769
2270002075	Off-Highway Tractors	1000	287,537.451	1.490	3.963	26.116
2270002075	Off-Highway Tractors	1200	360,768.859	1.869	4.973	32.768
2270002075	Off-Highway Tractors	2000	480,179.939	2.487	6.619	43.614
2270002075	Off-Highway Tractors	3000	723,120.664	3.746	9.968	65.679
2270002078	Dumpers/Tenders	11	1,461.742	0.019	0.016	0.237
2270002078	Dumpers/Tenders	16	2,091.691	0.021	0.022	0.339
2270002078	Dumpers/Tenders	25	3,471.533	0.035	0.037	0.563
2270002078	Dumpers/Tenders	40	4,699.172	0.030	0.050	0.550
2270002078	Dumpers/Tenders	50	7,088.956	0.046	0.075	0.830
2270002078	Dumpers/Tenders	75	8,448.072	0.035	0.090	0.979
2270002078	Dumpers/Tenders	100	12,483.299	0.123	0.133	5.292
2270002078	Dumpers/Tenders	175	14,435.385	0.158	0.170	4.512
2270002081	Other Construction Equipment	11	2,779.020	0.041	0.034	0.554
2270002081	Other Construction Equipment	16	5,276.452	0.063	0.065	1.051
2270002081	Other Construction Equipment	25	7,422.206	0.088	0.092	1.479
2270002081	Other Construction Equipment	40	12,008.651	0.091	0.149	1.733
2270002081	Other Construction Equipment	50	15,628.156	0.118	0.194	2.255
2270002081	Other Construction Equipment	75	21,051.481	0.102	0.261	2.944
2270002081	Other Construction Equipment	100	29,645.130	0.154	0.368	9.293
2270002081	Other Construction Equipment	175	43,615.659	0.252	0.601	9.591
2270002081	Other Construction Equipment	300	74,023.165	0.428	1.020	10.319
2270002081	Other Construction Equipment	600	140,189.907	0.725	1.932	19.253
2270002081	Other Construction Equipment	750	224,949.562	1.164	3.101	30.893
2270002081	Other Construction Equipment	1000	262,103.871	1.356	3.613	23.483
2270002081	Other Construction Equipment	1200	380,089.936	1.968	5.239	34.053

SCC	description	Power Class hp	Direct CO_2 g/hr	Direct CH_4 g/hr	Direct N_2O g/hr	Direct PM_{BC} g/hr
2270003010	Aerial Lifts	11	1,169.394	0.015	0.012	0.188
2270003010	Aerial Lifts	16	1,926.521	0.019	0.020	0.310
2270003010	Aerial Lifts	25	3,161.648	0.032	0.034	0.509
2270003010	Aerial Lifts	40	4,830.717	0.031	0.051	0.562
2270003010	Aerial Lifts	50	6,644.610	0.043	0.071	0.773
2270003010	Aerial Lifts	75	8,836.856	0.037	0.094	1.020
2270003010	Aerial Lifts	100	12,258.209	0.121	0.130	5.176
2270003010	Aerial Lifts	175	14,869.647	0.163	0.176	4.628
2270003020	Forklifts	16	5,276.452	0.063	0.065	1.176
2270003020	Forklifts	25	8,794.090	0.105	0.109	1.960
2270003020	Forklifts	40	12,198.597	0.093	0.151	1.971
2270003020	Forklifts	50	16,539.143	0.126	0.205	2.673
2270003020	Forklifts	75	21,716.208	0.106	0.270	3.238
2270003020	Forklifts	100	30,067.193	0.157	0.373	10.034
2270003020	Forklifts	175	42,950.532	0.249	0.592	10.143
2270003020	Forklifts	300	69,778.776	0.405	0.962	10.507
2270003020	Forklifts	600	112,095.014	0.582	1.545	16.230
2270003030	Sweepers/Scrubbers	6	1,269.447	0.019	0.016	0.263
2270003030	Sweepers/Scrubbers	11	2,792.691	0.033	0.035	0.579
2270003030	Sweepers/Scrubbers	25	5,506.684	0.066	0.069	1.142
2270003030	Sweepers/Scrubbers	40	8,842.268	0.067	0.111	1.329
2270003030	Sweepers/Scrubbers	50	11,078.879	0.085	0.139	1.665
2270003030	Sweepers/Scrubbers	75	15,437.365	0.076	0.193	2.219
2270003030	Sweepers/Scrubbers	100	20,781.521	0.104	0.260	4.496
2270003030	Sweepers/Scrubbers	175	30,668.456	0.170	0.427	4.424
2270003030	Sweepers/Scrubbers	300	49,485.161	0.275	0.690	4.273
2270003030	Sweepers/Scrubbers	600	83,076.132	0.435	1.158	7.001
2270003040	Other General Industrial Eqp	6	1,108.736	0.017	0.014	0.224
2270003040	Other General Industrial Eqp	11	2,432.261	0.036	0.030	0.491
2270003040	Other General Industrial Eqp	16	3,483.251	0.042	0.044	0.704
2270003040	Other General Industrial Eqp	25	5,742.788	0.069	0.072	1.160
2270003040	Other General Industrial Eqp	40	8,245.679	0.063	0.103	1.207
2270003040	Other General Industrial Eqp	50	11,248.948	0.086	0.141	1.646
2270003040	Other General Industrial Eqp	75	15,564.307	0.076	0.195	2.204
2270003040	Other General Industrial Eqp	100	21,860.458	0.109	0.274	4.660
2270003040	Other General Industrial Eqp	175	29,777.895	0.165	0.415	4.219
2270003040	Other General Industrial Eqp	300	53,481.376	0.296	0.745	4.524
2270003040	Other General Industrial Eqp	600	88,922.141	0.465	1.239	7.389
2270003040	Other General Industrial Eqp	750	148,431.522	0.777	2.068	12.334
2270003050	Other Material Handling Eqp	40	5,437.302	0.035	0.058	0.633

SCC	description	Power Class hp	Direct CO_2 g/hr	Direct CH_4 g/hr	Direct N_2O g/hr	Direct PM_{BC} g/hr
2270003050	Other Material Handling Eqp	75	9,460.997	0.039	0.101	1.093
2270003050	Other Material Handling Eqp	100	12,633.927	0.124	0.134	5.339
2270003050	Other Material Handling Eqp	175	16,961.981	0.186	0.200	5.284
2270003050	Other Material Handling Eqp	300	32,265.900	0.353	0.381	6.584
2270003050	Other Material Handling Eqp	600	56,359.120	0.558	0.666	11.460
2270003060	AC\Refrigeration	11	2,437.337	0.037	0.031	0.510
2270003060	AC\Refrigeration	16	3,361.390	0.040	0.042	0.704
2270003060	AC\Refrigeration	25	4,937.987	0.059	0.062	1.034
2270003060	AC\Refrigeration	40	8,080.661	0.062	0.101	1.226
2270003060	AC\Refrigeration	50	11,398.731	0.087	0.143	1.729
2270003060	AC\Refrigeration	75	14,470.134	0.071	0.181	2.091
2270004031	Leafblowers/Vacuums (com)	6	1,438.794	0.021	0.018	0.273
2270004031	Leafblowers/Vacuums (com)	40	7,108.341	0.054	0.089	0.977
2270004036	Snowblowers (com)	175	37,679.003	0.209	0.525	5.203
2270004036	Snowblowers (com)	300	57,500.449	0.318	0.801	4.723
2270004036	Snowblowers (com)	600	87,780.297	0.459	1.223	7.151
2270004046	Commercial Mowers (com)	6	1,269.443	0.019	0.016	0.248
2270004046	Commercial Mowers (com)	16	3,584.804	0.043	0.045	0.702
2270004046	Commercial Mowers (com)	25	5,298.496	0.063	0.066	1.037
2270004046	Commercial Mowers (com)	40	7,941.034	0.060	0.100	1.125
2270004046	Commercial Mowers (com)	50	11,337.779	0.086	0.142	1.607
2270004046	Commercial Mowers (com)	75	13,982.716	0.068	0.175	1.945
2270004046	Commercial Mowers (com)	100	20,977.002	0.104	0.263	4.395
2270004056	Lawn & Garden Tractors (com)	11	2,665.839	0.040	0.033	0.524
2270004056	Lawn & Garden Tractors (com)	16	3,711.741	0.044	0.047	0.730
2270004056	Lawn & Garden Tractors (com)	25	5,085.238	0.061	0.064	1.000
2270004056	Lawn & Garden Tractors (com)	40	6,684.375	0.051	0.084	0.952
2270004056	Lawn & Garden Tractors (com)	50	11,297.168	0.086	0.142	1.609
2270004056	Lawn & Garden Tractors (com)	100	20,309.345	0.101	0.255	4.267
2270004066	Chippers/Stump Grinders (com)	25	6,347.029	0.076	0.080	1.241
2270004066	Chippers/Stump Grinders (com)	40	9,443.908	0.072	0.118	1.337
2270004066	Chippers/Stump Grinders (com)	50	11,962.283	0.091	0.150	1.693
2270004066	Chippers/Stump Grinders (com)	75	15,503.356	0.076	0.194	2.155
2270004066	Chippers/Stump Grinders (com)	100	21,444.146	0.107	0.269	4.490
2270004066	Chippers/Stump Grinders (com)	175	27,699.804	0.153	0.386	3.838
2270004066	Chippers/Stump Grinders (com)	300	55,194.073	0.306	0.769	4.552
2270004066	Chippers/Stump Grinders (com)	600	99,197.969	0.519	1.382	8.103
2270004066	Chippers/Stump Grinders (com)	750	160,512.044	0.839	2.237	13.111
2270004066	Chippers/Stump Grinders (com)	1000	216,436.108	1.132	3.016	14.233
2270004066	Chippers/Stump Grinders (com)	1200	250,050.646	1.308	3.484	16.444

SCC	description	Power Class hp	Direct CO_2 g/hr	Direct CH_4 g/hr	Direct N_2O g/hr	Direct PM_{BC} g/hr
2270004071	Commercial Turf Equipment (com)	16	3,442.632	0.041	0.043	0.706
2270004071	Commercial Turf Equipment (com)	25	5,369.589	0.064	0.067	1.101
2270004071	Commercial Turf Equipment (com)	40	8,776.263	0.067	0.110	1.304
2270004071	Commercial Turf Equipment (com)	50	11,543.454	0.088	0.145	1.715
2270004071	Commercial Turf Equipment (com)	75	15,960.254	0.078	0.200	2.279
2270004071	Commercial Turf Equipment (com)	100	21,279.171	0.106	0.267	4.574
2270004071	Commercial Turf Equipment (com)	175	25,804.441	0.143	0.360	3.693
2270004076	Other Lawn & Garden Eqp. (com)	16	3,808.212	0.045	0.048	0.742
2270004076	Other Lawn & Garden Eqp. (com)	25	5,813.879	0.069	0.073	1.134
2270004076	Other Lawn & Garden Eqp. (com)	50	11,931.841	0.091	0.150	1.684
2270004076	Other Lawn & Garden Eqp. (com)	75	12,946.918	0.063	0.162	1.797
2270004076	Other Lawn & Garden Eqp. (com)	100	20,309.339	0.101	0.255	4.246
2270004076	Other Lawn & Garden Eqp. (com)	175	29,914.910	0.166	0.417	4.138
2270005010	2-Wheel Tractors	6	2,110.646	0.031	0.026	0.418
2270005010	2-Wheel Tractors	11	2,931.335	0.043	0.036	0.580
2270005015	Agricultural Tractors	25	7,376.473	0.087	0.092	1.449
2270005015	Agricultural Tractors	40	11,424.754	0.086	0.142	1.625
2270005015	Agricultural Tractors	50	16,317.508	0.123	0.203	2.321
2270005015	Agricultural Tractors	75	21,870.948	0.106	0.271	3.035
2270005015	Agricultural Tractors	100	30,299.367	0.158	0.376	9.425
2270005015	Agricultural Tractors	175	42,317.055	0.245	0.583	9.223
2270005015	Agricultural Tractors	300	74,909.977	0.433	1.033	10.342
2270005015	Agricultural Tractors	600	131,511.377	0.680	1.813	17.944
2270005030	Agricultural Mowers	100	26,732.668	0.139	0.332	8.260
2270005035	Sprayers	25	7,949.849	0.094	0.099	1.496
2270005035	Sprayers	40	11,276.968	0.085	0.140	1.535
2270005035	Sprayers	50	16,873.338	0.127	0.209	2.297
2270005035	Sprayers	75	22,391.536	0.108	0.278	3.034
2270005035	Sprayers	100	30,334.470	0.158	0.377	9.220
2270005035	Sprayers	175	40,669.991	0.235	0.561	8.631
2270005035	Sprayers	300	71,774.270	0.415	0.989	9.627
2270005035	Sprayers	600	113,552.181	0.587	1.565	15.195
2270005045	Swathers	75	24,621.574	0.119	0.306	3.340
2270005045	Swathers	100	29,898.366	0.155	0.371	9.099
2270005045	Swathers	175	41,588.545	0.240	0.573	8.839
2270005045	Swathers	300	63,348.826	0.366	0.873	8.509
2270005055	Other Agricultural Equipment	16	5,058.357	0.060	0.063	0.983
2270005055	Other Agricultural Equipment	25	7,341.303	0.087	0.091	1.427
2270005055	Other Agricultural Equipment	40	11,283.998	0.085	0.140	1.588
2270005055	Other Agricultural Equipment	50	15,835.650	0.119	0.197	2.229

SCC	description	Power Class hp	Direct CO_2 g/hr	Direct CH_4 g/hr	Direct N_2O g/hr	Direct PM_{BC} g/hr
2270005055	Other Agricultural Equipment	75	22,032.766	0.107	0.273	3.040
2270005055	Other Agricultural Equipment	100	29,880.777	0.156	0.371	9.243
2270005055	Other Agricultural Equipment	175	42,918.870	0.248	0.592	9.294
2270005055	Other Agricultural Equipment	300	72,977.838	0.422	1.006	10.005
2270005055	Other Agricultural Equipment	600	118,809.666	0.615	1.638	16.134
2270005060	Irrigation Sets	25	5,554.919	0.066	0.070	1.111
2270005060	Irrigation Sets	40	8,377.687	0.064	0.105	1.213
2270005060	Irrigation Sets	50	11,444.385	0.087	0.143	1.657
2270005060	Irrigation Sets	75	15,292.593	0.075	0.192	2.153
2270005060	Irrigation Sets	100	21,799.515	0.109	0.273	4.621
2270005060	Irrigation Sets	175	31,125.170	0.172	0.434	4.380
2270005060	Irrigation Sets	300	51,266.337	0.284	0.714	4.303
2270005060	Irrigation Sets	600	89,059.074	0.466	1.241	7.361
2270006005	Generator Sets	6	1,358.305	0.020	0.017	0.263
2270006005	Generator Sets	11	2,137.244	0.032	0.027	0.413
2270006005	Generator Sets	16	3,442.630	0.041	0.043	0.666
2270006005	Generator Sets	25	5,405.131	0.065	0.068	1.046
2270006005	Generator Sets	40	8,489.387	0.065	0.106	1.189
2270006005	Generator Sets	50	11,472.336	0.087	0.144	1.607
2270006005	Generator Sets	75	15,221.562	0.074	0.191	2.104
2270006005	Generator Sets	100	21,939.163	0.109	0.275	4.568
2270006005	Generator Sets	175	30,988.170	0.172	0.432	4.264
2270006005	Generator Sets	300	54,349.117	0.301	0.757	4.447
2270006005	Generator Sets	600	95,749.581	0.500	1.334	7.780
2270006010	Pumps	3	761.668	0.011	0.010	0.148
2270006010	Pumps	6	1,326.574	0.020	0.017	0.258
2270006010	Pumps	11	2,148.922	0.032	0.027	0.418
2270006010	Pumps	16	3,485.787	0.042	0.044	0.678
2270006010	Pumps	25	5,514.298	0.066	0.069	1.073
2270006010	Pumps	40	8,712.788	0.066	0.109	1.227
2270006010	Pumps	50	11,368.303	0.086	0.142	1.601
2270006010	Pumps	75	15,835.905	0.077	0.198	2.195
2270006010	Pumps	100	21,911.287	0.109	0.275	4.575
2270006010	Pumps	175	30,234.517	0.167	0.421	4.175
2270006010	Pumps	300	55,536.561	0.308	0.774	4.563
2270006010	Pumps	600	90,794.644	0.475	1.265	7.397
2270006015	Air Compressors	6	1,413.400	0.021	0.018	0.284
2270006015	Air Compressors	11	2,404.330	0.036	0.030	0.483
2270006015	Air Compressors	16	3,386.771	0.041	0.042	0.681
2270006015	Air Compressors	25	5,758.027	0.069	0.072	1.158

SCC	description	Power Class hp	Direct CO_2 g/hr	Direct CH_4 g/hr	Direct N_2O g/hr	Direct PM_{BC} g/hr
2270006015	Air Compressors	40	8,504.618	0.065	0.107	1.238
2270006015	Air Compressors	50	11,236.222	0.086	0.141	1.636
2270006015	Air Compressors	75	15,424.636	0.075	0.193	2.178
2270006015	Air Compressors	100	21,289.328	0.106	0.267	4.526
2270006015	Air Compressors	175	29,503.782	0.163	0.411	4.166
2270006015	Air Compressors	300	55,559.424	0.308	0.774	4.682
2270006015	Air Compressors	600	97,599.631	0.511	1.360	8.089
2270006025	Welders	11	1,292.611	0.016	0.014	0.210
2270006025	Welders	16	2,145.775	0.022	0.023	0.349
2270006025	Welders	25	3,111.951	0.032	0.033	0.506
2270006025	Welders	40	4,820.492	0.031	0.051	0.566
2270006025	Welders	50	6,758.622	0.044	0.072	0.794
2270006025	Welders	75	9,393.719	0.039	0.100	1.090
2270006025	Welders	100	12,366.396	0.122	0.131	5.251
2270006025	Welders	175	19,975.332	0.219	0.236	6.255
2270006025	Welders	600	50,003.430	0.495	0.591	10.206
2270006030	Pressure Washers	6	1,315.148	0.020	0.016	0.250
2270006030	Pressure Washers	11	2,295.411	0.034	0.029	0.437
2270006030	Pressure Washers	16	3,546.720	0.042	0.044	0.675
2270006030	Pressure Washers	25	5,184.246	0.062	0.065	0.987
2270006030	Pressure Washers	40	7,928.339	0.060	0.099	1.093
2270006030	Pressure Washers	50	11,502.850	0.087	0.144	1.585
2270006030	Pressure Washers	75	15,571.906	0.076	0.195	2.134
2270006030	Pressure Washers	100	22,474.860	0.112	0.282	4.639
2270006030	Pressure Washers	175	29,298.281	0.162	0.408	3.989
2270006030	Pressure Washers	300	51,654.520	0.286	0.720	4.176
2270006030	Pressure Washers	600	94,882.234	0.496	1.322	7.646
2270006030	Pressure Washers	750	157,315.152	0.822	2.192	12.678
2270007015	Forest Eqp - Feller/Bunch/Skidde	40	12,476.495	0.095	0.155	1.933
2270007015	Forest Eqp - Feller/Bunch/Skidde	50	15,803.991	0.120	0.196	2.448
2270007015	Forest Eqp - Feller/Bunch/Skidde	75	22,894.539	0.111	0.284	3.332
2270007015	Forest Eqp - Feller/Bunch/Skidde	100	31,291.282	0.163	0.388	10.197
2270007015	Forest Eqp - Feller/Bunch/Skidde	175	43,393.975	0.252	0.598	9.975
2270007015	Forest Eqp - Feller/Bunch/Skidde	300	71,330.832	0.414	0.983	10.432
2270007015	Forest Eqp - Feller/Bunch/Skidde	600	133,443.322	0.692	1.839	18.935
2270007015	Forest Eqp - Feller/Bunch/Skidde	750	218,330.260	1.132	3.009	30.981
2285002015	Railway Maintenance	11	1,216.170	0.015	0.013	0.200
2285002015	Railway Maintenance	16	2,065.376	0.021	0.022	0.340
2285002015	Railway Maintenance	25	2,557.974	0.026	0.027	0.421
2285002015	Railway Maintenance	40	4,873.103	0.031	0.052	0.580

SCC	description	Power Class hp	Direct CO_2 g/hr	Direct CH_4 g/hr	Direct N_2O g/hr	Direct PM_{BC} g/hr
2285002015	Railway Maintenance	50	6,448.758	0.042	0.069	0.767
2285002015	Railway Maintenance	75	8,712.623	0.036	0.093	1.018
2285002015	Railway Maintenance	100	12,840.029	0.127	0.137	5.487
2285002015	Railway Maintenance	175	17,633.052	0.193	0.208	5.561
2285002015	Railway Maintenance	300	30,792.010	0.337	0.364	6.365
2285002015	Railway Maintenance	600	59,635.661	0.591	0.704	12.232
2285002015	Railway Maintenance	750	90,690.427	0.898	1.071	18.602
2285004015	Railway Maintenance	3	3,943.624	2.782	0.014	0.294
2285004015	Railway Maintenance	6	4,559.598	3.265	0.016	0.345
2285004015	Railway Maintenance	11	7,669.532	2.404	0.030	0.154
2285004015	Railway Maintenance	16	13,627.690	4.403	0.055	0.281
2285004015	Railway Maintenance	25	20,662.826	5.976	0.083	0.382
2285004015	Railway Maintenance	40	14,974.695	0.519	0.152	0.497
2285006015	Railway Maintenance	40	11,338.917	0.172	0.152	0.451
2285002015	Railway Maintenance	750	90,690.427	0.898	1.071	18.602
2285004015	Railway Maintenance	3	3,943.624	2.782	0.014	0.294
2285004015	Railway Maintenance	6	4,559.598	3.265	0.016	0.345
2285004015	Railway Maintenance	11	7,669.532	2.404	0.030	0.154
2285004015	Railway Maintenance	16	13,627.690	4.403	0.055	0.281
2285004015	Railway Maintenance	25	20,662.826	5.976	0.083	0.382
2285004015	Railway Maintenance	40	14,974.695	0.519	0.152	0.497
2285006015	Railway Maintenance	40	11,338.917	0.172	0.152	0.451

Table 31. Upstream Emissions – 2010

SCC	Description	Power Class hp	Upstream CO_2 g/hr	Upstream CH_4 g/hr	Upstream N_2O g/hr	Upstream PM_{BC} g/hr
2260002006	Tampers/Rammers	6	744.924	4.546	0.011	0.023
2260002009	Plate Compactors	3	442.863	2.703	0.007	0.014
2260002021	Paving Equipment	3	489.593	2.988	0.007	0.015
2260002027	Signal Boards/Light Plants	3	590.842	3.606	0.009	0.018
2260002039	Concrete/Industrial Saws	3	509.467	3.109	0.008	0.016
2260002039	Concrete/Industrial Saws	6	900.265	5.494	0.014	0.028
2260002054	Crushing/Proc. Equipment	3	483.416	2.950	0.007	0.015
2260003030	Sweepers/Scrubbers	3	342.689	2.091	0.005	0.010
2260003040	Other General Industrial Eqp	3	548.946	3.350	0.008	0.017
2260004016	Rotary Tillers < 6 HP (com)	1	257.016	1.569	0.004	0.008
2260004016	Rotary Tillers < 6 HP (com)	3	675.172	4.121	0.010	0.021
2260004021	Chain Saws < 6 HP (com)	3	566.671	3.458	0.009	0.017
2260004021	Chain Saws < 6 HP (com)	6	777.899	4.748	0.012	0.024
2260004026	Trimmers/Edgers/Brush Cutter (com)	3	375.991	2.295	0.006	0.012
2260004026	Trimmers/Edgers/Brush Cutter (com)	6	655.533	4.001	0.010	0.020
2260004031	Leafblowers/Vacuums (com)	3	378.676	2.311	0.006	0.012
2260004031	Leafblowers/Vacuums (com)	6	679.371	4.146	0.010	0.021
2260004036	Snowblowers (com)	3	784.477	4.788	0.012	0.024
2260004036	Snowblowers (com)	6	930.857	5.681	0.014	0.028
2260004071	Commercial Turf Equipment (com)	3	805.694	4.917	0.012	0.025
2260005035	Sprayers	1	236.337	1.442	0.004	0.007
2260005035	Sprayers	3	689.405	4.207	0.011	0.021
2260006005	Generator Sets	1	214.852	1.311	0.003	0.007
2260006005	Generator Sets	3	446.623	2.726	0.007	0.014
2260006010	Pumps	1	266.148	1.624	0.004	0.008
2260006010	Pumps	3	536.592	3.275	0.008	0.016
2260006010	Pumps	40	6,009.053	36.674	0.092	0.184
2260006010	Pumps	75	8,697.313	53.080	0.133	0.266
2260006015	Air Compressors	3	593.259	3.621	0.009	0.018
2260007005	Chain Saws > 6 HP	11	1,935.724	11.814	0.030	0.059
2265002003	Pavers	6	1,609.869	9.825	0.025	0.049
2265002003	Pavers	11	2,645.363	16.145	0.040	0.081
2265002003	Pavers	16	3,561.938	21.739	0.055	0.109
2265002003	Pavers	25	5,912.931	36.087	0.090	0.181
2265002003	Pavers	40	5,020.722	30.642	0.077	0.154
2265002003	Pavers	75	9,869.078	60.232	0.151	0.302
2265002006	Tampers/Rammers	11	2,132.058	13.012	0.033	0.065
2265002009	Plate Compactors	6	1,326.712	8.097	0.020	0.041

SCC	Description	Power Class hp	Upstream CO_2 g/hr	Upstream CH_4 g/hr	Upstream N_2O g/hr	Upstream PM_{BC} g/hr
2265002009	Plate Compactors	11	2,332.559	14.236	0.036	0.071
2265002009	Plate Compactors	16	3,593.134	21.929	0.055	0.110
2265002015	Rollers	11	2,524.269	15.406	0.039	0.077
2265002015	Rollers	16	4,202.861	25.650	0.064	0.129
2265002015	Rollers	25	5,410.970	33.024	0.083	0.166
2265002015	Rollers	40	5,822.456	35.535	0.089	0.178
2265002015	Rollers	75	9,608.159	58.639	0.147	0.294
2265002015	Rollers	100	13,125.036	80.103	0.201	0.402
2265002021	Paving Equipment	6	1,545.474	9.432	0.024	0.047
2265002021	Paving Equipment	11	2,420.473	14.772	0.037	0.074
2265002021	Paving Equipment	16	3,760.454	22.950	0.058	0.115
2265002021	Paving Equipment	25	5,671.877	34.616	0.087	0.174
2265002021	Paving Equipment	40	5,787.666	35.323	0.089	0.177
2265002021	Paving Equipment	75	10,436.776	63.696	0.160	0.319
2265002024	Surfacing Equipment	6	1,552.696	9.476	0.024	0.048
2265002024	Surfacing Equipment	11	2,529.090	15.435	0.039	0.077
2265002024	Surfacing Equipment	16	4,426.900	27.018	0.068	0.135
2265002024	Surfacing Equipment	25	5,402.462	32.972	0.083	0.165
2265002024	Surfacing Equipment	40	4,781.941	29.185	0.073	0.146
2265002024	Surfacing Equipment	75	10,436.776	63.696	0.160	0.319
2265002027	Signal Boards/Light Plants	6	1,514.179	9.241	0.023	0.046
2265002027	Signal Boards/Light Plants	11	2,339.649	14.279	0.036	0.072
2265002027	Signal Boards/Light Plants	25	5,104.689	31.154	0.078	0.156
2265002030	Trenchers	3	850.781	5.192	0.013	0.026
2265002030	Trenchers	6	1,568.042	9.570	0.024	0.048
2265002030	Trenchers	11	2,519.164	15.375	0.039	0.077
2265002030	Trenchers	16	3,811.501	23.262	0.058	0.117
2265002030	Trenchers	25	5,473.361	33.404	0.084	0.168
2265002030	Trenchers	40	4,743.989	28.953	0.073	0.145
2265002030	Trenchers	75	9,755.223	59.537	0.149	0.299
2265002030	Trenchers	100	12,650.637	77.208	0.194	0.387
2265002033	Bore/Drill Rigs	1	255.234	1.558	0.004	0.008
2265002033	Bore/Drill Rigs	3	626.459	3.823	0.010	0.019
2265002033	Bore/Drill Rigs	6	1,447.076	8.832	0.022	0.044
2265002033	Bore/Drill Rigs	11	2,482.580	15.151	0.038	0.076
2265002033	Bore/Drill Rigs	16	4,537.501	27.693	0.069	0.139
2265002033	Bore/Drill Rigs	25	6,043.384	36.883	0.092	0.185
2265002033	Bore/Drill Rigs	40	4,963.794	30.294	0.076	0.152
2265002033	Bore/Drill Rigs	75	9,699.876	59.199	0.148	0.297
2265002033	Bore/Drill Rigs	175	18,675.503	113.978	0.286	0.572

SCC	Description	Power Class hp	Upstream CO_2 g/hr	Upstream CH_4 g/hr	Upstream N_2O g/hr	Upstream PM_{BC} g/hr
2265002039	Concrete/Industrial Saws	11	2,420.473	14.772	0.037	0.074
2265002039	Concrete/Industrial Saws	16	4,163.157	25.408	0.064	0.127
2265002039	Concrete/Industrial Saws	25	5,504.556	33.595	0.084	0.168
2265002039	Concrete/Industrial Saws	40	5,501.446	33.576	0.084	0.168
2265002039	Concrete/Industrial Saws	75	10,401.986	63.484	0.159	0.318
2265002042	Cement & Mortar Mixers	3	819.586	5.002	0.013	0.025
2265002042	Cement & Mortar Mixers	6	1,570.750	9.586	0.024	0.048
2265002042	Cement & Mortar Mixers	11	2,374.531	14.492	0.036	0.073
2265002042	Cement & Mortar Mixers	16	3,834.189	23.400	0.059	0.117
2265002042	Cement & Mortar Mixers	25	5,067.822	30.929	0.078	0.155
2265002045	Cranes	11	2,268.751	13.846	0.035	0.069
2265002045	Cranes	16	3,975.985	24.266	0.061	0.122
2265002045	Cranes	25	5,150.064	31.431	0.079	0.158
2265002045	Cranes	40	5,850.920	35.709	0.090	0.179
2265002045	Cranes	75	10,917.500	66.630	0.167	0.334
2265002045	Cranes	175	18,216.917	111.179	0.279	0.558
2265002054	Crushing/Proc. Equipment	6	1,300.232	7.935	0.020	0.040
2265002054	Crushing/Proc. Equipment	11	2,532.493	15.456	0.039	0.078
2265002054	Crushing/Proc. Equipment	16	4,537.501	27.693	0.069	0.139
2265002054	Crushing/Proc. Equipment	75	9,888.054	60.347	0.151	0.303
2265002057	Rough Terrain Forklift	25	6,522.658	39.808	0.100	0.200
2265002057	Rough Terrain Forklift	40	4,585.856	27.988	0.070	0.140
2265002057	Rough Terrain Forklift	75	10,420.962	63.600	0.159	0.319
2265002057	Rough Terrain Forklift	100	12,650.637	77.208	0.194	0.387
2265002057	Rough Terrain Forklift	175	17,916.465	109.345	0.274	0.548
2265002060	Rubber Tire Loaders	40	5,850.920	35.709	0.090	0.179
2265002060	Rubber Tire Loaders	75	11,132.561	67.943	0.170	0.341
2265002060	Rubber Tire Loaders	175	17,869.025	109.056	0.273	0.547
2265002066	Tractors/Loaders/Backhoes	11	3,062.813	18.693	0.047	0.094
2265002066	Tractors/Loaders/Backhoes	25	5,410.970	33.024	0.083	0.166
2265002066	Tractors/Loaders/Backhoes	40	4,743.989	28.953	0.073	0.145
2265002066	Tractors/Loaders/Backhoes	75	9,646.111	58.871	0.148	0.295
2265002066	Tractors/Loaders/Backhoes	100	12,650.637	77.208	0.194	0.387
2265002072	Skid Steer Loaders	16	4,517.650	27.572	0.069	0.138
2265002072	Skid Steer Loaders	25	5,220.962	31.864	0.080	0.160
2265002072	Skid Steer Loaders	40	5,049.186	30.816	0.077	0.155
2265002072	Skid Steer Loaders	75	8,608.759	52.540	0.132	0.263
2265002072	Skid Steer Loaders	100	12,492.504	76.243	0.191	0.382
2265002078	Dumpers/Tenders	6	1,492.514	9.109	0.023	0.046
2265002078	Dumpers/Tenders	11	2,416.219	14.746	0.037	0.074

SCC	Description	Power Class hp	Upstream CO_2 g/hr	Upstream CH_4 g/hr	Upstream N_2O g/hr	Upstream PM_{BC} g/hr
2265002078	Dumpers/Tenders	16	3,482.532	21.254	0.053	0.107
2265002078	Dumpers/Tenders	25	5,314.548	32.435	0.081	0.163
2265002078	Dumpers/Tenders	75	10,436.776	63.696	0.160	0.319
2265002081	Other Construction Equipment	25	5,104.689	31.154	0.078	0.156
2265002081	Other Construction Equipment	175	19,924.753	121.602	0.305	0.610
2265003010	Aerial Lifts	11	2,290.020	13.976	0.035	0.070
2265003010	Aerial Lifts	16	4,080.915	24.906	0.062	0.125
2265003010	Aerial Lifts	25	5,992.338	36.572	0.092	0.183
2265003010	Aerial Lifts	40	4,936.911	30.130	0.076	0.151
2265003010	Aerial Lifts	75	9,465.839	57.771	0.145	0.290
2265003010	Aerial Lifts	175	17,631.825	107.608	0.270	0.540
2265003020	Forklifts	40	5,711.763	34.859	0.087	0.175
2265003020	Forklifts	50	7,141.285	43.584	0.109	0.219
2265003020	Forklifts	75	9,926.006	60.579	0.152	0.304
2265003020	Forklifts	100	14,078.578	85.922	0.215	0.431
2265003020	Forklifts	175	22,881.840	139.649	0.350	0.700
2265003020	Forklifts	300	34,125.094	208.268	0.522	1.044
2265003030	Sweepers/Scrubbers	6	1,424.809	8.696	0.022	0.044
2265003030	Sweepers/Scrubbers	11	2,794.817	17.057	0.043	0.086
2265003030	Sweepers/Scrubbers	16	4,211.368	25.702	0.064	0.129
2265003030	Sweepers/Scrubbers	25	5,169.915	31.552	0.079	0.158
2265003030	Sweepers/Scrubbers	40	5,046.023	30.796	0.077	0.154
2265003030	Sweepers/Scrubbers	50	7,274.116	44.394	0.111	0.223
2265003030	Sweepers/Scrubbers	75	10,017.723	61.139	0.153	0.307
2265003030	Sweepers/Scrubbers	100	14,231.967	86.859	0.218	0.436
2265003030	Sweepers/Scrubbers	175	23,719.945	144.764	0.363	0.726
2265003030	Sweepers/Scrubbers	600	64,992.648	396.654	0.995	1.989
2265003040	Other General Industrial Eqp	6	1,290.603	7.877	0.020	0.040
2265003040	Other General Industrial Eqp	11	2,570.211	15.686	0.039	0.079
2265003040	Other General Industrial Eqp	16	3,837.024	23.418	0.059	0.117
2265003040	Other General Industrial Eqp	25	5,172.751	31.570	0.079	0.158
2265003040	Other General Industrial Eqp	40	4,762.965	29.069	0.073	0.146
2265003040	Other General Industrial Eqp	75	9,639.785	58.832	0.148	0.295
2265003040	Other General Industrial Eqp	100	12,650.637	77.208	0.194	0.387
2265003040	Other General Industrial Eqp	175	21,506.083	131.253	0.329	0.658
2265003040	Other General Industrial Eqp	300	30,835.928	188.194	0.472	0.944
2265003050	Other Material Handling Eqp	3	850.781	5.192	0.013	0.026
2265003050	Other Material Handling Eqp	25	5,138.720	31.362	0.079	0.157
2265003050	Other Material Handling Eqp	75	9,962.377	60.801	0.152	0.305
2265003050	Other Material Handling Eqp	100	13,599.435	82.998	0.208	0.416

SCC	Description	Power Class hp	Upstream CO_2 g/hr	Upstream CH_4 g/hr	Upstream N_2O g/hr	Upstream PM_{BC} g/hr
2265003060	AC\Refrigeration	11	2,552.344	15.577	0.039	0.078
2265003060	AC\Refrigeration	16	3,686.720	22.500	0.056	0.113
2265003060	AC\Refrigeration	25	5,104.689	31.154	0.078	0.156
2265004011	Lawn mowers (Com)	3	723.164	4.414	0.011	0.022
2265004011	Lawn mowers (Com)	6	1,233.731	7.530	0.019	0.038
2265004011	Lawn mowers (Com)	11	1,769.625	10.800	0.027	0.054
2265004016	Rotary Tillers < 6 HP (com)	6	1,417.888	8.653	0.022	0.043
2265004026	Trimmers/Edgers/Brush Cutter (co	6	993.003	6.060	0.015	0.030
2265004026	Trimmers/Edgers/Brush Cutter (co	11	2,240.391	13.673	0.034	0.069
2265004026	Trimmers/Edgers/Brush Cutter (co	16	4,537.501	27.693	0.069	0.139
2265004026	Trimmers/Edgers/Brush Cutter (co	25	5,104.689	31.154	0.078	0.156
2265004031	Leafblowers/Vacuums (com)	6	1,023.094	6.244	0.016	0.031
2265004031	Leafblowers/Vacuums (com)	11	2,353.829	14.366	0.036	0.072
2265004031	Leafblowers/Vacuums (com)	16	4,027.032	24.577	0.062	0.123
2265004031	Leafblowers/Vacuums (com)	25	5,955.470	36.347	0.091	0.182
2265004031	Leafblowers/Vacuums (com)	40	4,902.122	29.918	0.075	0.150
2265004031	Leafblowers/Vacuums (com)	75	9,679.319	59.074	0.148	0.296
2265004031	Leafblowers/Vacuums (com)	175	19,102.462	116.584	0.292	0.585
2265004036	Snowblowers (com)	11	2,466.983	15.056	0.038	0.076
2265004036	Snowblowers (com)	16	3,570.446	21.791	0.055	0.109
2265004041	Rear Engine Riding Mowers (com)	6	1,536.146	9.375	0.024	0.047
2265004041	Rear Engine Riding Mowers (com)	11	2,595.734	15.842	0.040	0.079
2265004041	Rear Engine Riding Mowers (com)	16	3,576.118	21.825	0.055	0.109
2265004041	Rear Engine Riding Mowers (com)	25	5,178.423	31.604	0.079	0.158
2265004046	Front Mowers (com)	11	2,268.751	13.846	0.035	0.069
2265004046	Front Mowers (com)	16	3,820.009	23.314	0.058	0.117
2265004046	Front Mowers (com)	25	4,821.095	29.423	0.074	0.148
2265004046	Front Mowers (com)	40	5,102.951	31.144	0.078	0.156
2265004051	Shredders < 6 HP (com)	3	846.811	5.168	0.013	0.026
2265004051	Shredders < 6 HP (com)	6	1,454.900	8.879	0.022	0.045
2265004056	Lawn & Garden Tractors (com)	6	1,505.152	9.186	0.023	0.046
2265004056	Lawn & Garden Tractors (com)	11	2,760.786	16.849	0.042	0.084
2265004056	Lawn & Garden Tractors (com)	16	3,859.712	23.556	0.059	0.118
2265004056	Lawn & Garden Tractors (com)	25	5,220.962	31.864	0.080	0.160
2265004066	Chippers/Stump Grinders (com)	6	1,053.185	6.428	0.016	0.032
2265004066	Chippers/Stump Grinders (com)	11	2,776.667	16.946	0.042	0.085
2265004066	Chippers/Stump Grinders (com)	16	4,344.657	26.516	0.066	0.133
2265004066	Chippers/Stump Grinders (com)	25	5,686.056	34.702	0.087	0.174
2265004066	Chippers/Stump Grinders (com)	40	5,550.467	33.875	0.085	0.170
2265004066	Chippers/Stump Grinders (com)	75	9,609.740	58.649	0.147	0.294

SCC	Description	Power Class hp	Upstream CO_2 g/hr	Upstream CH_4 g/hr	Upstream N_2O g/hr	Upstream PM_{BC} g/hr
2265004066	Chippers/Stump Grinders (com)	100	12,650.637	77.208	0.194	0.387
2265004066	Chippers/Stump Grinders (com)	175	18,817.823	114.846	0.288	0.576
2265004071	Commercial Turf Equipment (com)	6	1,569.848	9.581	0.024	0.048
2265004071	Commercial Turf Equipment (com)	11	2,487.401	15.181	0.038	0.076
2265004071	Commercial Turf Equipment (com)	16	3,967.478	24.214	0.061	0.121
2265004071	Commercial Turf Equipment (com)	25	5,481.869	33.456	0.084	0.168
2265004071	Commercial Turf Equipment (com)	40	4,307.542	26.289	0.066	0.132
2265004071	Commercial Turf Equipment (com)	75	9,423.143	57.510	0.144	0.288
2265004076	Other Lawn & Garden Eqp. (com)	1	259.205	1.582	0.004	0.008
2265004076	Other Lawn & Garden Eqp. (com)	3	663.610	4.050	0.010	0.020
2265004076	Other Lawn & Garden Eqp. (com)	6	1,464.529	8.938	0.022	0.045
2265004076	Other Lawn & Garden Eqp. (com)	11	2,327.738	14.206	0.036	0.071
2265004076	Other Lawn & Garden Eqp. (com)	16	4,407.048	26.897	0.067	0.135
2265004076	Other Lawn & Garden Eqp. (com)	25	5,683.220	34.685	0.087	0.174
2265004076	Other Lawn & Garden Eqp. (com)	40	5,699.112	34.782	0.087	0.174
2265004076	Other Lawn & Garden Eqp. (com)	75	10,436.776	63.696	0.160	0.319
2265004076	Other Lawn & Garden Eqp. (com)	100	13,599.435	82.998	0.208	0.416
2265004076	Other Lawn & Garden Eqp. (com)	175	17,869.025	109.056	0.273	0.547
2265005010	2-Wheel Tractors	11	2,324.619	14.187	0.036	0.071
2265005010	2-Wheel Tractors	16	4,024.196	24.560	0.062	0.123
2265005015	Agricultural Tractors	25	5,785.314	35.308	0.089	0.177
2265005015	Agricultural Tractors	40	4,823.055	29.435	0.074	0.148
2265005015	Agricultural Tractors	100	12,987.460	79.263	0.199	0.398
2265005015	Agricultural Tractors	175	19,766.621	120.637	0.303	0.605
2265005030	Agricultural Mowers	6	1,805.460	11.019	0.028	0.055
2265005030	Agricultural Mowers	11	2,610.765	15.934	0.040	0.080
2265005030	Agricultural Mowers	16	4,537.501	27.693	0.069	0.139
2265005030	Agricultural Mowers	25	5,104.689	31.154	0.078	0.156
2265005035	Sprayers	6	1,314.977	8.025	0.020	0.040
2265005035	Sprayers	11	2,326.604	14.199	0.036	0.071
2265005035	Sprayers	16	4,211.368	25.702	0.064	0.129
2265005035	Sprayers	25	5,816.509	35.499	0.089	0.178
2265005035	Sprayers	40	5,262.665	32.118	0.081	0.161
2265005035	Sprayers	75	9,804.244	59.836	0.150	0.300
2265005035	Sprayers	100	14,211.409	86.733	0.217	0.435
2265005035	Sprayers	175	20,604.725	125.752	0.315	0.631
2265005040	Tillers > 6 HP	11	2,127.237	12.983	0.033	0.065
2265005040	Tillers > 6 HP	16	4,185.845	25.546	0.064	0.128
2265005045	Swathers	100	12,650.637	77.208	0.194	0.387
2265005045	Swathers	175	19,276.408	117.645	0.295	0.590

SCC	Description	Power Class hp	Upstream CO_2 g/hr	Upstream CH_4 g/hr	Upstream N_2O g/hr	Upstream PM_{BC} g/hr
2265005055	Other Agricultural Equipment	6	1,456.405	8.889	0.022	0.045
2265005055	Other Agricultural Equipment	11	2,592.048	15.819	0.040	0.079
2265005055	Other Agricultural Equipment	16	4,001.509	24.421	0.061	0.122
2265005055	Other Agricultural Equipment	25	5,286.189	32.262	0.081	0.162
2265005055	Other Agricultural Equipment	40	5,096.625	31.105	0.078	0.156
2265005055	Other Agricultural Equipment	75	9,864.334	60.203	0.151	0.302
2265005055	Other Agricultural Equipment	100	13,922.026	84.967	0.213	0.426
2265005055	Other Agricultural Equipment	175	26,471.458	161.557	0.405	0.810
2265005055	Other Agricultural Equipment	300	36,386.395	222.069	0.557	1.114
2265005060	Irrigation Sets	6	1,411.870	8.617	0.022	0.043
2265005060	Irrigation Sets	11	2,529.090	15.435	0.039	0.077
2265005060	Irrigation Sets	75	9,440.538	57.616	0.144	0.289
2265005060	Irrigation Sets	100	12,690.170	77.449	0.194	0.388
2265005060	Irrigation Sets	175	19,055.022	116.294	0.292	0.583
2265005060	Irrigation Sets	300	33,239.549	202.863	0.509	1.017
2265006005	Generator Sets	6	1,374.256	8.387	0.021	0.042
2265006005	Generator Sets	11	2,500.163	15.259	0.038	0.077
2265006005	Generator Sets	16	4,066.735	24.820	0.062	0.124
2265006005	Generator Sets	25	5,876.064	35.862	0.090	0.180
2265006010	Pumps	6	1,393.514	8.505	0.021	0.043
2265006010	Pumps	11	2,364.322	14.430	0.036	0.072
2265006010	Pumps	16	4,200.025	25.633	0.064	0.129
2265006010	Pumps	25	5,203.947	31.760	0.080	0.159
2265006010	Pumps	40	5,052.348	30.835	0.077	0.155
2265006010	Pumps	50	7,274.116	44.394	0.111	0.223
2265006010	Pumps	75	9,582.858	58.485	0.147	0.293
2265006010	Pumps	100	12,848.303	78.414	0.197	0.393
2265006010	Pumps	175	18,232.731	111.276	0.279	0.558
2265006015	Air Compressors	6	1,561.121	9.528	0.024	0.048
2265006015	Air Compressors	11	2,814.669	17.178	0.043	0.086
2265006015	Air Compressors	16	3,865.384	23.591	0.059	0.118
2265006015	Air Compressors	25	5,294.697	32.314	0.081	0.162
2265006015	Air Compressors	40	5,008.071	30.565	0.077	0.153
2265006015	Air Compressors	75	9,603.415	58.610	0.147	0.294
2265006015	Air Compressors	100	12,917.882	78.839	0.198	0.395
2265006015	Air Compressors	175	20,857.738	127.296	0.319	0.638
2265006025	Welders	6	1,797.637	10.971	0.028	0.055
2265006025	Welders	11	2,644.796	16.141	0.040	0.081
2265006025	Welders	16	4,455.259	27.191	0.068	0.136
2265006025	Welders	25	5,161.408	31.500	0.079	0.158

SCC	Description	Power Class hp	Upstream CO_2 g/hr	Upstream CH_4 g/hr	Upstream N_2O g/hr	Upstream PM_{BC} g/hr
2265006025	Welders	75	10,062.000	61.409	0.154	0.308
2265006025	Welders	100	12,650.637	77.208	0.194	0.387
2265006025	Welders	175	20,557.285	125.462	0.315	0.629
2265006030	Pressure Washers	3	850.781	5.192	0.013	0.026
2265006030	Pressure Washers	6	1,452.493	8.865	0.022	0.044
2265006030	Pressure Washers	11	2,581.838	15.757	0.040	0.079
2265006030	Pressure Washers	16	4,007.181	24.456	0.061	0.123
2265006030	Pressure Washers	25	5,331.564	32.539	0.082	0.163
2265006030	Pressure Washers	40	5,779.760	35.274	0.088	0.177
2265006030	Pressure Washers	75	10,436.776	63.696	0.160	0.319
2265007010	Shredders > 6 HP	11	2,301.931	14.049	0.035	0.070
2265007010	Shredders > 6 HP	16	3,578.954	21.843	0.055	0.110
2265007010	Shredders > 6 HP	25	5,830.689	35.585	0.089	0.178
2265007015	Forest Eqp - Feller/Bunch/Skidde	6	1,655.005	10.101	0.025	0.051
2265007015	Forest Eqp - Feller/Bunch/Skidde	11	2,552.344	15.577	0.039	0.078
2267002003	Pavers	40	2,374.959	29.777	0.039	0.052
2267002003	Pavers	75	4,668.383	58.532	0.076	0.101
2267002015	Rollers	40	2,754.204	34.532	0.045	0.060
2267002015	Rollers	75	4,544.960	56.984	0.074	0.099
2267002015	Rollers	100	6,208.553	77.842	0.101	0.135
2267002021	Paving Equipment	40	2,737.748	34.326	0.045	0.059
2267002021	Paving Equipment	75	4,936.922	61.899	0.080	0.107
2267002024	Surfacing Equipment	40	2,262.008	28.361	0.037	0.049
2267002024	Surfacing Equipment	75	4,936.922	61.899	0.080	0.107
2267002030	Trenchers	40	2,244.055	28.136	0.037	0.049
2267002030	Trenchers	75	4,614.526	57.857	0.075	0.100
2267002030	Trenchers	100	5,984.148	75.029	0.097	0.130
2267002033	Bore/Drill Rigs	40	2,348.030	29.439	0.038	0.051
2267002033	Bore/Drill Rigs	75	4,588.345	57.528	0.075	0.100
2267002033	Bore/Drill Rigs	175	8,834.098	110.761	0.144	0.192
2267002039	Concrete/Industrial Saws	40	2,602.356	32.628	0.042	0.056
2267002039	Concrete/Industrial Saws	75	4,920.465	61.692	0.080	0.107
2267002045	Cranes	40	2,767.668	34.701	0.045	0.060
2267002045	Cranes	75	5,164.319	64.750	0.084	0.112
2267002045	Cranes	175	8,617.173	108.041	0.140	0.187
2267002054	Crushing/Proc. Equipment	75	4,677.359	58.644	0.076	0.102
2267002057	Rough Terrain Forklift	40	2,169.254	27.198	0.035	0.047
2267002057	Rough Terrain Forklift	75	4,929.442	61.805	0.080	0.107
2267002057	Rough Terrain Forklift	100	5,984.148	75.029	0.097	0.130
2267002057	Rough Terrain Forklift	175	8,475.049	106.260	0.138	0.184

SCC	Description	Power Class hp	Upstream CO_2 g/hr	Upstream CH_4 g/hr	Upstream N_2O g/hr	Upstream PM_{BC} g/hr
2267002060	Rubber Tire Loaders	40	2,767.668	34.701	0.045	0.060
2267002060	Rubber Tire Loaders	75	5,266.050	66.025	0.086	0.114
2267002060	Rubber Tire Loaders	175	8,452.609	105.978	0.138	0.184
2267002066	Tractors/Loaders/Backhoes	40	2,244.055	28.136	0.037	0.049
2267002066	Tractors/Loaders/Backhoes	75	4,562.913	57.209	0.074	0.099
2267002066	Tractors/Loaders/Backhoes	100	5,984.148	75.029	0.097	0.130
2267002072	Skid Steer Loaders	40	2,388.423	29.946	0.039	0.052
2267002072	Skid Steer Loaders	75	4,082.685	51.188	0.066	0.089
2267002072	Skid Steer Loaders	100	5,909.346	74.091	0.096	0.128
2267002081	Other Construction Equipment	175	9,425.033	118.170	0.153	0.205
2267003010	Aerial Lifts	40	2,335.314	29.280	0.038	0.051
2267003010	Aerial Lifts	75	4,479.135	56.159	0.073	0.097
2267003010	Aerial Lifts	175	8,340.406	104.571	0.136	0.181
2267003020	Forklifts	40	2,501.374	31.362	0.041	0.054
2267003020	Forklifts	50	3,398.248	42.607	0.055	0.074
2267003020	Forklifts	75	4,351.971	54.565	0.071	0.094
2267003020	Forklifts	100	5,971.431	74.869	0.097	0.130
2267003020	Forklifts	175	9,836.443	123.329	0.160	0.214
2267003020	Forklifts	300	16,142.238	202.390	0.263	0.350
2267003030	Sweepers/Scrubbers	40	2,318.857	29.074	0.038	0.050
2267003030	Sweepers/Scrubbers	50	3,515.687	44.079	0.057	0.076
2267003030	Sweepers/Scrubbers	75	4,738.697	59.413	0.077	0.103
2267003030	Sweepers/Scrubbers	100	6,732.166	84.407	0.110	0.146
2267003030	Sweepers/Scrubbers	175	11,220.277	140.679	0.183	0.244
2267003030	Sweepers/Scrubbers	600	30,743.559	385.460	0.501	0.667
2267003040	Other General Industrial Eqp	40	2,253.032	28.248	0.037	0.049
2267003040	Other General Industrial Eqp	75	4,559.921	57.172	0.074	0.099
2267003040	Other General Industrial Eqp	100	5,984.148	75.029	0.097	0.130
2267003040	Other General Industrial Eqp	175	10,173.051	127.549	0.166	0.221
2267003040	Other General Industrial Eqp	300	14,586.360	182.883	0.238	0.317
2267003050	Other Material Handling Eqp	75	4,009.379	50.269	0.065	0.087
2267003050	Other Material Handling Eqp	100	6,432.959	80.656	0.105	0.140
2267004066	Chippers/Stump Grinders (com)	40	2,625.545	32.919	0.043	0.057
2267004066	Chippers/Stump Grinders (com)	75	4,545.708	56.994	0.074	0.099
2267004066	Chippers/Stump Grinders (com)	100	5,984.148	75.029	0.097	0.130
2267004066	Chippers/Stump Grinders (com)	175	8,901.420	111.605	0.145	0.193
2267005055	Other Agricultural Equipment	175	11,519.484	144.430	0.188	0.250
2267006005	Generator Sets	40	2,267.992	28.436	0.037	0.049
2267006005	Generator Sets	50	3,440.137	43.132	0.056	0.075
2267006005	Generator Sets	75	4,705.784	59.001	0.077	0.102

SCC	Description	Power Class hp	Upstream CO_2 g/hr	Upstream CH_4 g/hr	Upstream N_2O g/hr	Upstream PM_{BC} g/hr
2267006005	Generator Sets	100	6,079.894	76.229	0.099	0.132
2267006005	Generator Sets	175	10,382.496	130.175	0.169	0.225
2267006005	Generator Sets	300	17,922.522	224.711	0.292	0.389
2267006005	Generator Sets	600	27,826.287	348.884	0.453	0.604
2267006010	Pumps	40	2,389.919	29.965	0.039	0.052
2267006010	Pumps	50	3,440.885	43.142	0.056	0.075
2267006010	Pumps	75	4,263.705	53.458	0.069	0.093
2267006010	Pumps	100	6,077.650	76.201	0.099	0.132
2267006010	Pumps	175	8,624.653	108.135	0.140	0.187
2267006015	Air Compressors	40	2,368.974	29.702	0.039	0.051
2267006015	Air Compressors	75	4,542.716	56.956	0.074	0.099
2267006015	Air Compressors	100	6,110.563	76.614	0.099	0.133
2267006015	Air Compressors	175	9,866.363	123.704	0.161	0.214
2267006025	Welders	75	4,759.641	59.676	0.078	0.103
2267006025	Welders	100	5,984.148	75.029	0.097	0.130
2267006025	Welders	175	9,724.240	121.922	0.158	0.211
2267006030	Pressure Washers	40	2,734.007	34.279	0.045	0.059
2267006030	Pressure Washers	75	4,936.922	61.899	0.080	0.107
2268002081	Other Construction Equipment	175	13,381.301	90.290	0.213	0.426
2268003020	Forklifts	50	6,117.166	41.276	0.097	0.195
2268003030	Sweepers/Scrubbers	300	24,213.783	163.383	0.386	0.771
2268003040	Other General Industrial Eqp	100	12,552.935	84.701	0.200	0.400
2268003060	AC\Refrigeration	50	6,117.166	41.276	0.097	0.195
2268003060	AC\Refrigeration	75	9,430.631	63.633	0.150	0.300
2268006005	Generator Sets	40	4,043.702	27.285	0.064	0.129
2268006005	Generator Sets	50	6,075.111	40.992	0.097	0.194
2268006005	Generator Sets	75	7,702.532	51.973	0.123	0.245
2268006005	Generator Sets	100	12,159.142	82.044	0.194	0.387
2268006005	Generator Sets	175	18,835.774	127.094	0.300	0.600
2268006005	Generator Sets	300	30,560.343	206.206	0.487	0.974
2268006005	Generator Sets	600	50,033.322	337.600	0.797	1.594
2268006010	Pumps	40	4,078.111	27.517	0.065	0.130
2268006010	Pumps	75	6,626.930	44.715	0.106	0.211
2268006010	Pumps	175	22,302.169	150.484	0.355	0.711
2268006010	Pumps	300	31,350.477	211.537	0.499	0.999
2268006010	Pumps	600	53,945.760	363.999	0.859	1.719
2268006015	Air Compressors	75	6,626.930	44.715	0.106	0.211
2268006015	Air Compressors	175	18,861.263	127.266	0.300	0.601
2268006020	Gas Compressors	40	3,504.627	23.647	0.056	0.112
2268006020	Gas Compressors	50	5,765.429	38.902	0.092	0.184

SCC	Description	Power Class hp	Upstream CO_2 g/hr	Upstream CH_4 g/hr	Upstream N_2O g/hr	Upstream PM_{BC} g/hr
2268006020	Gas Compressors	75	8,793.427	59.334	0.140	0.280
2268006020	Gas Compressors	100	11,622.616	78.424	0.185	0.370
2268006020	Gas Compressors	175	18,593.637	125.461	0.296	0.592
2268006020	Gas Compressors	300	30,853.457	208.184	0.491	0.983
2268006020	Gas Compressors	600	51,218.523	345.597	0.816	1.632
2270002003	Pavers	25	1,877.312	40.369	0.027	0.063
2270002003	Pavers	40	2,811.682	60.462	0.040	0.094
2270002003	Pavers	50	3,886.637	83.577	0.055	0.129
2270002003	Pavers	75	5,397.059	116.057	0.077	0.180
2270002003	Pavers	100	6,748.205	145.112	0.096	0.225
2270002003	Pavers	175	10,482.497	225.413	0.150	0.349
2270002003	Pavers	300	17,219.020	370.273	0.246	0.574
2270002003	Pavers	600	30,131.338	647.936	0.430	1.004
2270002006	Tampers/Rammers	6	360.033	7.742	0.005	0.012
2270002009	Plate Compactors	6	423.210	9.101	0.006	0.014
2270002009	Plate Compactors	11	733.266	15.768	0.010	0.024
2270002009	Plate Compactors	16	1,218.967	26.212	0.017	0.041
2270002009	Plate Compactors	25	1,744.443	37.512	0.025	0.058
2270002015	Rollers	6	466.156	10.024	0.007	0.016
2270002015	Rollers	11	745.353	16.028	0.011	0.025
2270002015	Rollers	16	1,161.533	24.977	0.017	0.039
2270002015	Rollers	25	1,687.009	36.277	0.024	0.056
2270002015	Rollers	40	2,787.680	59.946	0.040	0.093
2270002015	Rollers	50	3,926.926	84.444	0.056	0.131
2270002015	Rollers	75	5,206.756	111.965	0.074	0.173
2270002015	Rollers	100	6,601.014	141.947	0.094	0.220
2270002015	Rollers	175	10,295.588	221.394	0.147	0.343
2270002015	Rollers	300	16,899.717	363.407	0.241	0.563
2270002015	Rollers	600	32,748.069	704.206	0.468	1.091
2270002018	Scrapers	75	5,657.654	121.661	0.081	0.188
2270002018	Scrapers	175	12,522.924	269.290	0.179	0.417
2270002018	Scrapers	300	19,228.295	413.480	0.275	0.641
2270002018	Scrapers	600	32,903.826	707.555	0.470	1.096
2270002018	Scrapers	750	53,549.517	1,151.515	0.765	1.784
2270002018	Scrapers	1000	59,187.948	1,272.762	0.845	1.972
2270002021	Paving Equipment	6	396.036	8.516	0.006	0.013
2270002021	Paving Equipment	11	625.771	13.456	0.009	0.021
2270002021	Paving Equipment	16	1,260.114	27.097	0.018	0.042
2270002021	Paving Equipment	25	1,690.438	36.351	0.024	0.056
2270002021	Paving Equipment	40	2,899.119	62.342	0.041	0.097

SCC	Description	Power Class hp	Upstream CO_2 g/hr	Upstream CH_4 g/hr	Upstream N_2O g/hr	Upstream PM_{BC} g/hr
2270002021	Paving Equipment	75	5,233.330	112.536	0.075	0.174
2270002021	Paving Equipment	100	6,481.859	139.384	0.093	0.216
2270002021	Paving Equipment	175	10,225.497	219.886	0.146	0.341
2270002021	Paving Equipment	300	17,927.718	385.513	0.256	0.597
2270002021	Paving Equipment	600	35,824.284	770.356	0.512	1.194
2270002024	Surfacing Equipment	11	574.338	12.350	0.008	0.019
2270002024	Surfacing Equipment	16	1,140.103	24.516	0.016	0.038
2270002024	Surfacing Equipment	25	1,856.739	39.927	0.027	0.062
2270002024	Surfacing Equipment	40	2,716.531	58.416	0.039	0.091
2270002024	Surfacing Equipment	50	3,848.919	82.766	0.055	0.128
2270002024	Surfacing Equipment	75	4,708.711	101.255	0.067	0.157
2270002024	Surfacing Equipment	100	6,300.401	135.482	0.090	0.210
2270002024	Surfacing Equipment	175	9,851.678	211.848	0.141	0.328
2270002024	Surfacing Equipment	300	18,145.779	390.202	0.259	0.605
2270002024	Surfacing Equipment	600	38,363.136	824.951	0.548	1.278
2270002024	Surfacing Equipment	750	55,566.580	1,194.889	0.793	1.851
2270002024	Surfacing Equipment	1000	69,857.354	1,502.194	0.997	2.327
2270002024	Surfacing Equipment	2000	120,244.990	2,585.717	1.717	4.006
2270002027	Signal Boards/Light Plants	6	462.899	9.954	0.007	0.015
2270002027	Signal Boards/Light Plants	11	666.489	14.332	0.010	0.022
2270002027	Signal Boards/Light Plants	16	1,176.963	25.309	0.017	0.039
2270002027	Signal Boards/Light Plants	25	1,901.315	40.885	0.027	0.063
2270002027	Signal Boards/Light Plants	40	2,599.092	55.890	0.037	0.087
2270002027	Signal Boards/Light Plants	50	3,617.469	77.789	0.052	0.121
2270002027	Signal Boards/Light Plants	75	5,081.602	109.273	0.073	0.169
2270002027	Signal Boards/Light Plants	100	6,862.594	147.571	0.098	0.229
2270002027	Signal Boards/Light Plants	175	12,144.479	261.152	0.173	0.405
2270002027	Signal Boards/Light Plants	300	16,655.285	358.151	0.238	0.555
2270002030	Trenchers	11	822.931	17.696	0.012	0.027
2270002030	Trenchers	16	1,328.691	28.572	0.019	0.044
2270002030	Trenchers	25	1,851.596	39.816	0.026	0.062
2270002030	Trenchers	40	2,923.121	62.858	0.042	0.097
2270002030	Trenchers	50	3,861.777	83.043	0.055	0.129
2270002030	Trenchers	75	5,230.758	112.481	0.075	0.174
2270002030	Trenchers	100	6,755.993	145.279	0.096	0.225
2270002030	Trenchers	175	10,459.133	224.911	0.149	0.348
2270002030	Trenchers	300	19,508.659	419.509	0.279	0.650
2270002030	Trenchers	600	32,288.583	694.325	0.461	1.076
2270002030	Trenchers	750	57,762.765	1,242.115	0.825	1.924
2270002030	Trenchers	2000	116,818.320	2,512.031	1.668	3.892

SCC	Description	Power Class hp	Upstream CO_2 g/hr	Upstream CH_4 g/hr	Upstream N_2O g/hr	Upstream PM_{BC} g/hr
2270002033	Bore/Drill Rigs	11	685.776	14.747	0.010	0.023
2270002033	Bore/Drill Rigs	16	1,242.969	26.728	0.018	0.041
2270002033	Bore/Drill Rigs	25	2,012.753	43.282	0.029	0.067
2270002033	Bore/Drill Rigs	40	2,698.529	58.028	0.039	0.090
2270002033	Bore/Drill Rigs	50	3,851.491	82.821	0.055	0.128
2270002033	Bore/Drill Rigs	75	5,301.907	114.011	0.076	0.177
2270002033	Bore/Drill Rigs	100	6,563.416	141.138	0.094	0.219
2270002033	Bore/Drill Rigs	175	10,162.808	218.538	0.145	0.339
2270002033	Bore/Drill Rigs	300	18,444.186	396.619	0.263	0.615
2270002033	Bore/Drill Rigs	600	34,474.898	741.339	0.492	1.149
2270002033	Bore/Drill Rigs	750	53,242.937	1,144.922	0.760	1.774
2270002033	Bore/Drill Rigs	1000	67,006.679	1,440.894	0.957	2.232
2270002033	Bore/Drill Rigs	1200	80,963.191	1,741.011	1.156	2.697
2270002033	Bore/Drill Rigs	2000	115,661.700	2,487.159	1.652	3.854
2270002036	Excavators	6	514.332	11.060	0.007	0.017
2270002036	Excavators	11	682.947	14.686	0.010	0.023
2270002036	Excavators	16	1,126.387	24.222	0.016	0.038
2270002036	Excavators	25	1,846.452	39.706	0.026	0.062
2270002036	Excavators	40	2,833.113	60.923	0.040	0.094
2270002036	Excavators	50	3,923.497	84.370	0.056	0.131
2270002036	Excavators	75	5,254.760	112.997	0.075	0.175
2270002036	Excavators	100	7,139.157	153.519	0.102	0.238
2270002036	Excavators	175	10,716.134	230.437	0.153	0.357
2270002036	Excavators	300	18,169.142	390.705	0.259	0.605
2270002036	Excavators	600	31,977.068	687.627	0.457	1.065
2270002036	Excavators	750	56,026.066	1,204.770	0.800	1.867
2270002036	Excavators	1000	68,844.929	1,480.423	0.983	2.294
2270002036	Excavators	1200	93,454.655	2,009.624	1.334	3.114
2270002036	Excavators	2000	137,689.860	2,960.847	1.966	4.587
2270002036	Excavators	3000	183,015.370	3,935.515	2.613	6.098
2270002039	Concrete/Industrial Saws	11	857.220	18.433	0.012	0.029
2270002039	Concrete/Industrial Saws	25	1,724.727	37.088	0.025	0.057
2270002039	Concrete/Industrial Saws	40	2,823.684	60.720	0.040	0.094
2270002039	Concrete/Industrial Saws	50	3,703.191	79.632	0.053	0.123
2270002039	Concrete/Industrial Saws	75	4,959.019	106.638	0.071	0.165
2270002039	Concrete/Industrial Saws	100	6,344.792	136.437	0.091	0.211
2270002039	Concrete/Industrial Saws	175	9,415.557	202.470	0.134	0.314
2270002039	Concrete/Industrial Saws	300	18,807.749	404.437	0.269	0.627
2270002042	Cement & Mortar Mixers	6	512.875	11.029	0.007	0.017
2270002042	Cement & Mortar Mixers	11	692.805	14.898	0.010	0.023

SCC	Description	Power Class hp	Upstream CO_2 g/hr	Upstream CH_4 g/hr	Upstream N_2O g/hr	Upstream PM_{BC} g/hr
2270002042	Cement & Mortar Mixers	16	1,121.244	24.111	0.016	0.037
2270002042	Cement & Mortar Mixers	25	1,807.020	38.858	0.026	0.060
2270002042	Cement & Mortar Mixers	40	2,809.968	60.425	0.040	0.094
2270002042	Cement & Mortar Mixers	75	5,105.604	109.790	0.073	0.170
2270002042	Cement & Mortar Mixers	100	6,435.417	138.386	0.092	0.214
2270002042	Cement & Mortar Mixers	175	9,939.196	213.730	0.142	0.331
2270002042	Cement & Mortar Mixers	300	19,515.984	419.667	0.279	0.650
2270002042	Cement & Mortar Mixers	600	31,020.468	667.056	0.443	1.034
2270002042	Cement & Mortar Mixers	750	54,337.867	1,168.467	0.776	1.810
2270002045	Cranes	40	3,377.448	72.628	0.048	0.113
2270002045	Cranes	50	3,574.608	76.867	0.051	0.119
2270002045	Cranes	75	5,486.210	117.974	0.078	0.183
2270002045	Cranes	100	6,796.282	146.146	0.097	0.226
2270002045	Cranes	175	11,196.053	240.757	0.160	0.373
2270002045	Cranes	300	18,328.524	394.132	0.262	0.611
2270002045	Cranes	600	31,768.414	683.140	0.454	1.058
2270002045	Cranes	750	51,585.119	1,109.273	0.737	1.719
2270002045	Cranes	1000	68,070.767	1,463.776	0.972	2.268
2270002045	Cranes	1200	82,582.455	1,775.832	1.179	2.751
2270002048	Graders	50	4,140.374	89.034	0.059	0.138
2270002048	Graders	75	5,103.889	109.753	0.073	0.170
2270002048	Graders	100	6,558.180	141.025	0.094	0.218
2270002048	Graders	175	10,965.346	235.796	0.157	0.365
2270002048	Graders	300	18,005.597	387.188	0.257	0.600
2270002048	Graders	600	26,619.001	572.408	0.380	0.887
2270002048	Graders	750	58,409.159	1,256.015	0.834	1.946
2270002051	Off-highway Trucks	175	12,499.560	268.787	0.178	0.416
2270002051	Off-highway Trucks	300	19,025.810	409.126	0.272	0.634
2270002051	Off-highway Trucks	600	32,701.341	703.201	0.467	1.090
2270002051	Off-highway Trucks	750	53,588.457	1,152.352	0.765	1.785
2270002051	Off-highway Trucks	1000	67,598.867	1,453.628	0.965	2.252
2270002051	Off-highway Trucks	1200	89,794.347	1,930.914	1.282	2.992
2270002051	Off-highway Trucks	2000	139,169.560	2,992.666	1.987	4.637
2270002051	Off-highway Trucks	3000	188,778.400	4,059.441	2.696	6.290
2270002054	Crushing/Proc. Equipment	25	1,750.444	37.641	0.025	0.058
2270002054	Crushing/Proc. Equipment	40	2,751.677	59.171	0.039	0.092
2270002054	Crushing/Proc. Equipment	50	3,908.924	84.056	0.056	0.130
2270002054	Crushing/Proc. Equipment	75	5,206.756	111.965	0.074	0.173
2270002054	Crushing/Proc. Equipment	100	6,861.052	147.538	0.098	0.229
2270002054	Crushing/Proc. Equipment	175	10,201.362	219.367	0.146	0.340

SCC	Description	Power Class hp	Upstream CO_2 g/hr	Upstream CH_4 g/hr	Upstream N_2O g/hr	Upstream PM_{BC} g/hr
2270002054	Crushing/Proc. Equipment	300	18,606.112	400.101	0.266	0.620
2270002054	Crushing/Proc. Equipment	600	32,632.021	701.711	0.466	1.087
2270002054	Crushing/Proc. Equipment	750	51,376.928	1,104.796	0.734	1.712
2270002054	Crushing/Proc. Equipment	1000	70,939.177	1,525.458	1.013	2.363
2270002057	Rough Terrain Forklifts	16	1,157.247	24.885	0.017	0.039
2270002057	Rough Terrain Forklifts	25	1,924.459	41.383	0.027	0.064
2270002057	Rough Terrain Forklifts	40	2,859.687	61.494	0.041	0.095
2270002057	Rough Terrain Forklifts	50	3,862.634	83.061	0.055	0.129
2270002057	Rough Terrain Forklifts	75	5,265.047	113.218	0.075	0.175
2270002057	Rough Terrain Forklifts	100	6,666.432	143.353	0.095	0.222
2270002057	Rough Terrain Forklifts	175	9,812.739	211.011	0.140	0.327
2270002057	Rough Terrain Forklifts	300	17,842.051	383.671	0.255	0.594
2270002057	Rough Terrain Forklifts	600	26,953.880	579.609	0.385	0.898
2270002060	Rubber Tire Loaders	25	1,957.034	42.084	0.028	0.065
2270002060	Rubber Tire Loaders	40	2,947.123	63.374	0.042	0.098
2270002060	Rubber Tire Loaders	50	3,895.209	83.762	0.056	0.130
2270002060	Rubber Tire Loaders	75	5,289.049	113.734	0.076	0.176
2270002060	Rubber Tire Loaders	100	6,657.087	143.152	0.095	0.222
2270002060	Rubber Tire Loaders	175	10,614.891	228.260	0.152	0.354
2270002060	Rubber Tire Loaders	300	17,912.142	385.178	0.256	0.597
2270002060	Rubber Tire Loaders	600	32,662.402	702.364	0.466	1.088
2270002060	Rubber Tire Loaders	750	53,907.760	1,159.218	0.770	1.796
2270002060	Rubber Tire Loaders	1000	67,466.473	1,450.781	0.963	2.248
2270002060	Rubber Tire Loaders	1200	84,264.947	1,812.011	1.203	2.807
2270002060	Rubber Tire Loaders	2000	145,399.870	3,126.641	2.076	4.844
2270002060	Rubber Tire Loaders	3000	174,682.330	3,756.323	2.494	5.820
2270002066	Tractors/Loaders/Backhoes	16	1,328.691	28.572	0.019	0.044
2270002066	Tractors/Loaders/Backhoes	25	1,952.748	41.991	0.028	0.065
2270002066	Tractors/Loaders/Backhoes	40	2,785.109	59.890	0.040	0.093
2270002066	Tractors/Loaders/Backhoes	50	3,962.929	85.218	0.057	0.132
2270002066	Tractors/Loaders/Backhoes	75	5,354.198	115.135	0.076	0.178
2270002066	Tractors/Loaders/Backhoes	100	7,931.355	170.554	0.113	0.264
2270002066	Tractors/Loaders/Backhoes	175	10,982.156	236.157	0.157	0.366
2270002066	Tractors/Loaders/Backhoes	300	18,197.441	391.313	0.260	0.606
2270002069	Crawler Tractor/Dozers	75	4,970.163	106.877	0.071	0.166
2270002069	Crawler Tractor/Dozers	100	6,842.438	147.138	0.098	0.228
2270002069	Crawler Tractor/Dozers	175	10,599.315	227.925	0.151	0.353
2270002069	Crawler Tractor/Dozers	300	18,340.476	394.389	0.262	0.611
2270002069	Crawler Tractor/Dozers	600	33,121.887	712.244	0.473	1.104
2270002069	Crawler Tractor/Dozers	750	55,060.367	1,184.004	0.786	1.834

SCC	Description	Power Class hp	Upstream CO_2 g/hr	Upstream CH_4 g/hr	Upstream N_2O g/hr	Upstream PM_{BC} g/hr
2270002069	Crawler Tractor/Dozers	1000	71,882.205	1,545.736	1.026	2.395
2270002069	Crawler Tractor/Dozers	1200	82,941.006	1,783.542	1.184	2.763
2270002069	Crawler Tractor/Dozers	2000	114,715.590	2,466.814	1.638	3.822
2270002072	Skid Steer Loaders	11	814.359	17.512	0.012	0.027
2270002072	Skid Steer Loaders	16	1,326.120	28.517	0.019	0.044
2270002072	Skid Steer Loaders	25	1,740.157	37.420	0.025	0.058
2270002072	Skid Steer Loaders	40	2,997.699	64.462	0.043	0.100
2270002072	Skid Steer Loaders	50	3,852.348	82.840	0.055	0.128
2270002072	Skid Steer Loaders	75	4,943.589	106.306	0.071	0.165
2270002072	Skid Steer Loaders	100	7,674.771	165.036	0.110	0.256
2270002072	Skid Steer Loaders	175	10,490.825	225.592	0.150	0.350
2270002075	Off-Highway Tractors	300	22,584.875	485.659	0.322	0.752
2270002075	Off-Highway Tractors	600	31,953.704	687.124	0.456	1.065
2270002075	Off-Highway Tractors	750	52,646.122	1,132.088	0.752	1.754
2270002075	Off-Highway Tractors	1000	70,698.446	1,520.281	1.009	2.355
2270002075	Off-Highway Tractors	1200	88,704.043	1,907.469	1.267	2.955
2270002075	Off-Highway Tractors	2000	118,064.380	2,538.826	1.686	3.934
2270002075	Off-Highway Tractors	3000	177,797.480	3,823.311	2.539	5.924
2270002078	Dumpers/Tenders	11	857.220	18.433	0.012	0.029
2270002078	Dumpers/Tenders	16	1,226.682	26.378	0.018	0.041
2270002078	Dumpers/Tenders	25	2,035.898	43.779	0.029	0.068
2270002078	Dumpers/Tenders	40	2,755.963	59.264	0.039	0.092
2270002078	Dumpers/Tenders	50	4,157.518	89.402	0.059	0.139
2270002078	Dumpers/Tenders	75	4,954.733	106.545	0.071	0.165
2270002078	Dumpers/Tenders	100	7,770.307	167.091	0.111	0.259
2270002078	Dumpers/Tenders	175	9,981.296	214.635	0.143	0.333
2270002081	Other Construction Equipment	11	677.204	14.562	0.010	0.023
2270002081	Other Construction Equipment	16	1,285.830	27.650	0.018	0.043
2270002081	Other Construction Equipment	25	1,808.735	38.895	0.026	0.060
2270002081	Other Construction Equipment	40	2,926.550	62.932	0.042	0.098
2270002081	Other Construction Equipment	50	3,808.630	81.900	0.054	0.127
2270002081	Other Construction Equipment	75	5,130.463	110.324	0.073	0.171
2270002081	Other Construction Equipment	100	6,563.632	141.143	0.094	0.219
2270002081	Other Construction Equipment	175	10,723.922	230.604	0.153	0.357
2270002081	Other Construction Equipment	300	18,200.294	391.374	0.260	0.606
2270002081	Other Construction Equipment	600	34,469.192	741.217	0.492	1.148
2270002081	Other Construction Equipment	750	55,309.580	1,189.363	0.790	1.843
2270002081	Other Construction Equipment	1000	64,444.772	1,385.804	0.920	2.147
2270002081	Other Construction Equipment	1200	93,454.655	2,009.624	1.334	3.114
2270003010	Aerial Lifts	11	685.776	14.747	0.010	0.023

SCC	Description	Power Class hp	Upstream CO_2 g/hr	Upstream CH_4 g/hr	Upstream N_2O g/hr	Upstream PM_{BC} g/hr
2270003010	Aerial Lifts	16	1,129.816	24.295	0.016	0.038
2270003010	Aerial Lifts	25	1,854.167	39.872	0.026	0.062
2270003010	Aerial Lifts	40	2,833.113	60.923	0.040	0.094
2270003010	Aerial Lifts	50	3,896.923	83.798	0.056	0.130
2270003010	Aerial Lifts	75	5,182.754	111.449	0.074	0.173
2270003010	Aerial Lifts	100	7,630.187	164.078	0.109	0.254
2270003010	Aerial Lifts	175	10,281.554	221.092	0.147	0.343
2270003020	Forklifts	16	1,285.830	27.650	0.018	0.043
2270003020	Forklifts	25	2,143.051	46.084	0.031	0.071
2270003020	Forklifts	40	2,972.840	63.927	0.042	0.099
2270003020	Forklifts	50	4,030.650	86.674	0.058	0.134
2270003020	Forklifts	75	5,292.478	113.808	0.076	0.176
2270003020	Forklifts	100	6,657.087	143.152	0.095	0.222
2270003020	Forklifts	175	10,560.376	227.088	0.151	0.352
2270003020	Forklifts	300	17,156.717	368.934	0.245	0.572
2270003020	Forklifts	600	27,561.335	592.672	0.394	0.918
2270003030	Sweepers/Scrubbers	6	428.610	9.217	0.006	0.014
2270003030	Sweepers/Scrubbers	11	942.942	20.277	0.013	0.031
2270003030	Sweepers/Scrubbers	25	1,859.311	39.982	0.027	0.062
2270003030	Sweepers/Scrubbers	40	2,985.698	64.204	0.043	0.099
2270003030	Sweepers/Scrubbers	50	3,740.909	80.444	0.053	0.125
2270003030	Sweepers/Scrubbers	75	5,212.756	112.094	0.074	0.174
2270003030	Sweepers/Scrubbers	100	6,312.045	135.733	0.090	0.210
2270003030	Sweepers/Scrubbers	175	10,355.578	222.684	0.148	0.345
2270003030	Sweepers/Scrubbers	300	16,709.260	359.312	0.239	0.557
2270003030	Sweepers/Scrubbers	600	28,051.818	603.219	0.401	0.935
2270003040	Other General Industrial Eqp	6	374.348	8.050	0.005	0.012
2270003040	Other General Industrial Eqp	11	821.217	17.659	0.012	0.027
2270003040	Other General Industrial Eqp	16	1,176.106	25.291	0.017	0.039
2270003040	Other General Industrial Eqp	25	1,939.032	41.696	0.028	0.065
2270003040	Other General Industrial Eqp	40	2,784.251	59.872	0.040	0.093
2270003040	Other General Industrial Eqp	50	3,798.343	81.679	0.054	0.127
2270003040	Other General Industrial Eqp	75	5,255.617	113.015	0.075	0.175
2270003040	Other General Industrial Eqp	100	6,639.753	142.780	0.095	0.221
2270003040	Other General Industrial Eqp	175	10,054.857	216.217	0.144	0.335
2270003040	Other General Industrial Eqp	300	18,058.647	388.328	0.258	0.602
2270003040	Other General Industrial Eqp	600	30,025.778	645.667	0.429	1.000
2270003040	Other General Industrial Eqp	750	50,120.071	1,077.769	0.716	1.670
2270003050	Other Material Handling Eqp	40	3,188.859	68.572	0.046	0.106
2270003050	Other Material Handling Eqp	75	5,548.787	119.320	0.079	0.185

SCC	Description	Power Class hp	Upstream CO_2 g/hr	Upstream CH_4 g/hr	Upstream N_2O g/hr	Upstream PM_{BC} g/hr
2270003050	Other Material Handling Eqp	100	7,864.024	169.106	0.112	0.262
2270003050	Other Material Handling Eqp	175	11,728.251	252.201	0.167	0.391
2270003050	Other Material Handling Eqp	300	22,310.063	479.750	0.319	0.743
2270003050	Other Material Handling Eqp	600	38,969.820	837.997	0.556	1.298
2270003060	AC\Refrigeration	11	822.931	17.696	0.012	0.027
2270003060	AC\Refrigeration	16	1,134.960	24.406	0.016	0.038
2270003060	AC\Refrigeration	25	1,667.293	35.853	0.024	0.056
2270003060	AC\Refrigeration	40	2,728.532	58.674	0.039	0.091
2270003060	AC\Refrigeration	50	3,848.919	82.766	0.055	0.128
2270003060	AC\Refrigeration	75	4,886.155	105.071	0.070	0.163
2270004031	Leafblowers/Vacuums (com)	6	485.787	10.446	0.007	0.016
2270004031	Leafblowers/Vacuums (com)	40	2,400.217	51.614	0.034	0.080
2270004036	Snowblowers (com)	175	12,722.787	273.588	0.182	0.424
2270004036	Snowblowers (com)	300	19,415.744	417.511	0.277	0.647
2270004036	Snowblowers (com)	600	29,640.239	637.376	0.423	0.988
2270004046	Commercial Mowers (com)	6	428.610	9.217	0.006	0.014
2270004046	Commercial Mowers (com)	16	1,210.395	26.028	0.017	0.040
2270004046	Commercial Mowers (com)	25	1,789.019	38.471	0.026	0.060
2270004046	Commercial Mowers (com)	40	2,681.385	57.660	0.038	0.089
2270004046	Commercial Mowers (com)	50	3,828.346	82.324	0.055	0.128
2270004046	Commercial Mowers (com)	75	4,721.569	101.531	0.067	0.157
2270004046	Commercial Mowers (com)	100	6,371.418	137.009	0.091	0.212
2270004056	Lawn & Garden Tractors (com)	11	900.081	19.355	0.013	0.030
2270004056	Lawn & Garden Tractors (com)	16	1,253.256	26.950	0.018	0.042
2270004056	Lawn & Garden Tractors (com)	25	1,717.012	36.922	0.025	0.057
2270004056	Lawn & Garden Tractors (com)	40	2,257.061	48.535	0.032	0.075
2270004056	Lawn & Garden Tractors (com)	50	3,814.630	82.029	0.054	0.127
2270004056	Lawn & Garden Tractors (com)	100	6,168.624	132.649	0.088	0.206
2270004066	Chippers/Stump Grinders (com)	25	2,143.051	46.084	0.031	0.071
2270004066	Chippers/Stump Grinders (com)	40	3,188.859	68.572	0.046	0.106
2270004066	Chippers/Stump Grinders (com)	50	4,039.222	86.858	0.058	0.135
2270004066	Chippers/Stump Grinders (com)	75	5,235.044	112.573	0.075	0.174
2270004066	Chippers/Stump Grinders (com)	100	6,513.296	140.060	0.093	0.217
2270004066	Chippers/Stump Grinders (com)	175	9,353.176	201.128	0.134	0.312
2270004066	Chippers/Stump Grinders (com)	300	18,636.956	400.764	0.266	0.621
2270004066	Chippers/Stump Grinders (com)	600	33,495.629	720.281	0.478	1.116
2270004066	Chippers/Stump Grinders (com)	750	54,199.073	1,165.483	0.774	1.806
2270004066	Chippers/Stump Grinders (com)	1000	73,082.774	1,571.553	1.044	2.435
2270004066	Chippers/Stump Grinders (com)	1200	84,433.042	1,815.626	1.206	2.813
2270004071	Commercial Turf Equipment (com)	16	1,162.391	24.996	0.017	0.039

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2270004071	Commercial Turf Equipment (com)	25	1,813.021	38.987	0.026	0.060
2270004071	Commercial Turf Equipment (com)	40	2,963.410	63.724	0.042	0.099
2270004071	Commercial Turf Equipment (com)	50	3,897.780	83.817	0.056	0.130
2270004071	Commercial Turf Equipment (com)	75	5,389.344	115.891	0.077	0.180
2270004071	Commercial Turf Equipment (com)	100	6,463.176	138.982	0.092	0.215
2270004071	Commercial Turf Equipment (com)	175	8,713.182	187.366	0.124	0.290
2270004076	Other Lawn & Garden Eqp. (com)	16	1,285.830	27.650	0.018	0.043
2270004076	Other Lawn & Garden Eqp. (com)	25	1,963.034	42.213	0.028	0.065
2270004076	Other Lawn & Garden Eqp. (com)	50	4,028.935	86.637	0.058	0.134
2270004076	Other Lawn & Garden Eqp. (com)	75	4,371.823	94.011	0.062	0.146
2270004076	Other Lawn & Garden Eqp. (com)	100	6,168.624	132.649	0.088	0.206
2270004076	Other Lawn & Garden Eqp. (com)	175	10,101.122	217.212	0.144	0.337
2270005010	2-Wheel Tractors	6	514.332	11.060	0.007	0.017
2270005010	2-Wheel Tractors	11	714.322	15.361	0.010	0.024
2270005015	Agricultural Tractors	25	1,797.591	38.655	0.026	0.060
2270005015	Agricultural Tractors	40	2,784.251	59.872	0.040	0.093
2270005015	Agricultural Tractors	50	3,976.645	85.513	0.057	0.132
2270005015	Agricultural Tractors	75	5,330.196	114.619	0.076	0.178
2270005015	Agricultural Tractors	100	6,708.487	144.258	0.096	0.224
2270005015	Agricultural Tractors	175	10,404.618	223.738	0.149	0.347
2270005015	Agricultural Tractors	300	18,418.355	396.064	0.263	0.614
2270005015	Agricultural Tractors	600	32,335.311	695.330	0.462	1.077
2270005030	Agricultural Mowers	100	5,918.795	127.276	0.085	0.197
2270005035	Sprayers	25	1,937.318	41.660	0.028	0.065
2270005035	Sprayers	40	2,748.248	59.098	0.039	0.092
2270005035	Sprayers	50	4,112.086	88.425	0.059	0.137
2270005035	Sprayers	75	5,457.064	117.347	0.078	0.182
2270005035	Sprayers	100	6,716.275	144.425	0.096	0.224
2270005035	Sprayers	175	9,999.648	215.030	0.143	0.333
2270005035	Sprayers	300	17,647.354	379.484	0.252	0.588
2270005035	Sprayers	600	27,919.578	600.375	0.399	0.930
2270005045	Swathers	75	6,000.542	129.034	0.086	0.200
2270005045	Swathers	100	6,619.705	142.348	0.095	0.221
2270005045	Swathers	175	10,225.497	219.886	0.146	0.341
2270005045	Swathers	300	15,575.776	334.937	0.222	0.519
2270005055	Other Agricultural Equipment	16	1,232.683	26.507	0.018	0.041
2270005055	Other Agricultural Equipment	25	1,789.019	38.471	0.026	0.060
2270005055	Other Agricultural Equipment	40	2,749.963	59.134	0.039	0.092
2270005055	Other Agricultural Equipment	50	3,859.206	82.987	0.055	0.129
2270005055	Other Agricultural Equipment	75	5,369.628	115.467	0.077	0.179

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2270005055	Other Agricultural Equipment	100	6,615.811	142.265	0.094	0.220
2270005055	Other Agricultural Equipment	175	10,552.588	226.920	0.151	0.352
2270005055	Other Agricultural Equipment	300	17,943.294	385.848	0.256	0.598
2270005055	Other Agricultural Equipment	600	29,212.368	628.175	0.417	0.973
2270005060	Irrigation Sets	25	1,875.598	40.332	0.027	0.062
2270005060	Irrigation Sets	40	2,828.827	60.830	0.040	0.094
2270005060	Irrigation Sets	50	3,864.349	83.098	0.055	0.129
2270005060	Irrigation Sets	75	5,163.895	111.043	0.074	0.172
2270005060	Irrigation Sets	100	6,621.247	142.382	0.095	0.221
2270005060	Irrigation Sets	175	10,509.793	226.000	0.150	0.350
2270005060	Irrigation Sets	300	17,310.701	372.245	0.247	0.577
2270005060	Irrigation Sets	600	30,072.042	646.661	0.429	1.002
2270006005	Generator Sets	6	458.613	9.862	0.007	0.015
2270006005	Generator Sets	11	721.608	15.517	0.010	0.024
2270006005	Generator Sets	16	1,162.391	24.996	0.017	0.039
2270006005	Generator Sets	25	1,825.022	39.245	0.026	0.061
2270006005	Generator Sets	40	2,866.545	61.641	0.041	0.096
2270006005	Generator Sets	50	3,873.778	83.301	0.055	0.129
2270006005	Generator Sets	75	5,139.893	110.527	0.073	0.171
2270006005	Generator Sets	100	6,663.656	143.294	0.095	0.222
2270006005	Generator Sets	175	10,463.529	225.005	0.149	0.349
2270006005	Generator Sets	300	18,351.657	394.629	0.262	0.611
2270006005	Generator Sets	600	32,331.301	695.244	0.462	1.077
2270006010	Pumps	3	257.166	5.530	0.004	0.009
2270006010	Pumps	6	447.898	9.631	0.006	0.015
2270006010	Pumps	11	725.551	15.602	0.010	0.024
2270006010	Pumps	16	1,176.963	25.309	0.017	0.039
2270006010	Pumps	25	1,861.882	40.037	0.027	0.062
2270006010	Pumps	40	2,941.980	63.264	0.042	0.098
2270006010	Pumps	50	3,838.632	82.545	0.055	0.128
2270006010	Pumps	75	5,347.340	114.988	0.076	0.178
2270006010	Pumps	100	6,655.174	143.111	0.095	0.222
2270006010	Pumps	175	10,209.073	219.533	0.146	0.340
2270006010	Pumps	300	18,752.617	403.251	0.268	0.625
2270006010	Pumps	600	30,658.062	659.263	0.438	1.021
2270006015	Air Compressors	6	477.215	10.262	0.007	0.016
2270006015	Air Compressors	11	811.788	17.456	0.012	0.027
2270006015	Air Compressors	16	1,143.532	24.590	0.016	0.038
2270006015	Air Compressors	25	1,944.176	41.807	0.028	0.065
2270006015	Air Compressors	40	2,871.688	61.752	0.041	0.096

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2270006015	Air Compressors	50	3,794.057	81.586	0.054	0.126
2270006015	Air Compressors	75	5,208.470	112.002	0.074	0.174
2270006015	Air Compressors	100	6,466.260	139.049	0.092	0.215
2270006015	Air Compressors	175	9,962.328	214.227	0.142	0.332
2270006015	Air Compressors	300	18,760.328	403.417	0.268	0.625
2270006015	Air Compressors	600	32,955.874	708.675	0.471	1.098
2270006025	Welders	11	758.040	16.301	0.011	0.025
2270006025	Welders	16	1,258.399	27.060	0.018	0.042
2270006025	Welders	25	1,825.022	39.245	0.026	0.061
2270006025	Welders	40	2,827.112	60.793	0.040	0.094
2270006025	Welders	50	3,963.786	85.236	0.057	0.132
2270006025	Welders	75	5,509.355	118.472	0.079	0.184
2270006025	Welders	100	7,697.518	165.525	0.110	0.256
2270006025	Welders	175	13,811.858	297.007	0.197	0.460
2270006025	Welders	600	34,575.138	743.495	0.494	1.152
2270006030	Pressure Washers	6	444.040	9.549	0.006	0.015
2270006030	Pressure Washers	11	775.013	16.666	0.011	0.026
2270006030	Pressure Washers	16	1,197.537	25.752	0.017	0.040
2270006030	Pressure Washers	25	1,750.444	37.641	0.025	0.058
2270006030	Pressure Washers	40	2,677.099	57.568	0.038	0.089
2270006030	Pressure Washers	50	3,884.065	83.522	0.055	0.129
2270006030	Pressure Washers	75	5,258.189	113.071	0.075	0.175
2270006030	Pressure Washers	100	6,826.354	146.792	0.097	0.227
2270006030	Pressure Washers	175	9,892.931	212.735	0.141	0.330
2270006030	Pressure Washers	300	17,441.785	375.064	0.249	0.581
2270006030	Pressure Washers	600	32,038.291	688.943	0.457	1.067
2270006030	Pressure Washers	750	53,119.564	1,142.269	0.758	1.770
2270007015	Forest Eqp - Feller/Bunch/Skidder	40	3,040.560	65.383	0.043	0.101
2270007015	Forest Eqp - Feller/Bunch/Skidder	50	3,851.491	82.821	0.055	0.128
2270007015	Forest Eqp - Feller/Bunch/Skidder	75	5,579.647	119.983	0.080	0.186
2270007015	Forest Eqp - Feller/Bunch/Skidder	100	6,928.105	148.980	0.099	0.231
2270007015	Forest Eqp - Feller/Bunch/Skidder	175	10,669.406	229.432	0.152	0.355
2270007015	Forest Eqp - Feller/Bunch/Skidder	300	17,538.324	377.140	0.250	0.584
2270007015	Forest Eqp - Feller/Bunch/Skidder	600	32,810.372	705.546	0.468	1.093
2270007015	Forest Eqp - Feller/Bunch/Skidder	750	53,681.911	1,154.362	0.767	1.789
2285002015	Railway Maintenance	11	841.585	18.097	0.012	0.028
2285002015	Railway Maintenance	16	1,429.278	30.735	0.020	0.048
2285002015	Railway Maintenance	25	1,770.160	38.065	0.025	0.059
2285002015	Railway Maintenance	40	3,372.407	72.519	0.048	0.112
2285002015	Railway Maintenance	50	4,462.826	95.967	0.064	0.149

SCC	Description	Power Class hp	Upstream CO_2 g/hr	Upstream CH_4 g/hr	Upstream N_2O g/hr	Upstream PM_{BC} g/hr
2285002015	Railway Maintenance	75	6,029.670	129.660	0.086	0.201
2285002015	Railway Maintenance	100	7,992.316	171.865	0.114	0.266
2285002015	Railway Maintenance	175	12,192.285	262.180	0.174	0.406
2285002015	Railway Maintenance	300	21,291.006	457.836	0.304	0.709
2285002015	Railway Maintenance	600	41,235.401	886.715	0.589	1.374
2285002015	Railway Maintenance	750	62,708.382	1,348.465	0.895	2.089
2285004015	Railway Maintenance	3	902.730	5.509	0.014	0.028
2285004015	Railway Maintenance	6	1,059.203	6.464	0.016	0.032
2285004015	Railway Maintenance	11	1,868.883	11.406	0.029	0.057
2285004015	Railway Maintenance	16	3,422.978	20.891	0.052	0.105
2285004015	Railway Maintenance	25	2,876.439	17.555	0.044	0.088
2285004015	Railway Maintenance	40	5,242.108	31.993	0.080	0.160
2285006015	Railway Maintenance	40	2,479.681	31.090	0.040	0.054

APPENDIX D. COOL PAVEMENT TECHNOLOGY

Background Information:

The US EPA describes a "heat island" as a built up area that is hotter than nearby rural areas(EPA 2010c). The impacts of the heat island effect are significant. Annual temperatures in a city of one million range from 1.8 to 5.4 deg F higher than surrounding areas (EPA 2010c). On a clear summer night the difference can be as high as 22 deg F. (EPA 2010c).

This increased temperature has significant impacts on CO_2 emissions in two ways. The first is through increased energy demand for cooling. Peak urban electric demand increases 1.5 to 2% for every 1 deg F increase in summertime temperature (EPA 2008b). It is estimated that 5 to 10 percent of electricity demand is used to compensate for the heat island effect (EPA 2008b).

The second way is through increased formation of ground level ozone. NOx and VOCs react in the presence of sunlight to form ozone, and higher temperatures increase the rate of this reaction (EPA 2008b).

One of the methods proposed by the EPA to reduce the heat island effect is the introduction of cooler pavement (EPA 2008b). The contribution of pavements to the heat island effect is often measured by the albedo of a pavement. Albedo is the surface reflectivity of the sun's radiation (Budikova 2010). Albedo is measured in percentages with 100% Albedo meaning that all of the sun's radiation is reflected and 0% meaning that no radiation is reflected off of a surface. As the albedo of a surface decreases, the heat island effect increases.

Over 60% of US urban surfaces are either pavement or roof (Menon et al. 2010). It is estimated that a .15 increase in the albedo of 26 m^2 of paved area will offset one ton of emitted CO_2 (Menon et al. 2010).

There are multiple new technologies available for increasing the albedo of pavements. The technologies often focus around creating a lighter colored pavement and increasing the permeability of the pavement. In an effort to increase the utilization of these new technologies the EPA has been hosting a database of local demonstration projects that include heat island mitigation measures (EPA 2010c). They can be found at: http://yosemite.epa.gov/gw/statepolicyactions.nsf/HIRIInitiative?OpenView&count=500&type=Demonstration%20Project.

Asphalt Technology

One new approach to increasing albedo in asphalt is the introduction of Cool Asphalt. Traditional asphalt has an albedo of 0.04 for newly laid pavement that increases up to 0.15 as it ages (Houston Advanced Research Center (HARC) 2006). Cool Asphalt technology refers generally to asphalts that utilize white aggregates or light colors to make a traditional asphalt of a lighter color. By using an aggregate that is 30-40% more reflective it is expected that the asphalt concrete could increase in reflectivity by 10 to 15% (Houston Advanced Research Center (HARC) 2006).

Another approach to creating lighter asphalt involves the use of lightly colored aggregate in chip seals. Light colored chip seal increases albedo by an estimated 20% (Houston Advanced Research Center (HARC) 2006). This approach is particularly well suited to low volume asphalt roads as a resurfacing technique which will also extend pavement life (EPA 2008b).

This effect can also be achieved by utilizing Ultra-thin whitetopping as a surface coating on a pavement. Whitetopping is the application of a layer of concrete over an existing asphalt surface (EPA 2008b). The albedo of a white topped asphalt surface is roughly the same as any other concrete surface (EPA 2008b).

Another source of high reflectivity asphalt can come from the use of open-graded asphalt or rubberized asphalt. Open-graded asphalt is a form of asphalt that removes sand and other fine aggregates from the mixture (Houston Advanced Research Center (HARC) 2006). Rubberized asphalt is made by mixing shredded rubber into traditional asphalt (EPA 2008b). These types of asphalt allow water to permeate the pavement providing a cooling effect, reduced roadway noise, as well as improved storm water drainage (Houston Advanced Research Center (HARC) 2006). This surface type also has the added benefit of improved friction during wet weather (EPA 2008b).

Other techniques to increase reflectivity in asphalt include resin based pavements which use clear tree resins as opposed to petroleum based binders (EPA 2008b). There are also colored asphalts which add pigments or seals to the asphalt mix in order to increase reflectance (EPA 2008b).

Cement Technology

Cement is preferable to asphalt because it is lighter and has a higher albedo, 0.35.-04 vs. 0.05-0.1 respectively (EPA 2008b). Even as concrete ages and darkens, it retains a higher albedo than asphalt, 0.25-0.35 vs. 0.1-0.2 respectively (EPA 2008b). One of the materials that causes darkness in concrete is the presence of iron oxide in the clay substrate (Houston Advanced Research Center (HARC) 2006). White cement is a highly reflective paving material that substitutes kaolin for the ordinary clay, resulting in concrete with a much higher albedo (Houston Advanced Research Center (HARC) 2006). The use of lighter colored materials in the composition of concrete can increase the reflectance of concrete to 0.4-0.8 (Houston Advanced Research Center (HARC) 2006).

Slag and Fly Ash Cement also represent a form of higher reflectivity concrete, which have additional benefits as recycled byproducts of Iron manufacturing (EPA 2008b). These products make concrete stronger, cheaper and less carbon intensive while slag cement has an albedo of up to 0.6 compared with 0.35 for traditional concrete mixes (EPA 2008b).

One great example of the use of slag cement is in the Detroit Airport. Local fine aggregates in the Detroit area were susceptible to alkali-silica reaction from water that infiltrated the concrete (Slag Cement Association (SCA) 2010). They used slag cement instead which reduced the permeability of the concrete, and lowered the number of alkalis in the concrete mixture (Slag Cement Association (SCA) 2010). The slag cement also produced a smoother pavement finish, increased the durability of the pavement, and produced a higher albedo surface (Slag Cement Association (SCA) 2010).

Porous Pavements

Porous pavement represents another paving type that can substantially decrease the urban heat island effect. These pavements can be asphalt, concrete, or pavers; and they sometimes have lattice structures that permit grass and other vegetation to grow through them (EPA 2008b). These surfaces are generally targeted at parking lots, sidewalks, shoulders, and other areas with low traffic volume(FHWA). These pavements reduce heat by absorbing moisture and the cooling effect of the grasses (Houston Advanced Research Center (HARC) 2006). The main benefit of these surfaces is their ability to handle ground water, and the potential to reduce the need for curbs, gutters, and storm drains (FHWA). Many porous pavements are prefabricated and commercial examples include: GrassPave, GrassCrete, Turfstone, and StoneyCrete Pervious Pavement (Houston Advanced Research Center (HARC) 2006).

Considerations

All of these technologies share similar issues which must be considered before implementing one of the new technologies. One of the biggest concerns is the determination of situations in which these techniques are suitable. The FHWA fact sheet only encourages porous pavement in areas with high soil infiltration capacity and with organizations that can perform regular maintenance (FHWA). Testing should be done with these products to determine projects in which they may be suitable.

It is also important to consider some of the many ancillary benefits of these technologies outside of heat reduction and CO_2 savings. The biggest benefit is likely to be in the area of water quality and storm water runoff. Lower temperature runoff has a reduced impact on aquatic life and water ways (EPA 2008b). Permeable and porous pavements can improve the filtering of storm water and reduce the need for drains, treatment ponds, grading, inlets, and storm water pipes (EPA 2008b). Reduced pavement temperatures have also been linked to increased pavement life with a 20 deg F reduction in surface temperature lasting ten times longer (EPA 2008b). Pavements with a higher level of reflectivity also enhance night time visibility and increase safety on the roads and potentially reduce lighting costs (EPA 2008b). There is also the benefit of reduced noise as permeable pavements reduce tire noise by two to eight decibels (EPA 2008b).

Applications

Each cool pavement technology has a feature that may leave it unsuitable for certain applications. That can make planning for the use of these technologies difficult. The City of Chicago has done work to identify uses and design strategies for many of these cool pavement technologies. They have published a Green Alley Handbook, which provides implementation strategies, example applications, basic cost estimates, and pilot approaches for the use of these techniques in alleys and other urban settings (City of Chicago 2010).

APPENDIX E. EMISSIONS OF HFC-134A FROM MOBILE AIR CONDITIONING SYSTEMS

This section summarizes the content of three reports of several studied regarding HFC-134a emissions from Mobile Air Conditioners (MACs). The first report, (Hwang, Doniger 2004), is a meta-analysis of studies done on passenger cars. Table 32, shown below, reproduces the summary from the report of estimated leakage rates for passenger cars. The rates estimated are highly variable and tend to have high standard deviations. They also vary by the age, size and construction of the vehicle, and also by climate and the initial charge of the air-conditioning system.

“Regular” emissions are leakages due to the regular operation of the vehicle. Losses during accidents, servicing, manufacturing and end of life are included in the “irregular” category of HFC-134a emissions.

Table 32. Summary of Vehicle Leak Rate Estimates (grams/year)

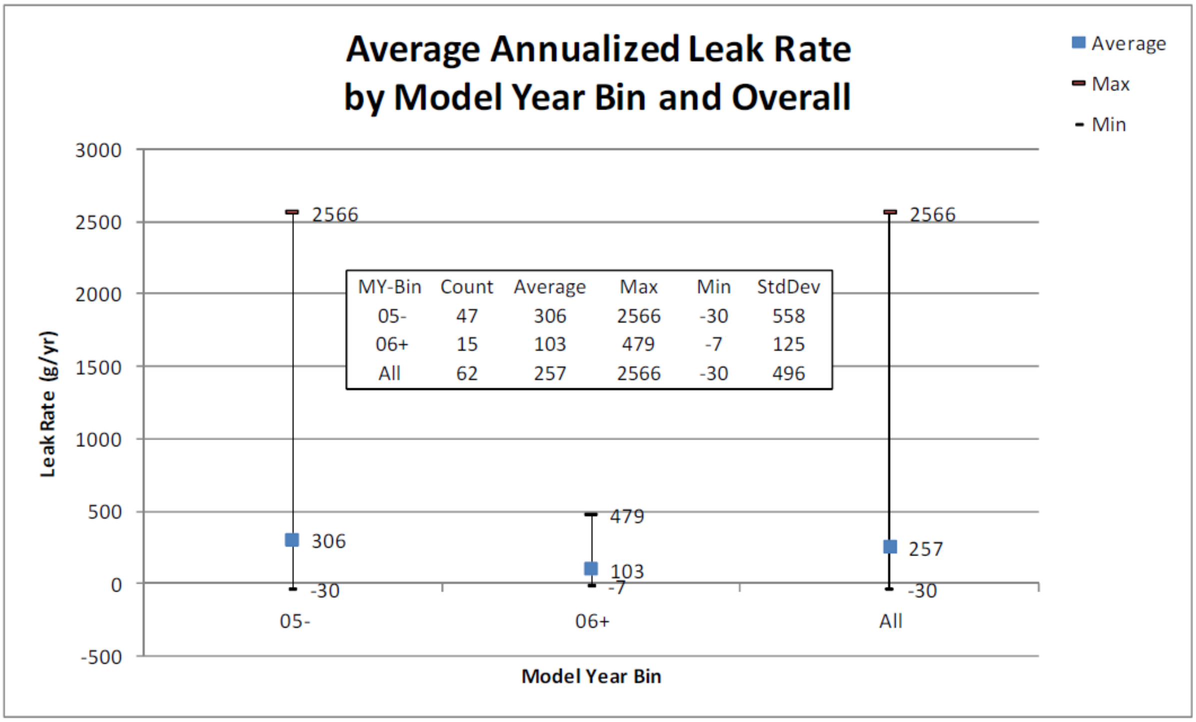
	Normal	Irregular	Total
IPCC Inventory Method	na	na	70
Baker (1999)(Baker 1999)			
Component specs and/or benchtop testing			
Schwarz (2001)(Schwarz 2001)	34 to 83	na	
Barrault et al. (2003)(Schwarz, Harnisch 2003)	5.8 to 40.3	na	
Baker (2003)(Baker 2003)	25	na	
Repair Records			
Schwarz (2001)(Schwarz 2001)	52	16	70
In-use Vehicle Testing			
Schwarz and Hamisch (2003)(Schwarz, Harnisch 2003)	52.4	na	
Siegl et al. (2001)(Siegl et al. 2002)	25.5	na	
Meta-analysis			
Barrault et al. (2003)(Barrault, Benouali & Clodic 2003)	57.5	na	75 to 107.3
Source: Hwang and Doniger (2004) (Hwang, Doniger 2004)			

The second report is titled “Establishment of Leakage Rates of Mobile Air Conditioners in Heavy Duty Vehicles” (Schwarz, Harnisch 2003) which was carried out for the European Commission in two parts, the first for trucks and the second for buses and coaches. This review is concerned only with the first part.

The first study is an experimental study that uses a “gravimetric” approach to estimate the coolant liquid lost from a fully charged air conditioning unit due to leakage in a certain period of time. This report concludes that annual leakage rates for trucks might be as high as 87.8 grams per annum, and an additional 30 g/annum might be lost due to “irregular” leakages.

The third report is from a presentation to the California Air Resources Board. Titled “A Study of R134a Leaks in Heavy Duty Vehicles”(Burnette, Baker), the study includes both trucks and off-road vehicles. It uses fleet maintenance records as well as gravimetric measurements to arrive at leakage rate estimates. The authors come up with point estimates of leakage rates.

Figure 5. Average Annualized Leak rate by Model Year Bin and Overall



(Source: Burnette and Baker 2010)

The authors find that new on-road vehicles (not older than 2006) have leakage rates of 103 g/yr and older vehicles have leakage rates of 306 g/yr. The authors make an informed assumption that all off-road vehicles have leakage rates of 306 g/yr.

APPENDIX F. DOCUMENTATION OF MATERIALS CALCULATIONS

General Note

Densities of all materials used in our computations are given in a separate worksheet. They are obtained from four online sources.[22] Since densities are known, the computations described in this document may arrive at either the weight or the volume of materials consumed. It is to be noted that while we have estimated lifecycle emissions for basic materials such as concrete and steel, we have not been able to fully include the emissions at the last stage of manufacturing – for instance, the emissions in the manufacture of a precast concrete pipe. Direct equipment emissions due to the road project are covered in the equipment section.

Densities of concrete and aggregate materials (stone/sand/coarse aggregate/soil aggregate) are only approximately determined to be 150 lb/cu.ft and 100 lb/cu.ft.

Emission factors for major materials (cement, aggregate, steel and asphalt binder) are reported in a previous section of this report. For most of the other materials, the GREET vehicle cycle model is used as a source of emission factors. In the case of wood, calculations from a lifecycle analysis carried out by Puettmann and Wilson(Puettmann, Wilson 2005) are used to estimate final emission factors for carbon dioxide and methane. The authors give no estimate for nitrous oxide. A notable gap in our estimates for material emissions is our inability to obtain the emissions from brick kilns. We also do not distinguish between PVC, polypropylene and HDPE for the purposes of emission rates (g/lb).

For recycled materials, the GreenDOT spreadsheet for estimating the carbon footprint of transportation construction projects is used as a source for CO_2 emission factors (Gallivan 2010). We assume that other emissions (CH_4 and N_2O) are emitted in the same ratio as in the case of the material being replaced. (For instance, if the ratio of N_2O emissions to CO_2 emissions in cement production is 0.1%, then we assume that the same will hold true of any cement alternative). In the case of Ground Bituminous Shingle Material, we assume that it has the same emission factors as Recycled Asphalt Pavement (RAP). In the case of Remediated Petroleum Contaminated Soil Aggregate (RPCSA), we assume that there are no additional emissions that need to be attributed to the use of the material for construction purposes, as the remediation would have taken place regardless of its use as recycled material.

Weights and dimensions of standard rebars are obtained from an online source[23]. Epoxy-coating, where relevant, is not estimated due to unavailability of emission data. The zinc coating in galvanized steel is estimated to weigh 3 oz per sq. ft of surface area

[22] http://www.simetric.co.uk/si_materials.htm
http://www.coolmagnetman.com/magconda.htm
http://www.substech.com/dokuwiki/doku.php?id=thermoplastic_high_density_polyethylene_hdpe
http://www.wsdot.wa.gov/research/reports/fullreports/692.1.pdf

[23] http://www.sizes.com/materls/rebar.htm

of the rebar[24]. The electricity consumed in galvanization of reinforcement steel has been ignored in this analysis. The same assumptions for galvanization of rebars have been used throughout this study. Rebar sizes and weights have been derived from an online source and used, often with appropriate radius adjustments.[25]

Subbase, Base and Surface Courses

Sections 203, 301, 302, 305– Aggregates – Cu. Yard

The volume is available directly in the input. Dense-graded aggregate (DGA) is treated to have the same emission factors as soil aggregate.

Section 303, 401, 402, 403, 404– Asphalt-Aggregate mixes – Tons

Since the grade of aggregate used in asphalt-aggregate mixes is found to have negligible impacts, we treat all types of asphalt-aggregate mixes equivalently. Users have the option of changing the ratio of asphalt binder to aggregate, the amount of moisture in the mix and the temperature to which it is heated. A heating model (described previously in this report) calculates the total emissions.

Section 304, 405 – Concrete Surface and Base courses – Inches x Sq. yards[26]

The inputs consist of the thickness and area of the concrete layer. Volume of concrete is estimated simply by multiplying area by thickness and removing the volume occupied by reinforcement steel. Users have the option of altering the ratios of cement and aggregate, which is reflected in their respective weights and by extension in the total emissions from these items.

Based on detailed geometric calculations from drawings, it was determined that the *volume of steel* used in concrete courses is 0.001392 cu. ft. per sq. ft for surface courses and reinforced base courses less than ten inches thick and 0.002013 cu. ft. per sq. ft for concrete surface and reinforced base courses ten inches thick or more. This is based on a twenty foot lane width. We assume that all concrete surface courses are reinforced.

Section 401 – Asphalt Binder – Type – Gallons

Tack and Prime Coats consist primarily of heated binder material, and are treated as such. Calculations for cut-back asphalt also consider emissions from vaporization during the heating process.

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[24] http://www.galvanizeit.org/aga/inspection-course/galvanizing-standards/astm-a-767-a-767m

[25] http://www.sizes.com/materls/rebar.htm

[26] STANDARD ROADWAY DETAILS (English units) 2001; CD-405-1, SHEET 14

Section 203, 401, 603 – Geotextiles and Reinforcement Meshes – Sq. Yard

Geotextiles are estimated to weigh 0.25 lb/sq.yard based on Maine Government specifications[27]. Geotextile plastics are assumed to have similar emission factors as polypropylene. Another source suggests approximately 3 lb/ sq. yard as the density of a steel reinforcement mesh (which is also used to estimate the density of Pavetrac).[28]

Bridges and Structures

Section 501 – Temporary/Permanent Sheeting – Sq. Yard

All sheeting is assumed to be made of stamped steel, which, based on a manufacturer's specification, is estimated at 31.7465 lb/sq.ft.[29] For cofferdams,another manufacturer's drawings are used to estimate that 1.78 cu. Ft. of aluminum will be used to produce one unit of this product.[30]

Section 502 – Cast-in-place piles – Feet

We assume that cast-in-place piles are akin to filled cylinders with the given nominal diameter. The casing is assumed to have the same geometry as a seamless steel pipe pile of the given diameter, except in the case of 30" and 36" piles, where a 0.3 inch thick pipe is assumed. The weights of seamless steel pipe piles are obtained from Fuller (1983)(Fuller 1983). Reinforcement is assumed to consist of 12 #5 axial bars and spiral bars at 6 inch intervals. The spiral bars are 2.5 inch from the concrete surface.

Section 502 – Precast and pre-stressed concrete piles – Feet

Precast and Prestressed concrete piles are estimated with perfect square cross-sections. Reinforcement is assumed to consist of 12 #5 axial bars and spiral bars at 6 inch intervals. The spiral bars are 2.5 inch from the concrete surface.

Section 502 – Steel H-piles and timber piles – Feet

Cross-sectional areas (in sq. inch) of Steel H-Piles are obtained from Fuller (1983) (Fuller 1983). Timber piles are estimated to be perfect cylinders of 12" diameter. Steel Soldier Piles are assumed to have the same material content as 12" x 74" Steel H-piles.

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[27] http://www.maine.gov/mdot/mlrc/geotextiles.php

[28] http://www.acfenvironmental.com/PDFs/PavPreservation/Install%20-%20with%20Slurry%20Seal%20-%2010-10-03.pdf (p. 4)

[29] http://www.skylinesteel.com/assets/ProductBrochures/GenProductBrochUS.pdf

[30] http://www.supsalv.org/pdf/7370421g3.pdf

Section 504 – Reinforcement Steel - Tons

Users are required to input reinforcement steel in tons. To enable an estimation of the quantity of zinc, the reinforcement bars are assumed to be of the #10 size.

Section 504 – Structural Concrete –Cu. Yard

Given the volume, the estimate for density of concrete is used to estimate total emissions. HPC, HES and VESLMC concrete are all assumed to be equivalent to traditional concrete mixes (users do have the option of altering the cement/aggregate ratios).

Section 505 – Pre-tensioned Pre-stressed concrete beam – Inches x Feet

The concrete content had to be estimated volumetrically, using the NJDOT drawings for the four sizes of Pre-tensioned, Pre-stressed beams.[31] Similarly, the length and size of each reinforcement bar was accounted for, as was the zinc contained in those rebars which were specifically required by NJDOT to be galvanized. The steel in the hooks inserted at the end of each beam at the time of casting was not included for the sake of simplicity. For estimation purposes, we considered beams of 54' to be typical. For the beam of height 93.5 inches, the drawing of the 72" beam was adopted – essentially by assuming that while the height of the beam changed, it only lengthened the neck of the beam and didn't affect the cross-section otherwise.

Section 505 –Pre-stressed concrete box-beams and slab-beams – Inches x Inches x Feet

Texas DOT drawings of box-beams and slab-beams were used to estimate the quantity of concrete, steel and zinc in them.[32] However, to the extent that there was an incongruity in the sizes of beams used in the two states, the drawings often had to be modified to fit the dimensions included in the NJDOT bid-sheets.

Section 505 – Channel beams – Inches x Inches x Feet

A product drawing from a manufacturer served as a reference in the estimation.[33]

Section 505, 602 – Precast Concrete Culverts – Feet/Cu. Yards

An NJDOT drawing was used as a reference for concrete culverts.[34] We assume a 4' x 4' culvert with a maximum depth of fill of 15 ft, for which NJDOT provides the volume of

[31] NJDOT Bridge Manual Standard Drawing Plates- Sheet SP 2.4-1
NJDOT Bridge Manual Standard Drawing Plates- Sheet SP 2.4-2
NJDOT Bridge Manual Standard Drawing Plates- Sheet SP 2.4-3
NJDOT Bridge Manual Standard Drawing Plates- Sheet SP 2.4-4
[32] Texas DOT Bridge Standards (English) – BB-B34
Texas DOT Bridge Standards (English) – PSB-4SB15
[33] http://www.mccannconcreteproducts.com/images/Channel%20Beam%20Superstructure.pdf

concrete and weight of reinforcement steel needed per foot. In Section 505, the input is in Feet, and the values obtained are used directly. In Section 602, the input is in cubic yards. We estimate concrete simply by the volume inputted. For reinforcement steel, the volume of concrete is reduced to a length based on an assumed average cross-sectional area of 8 sq. ft, and the resulting length is then used to estimate the weight of reinforcement steel used.

Section 602 –Concrete Headwall – Cu. Yard

We assume square headwalls. The volume input (reduced, the volume of steel) is taken to be the volume of concrete used. A FHWA drawing suggests the appropriate amount of reinforcement steel for a given volume of concrete.[35] When this relationship is modeled as a linear relationship, the regression has an R^2 of 0.99, and the coefficient is 85.39 lb of reinforcement steel per cu. Yd. of concrete. This rate is used to estimate the amount of steel needed.

Section 505 – Precast Concrete Arch structures – Feet

A product brochure is used to obtain recommended weight for bridge arch structures, assuming a 12 feet rise and a 48 feet span.[36] The weight of concrete needed is 5.67 ton per feet of arch structure. As no information about the steel requirements is available, we assume a steel/concrete ratio of 85.39 lb/cu.yard which is also obtained for concrete headwalls.

Section 505 – Superstructures and Deck panels – Sq. Feet

We assume that the material requirements are akin to the requirements of a concrete slab of the given area and 2' thickness. A steel/concrete ratio of 80 lb/cu.yard is assumed.

Section 506 – Structural Steel – Tons/Pounds (Direct)

Section 507 – Bridge Decks and approach slabs; median, moment and bridge-relief slabs – Cu. Yard

For all concrete bridge decks and approaches, the amount of concrete is obtained directly from the input (less, the volume of concrete). Based on a drawing from Texas DOT, reinforcement steel is estimated for 13" thick decks and reinforcement at 8.5lb/sq. foot[37]. Assuming the reinforcement bars to be of #5 size allows the amount of zinc to be estimated. Median, moment and bridge-relief slabs are assumed to have the same geometry as approach slabs. All types of concrete are treated to be equivalent.

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[34] NJDOT Roadway construction Details (English Units) 2001; CD-610-2 (SHEET NO. 41)
[35] Federal Lands Highway Standard Drawing 601-1 for Concrete Headwalls, accessed at http://flh.fhwa.dot.gov/resources/pse/standard/st60101.pdf
[36] http://www.contech-cpi.com/Products/Bridges-and-Structures/Precast/CONSPAN-Bridge.aspx
[37] Texas DOT Bridge Standards (English) – BAS-C

Section 507 – Bridge Sidewalks – Cu. Yard

The amount of concrete is obtained directly, as in the case of approach slabs. Reinforcement concrete is estimated using the same estimate as concrete surface courses, i.e. 0.0089 cu. ft per sq. foot of sidewalk.

Section 507 – Bridge Parapets – Feet

Concrete parapets are assumed to be of the type of 2' 10" height. An NJDOT drawing for these types of parapets is used to estimate the volume of concrete to be 3.68 cu. Ft of concrete per feet of parapet.[38] Reinforcement steel is estimated at 255.05 lb per foot of parapet. All types of concrete are dealt with equivalently. Open steel parapets are estimated at 0.268 cu. Ft of stamped steel per foot of parapet, based on a similar NJDOT drawing.[39] Half Concrete Barriers are assumed to have similar geometries as bridge parapets.

Section 507, 607 –24" and 15" Concrete Barrier Curbs – Inches x Inches x Feet

Estimations for Concrete barrier curbs of various heights are carried out using the drawings made available by NJDOT.[40] Concrete is estimated volumetrically, while reinforcement steel requirements are measured in lb/ft. When not specified, barrier curbs are assumed to be of the 24" x 32" size. Dowelled curbs are treated to be the same as common barrier curbs.

Section 507 – Median barriers – Inches x Inches x Feet

Median barriers in Section 507 are assumed to have the same outside geometry as 24" x 32" barrier curbs while having a greater quantity of reinforcement steel, as shown in an NJDOT drawing.[41]

Section 507, 607 – Concrete Vertical and Sloping Curbs – Inches x Inches x Feet

Estimations for Concrete vertical and sloping curbs of various heights are carried out using the drawings made available by NJDOT.[42] Where dimensions are missing, a size of 9" x 6" is assumed. Dowelled curbs are assumed to have the same materials requirements as usual vertical curbs. White concrete is estimated in the same manner as normal concrete.

[38] NJDOT Bridge Manual Standard Drawing Plates- Sheet BCD-507-2
[39] NJDOT Bridge Manual Standard Drawing Plates- Sheet BCD-507-10
[40] NJDOT Roadway construction Details (English Units) 2001; CD-605-3 (SHEET NO. 36)
[41] NJDOT Bridge Manual Standard Drawing Plates- Sheet BCD-507-9
[42] NJDOT Roadway construction Details (English Units) 2001; CD-605-1 (SHEET NO. 34)
NJDOT Roadway construction Details (English Units) 2001; CD-605-2 (SHEET NO. 35)

Section 607 – Variable height/width Barrier/Vertical Curbs – Inches x Feet

Estimations are made based on the closest "standard" prototype of curbs whose height/width is known. For instance, for barrier curbs, a height of 32" is considered "standard", and for vertical curbs, a size of 6" is assumed to be the "standard".
Section 607 – Granite/Belgian Block/Bluestone Curbs – Feet

These curbs are assumed to have the same geometry as 9" x 6" vertical curbs and the same emission factors as aggregates. Emissions from cutting the granite are not included at this stage (they might be included in the equipment stage).

Section 607 – HMA Curbs – Inches x Inches x Feet

Estimations are made based on the assumption that the curbs have the same geometry as the corresponding concrete curbs. The volumes are converted to tons of HMA using an estimate of the density of HMA.

Section 509, 605 – Bridge Railing/Handrails – Feet

Based on a volumetric approach, the volume of metal required to manufacture rails, post bases, stems and splices is estimated from NJDOT drawings.[43] The metal might be either steel or aluminum based on the item specifications. Handrails and rail & post fences are assumed to have the same geometry as bridge railing. Ornamental Railing is also assumed to have the same geometry as bridge railing.

Section 509, 605 – Chain-link fences – Feet x Feet (or units x feet)

An NJDOT drawing provides the relative dimensions of the various posts and rails used to hold the fence, given its height and length.[44]Using a product manufacturer's specifications, the weight of the fabric per foot of fence is obtained as a function of the height.[45] The fabric is assumed to be of 9 gauge and 2" mesh. Specifications for line posts and top rails are obtained from Ohio DOT[46]. These specifications make it possible to estimate the weight of these elements per foot of fence. Aluminum-coating, where specified, is estimated at 0.4 oz/sq.ft.[47] Similarly, the weight of zinc is estimated for galvanized fences using previously used assumptions regarding galvanization.[48] In the case of PVC-coated chain-link fences, the contributions of the PVC to total emissions are not included. In this case, it is assumed that the rails and posts are galvanized.

[43] NJDOT Bridge Manual Standard Drawing Plates Sheet 509-3
NJDOT Bridge Manual Standard Drawing Plates- Sheet 509-4
[44] NJDOT Roadway construction Details (English Units) 2001; CD-614-1 (SHEET NO. 59)
[45] http://www.buildersfence.com/ChainLink_Pages/ChainLFabric-Blank.pdf
[46] http://www.dot.state.oh.us/Divisions/ConstructionMgt/Materials/TAS%20Manual/TAS-Manual-Tranning/ChainLinkFence.pdf
[47] http://www.soncoww.com/customer/astm.asp
[48] http://www.galvanizeit.org/aga/inspection-course/galvanizing-standards/astm-a-767-a-767m

Goose exclusion fences, ornamental and rock-catch fences, and several other items are assumed to have the same geometry as chain-link fences. Fence gates were all assumed to be 6' high, and their width is to be inputted.

Section 512 –Overhead Sign support structures – Units

Assuming a structure of span 95 feet, height 30 feet, width 4 feet and depth 5 feet, we arrive at estimates of sheet metal in the truss structures, concrete in the foundation and rolled steel for reinforcement. An NJDOT drawing is used for the dimensions.[49] Bridge-mounted support structures are assumed to have the same geometry.

Section 512 – Cantilever/Butterfly Sign support structures – Units

Assuming a structure of span 40 feet, height 30 feet and depth 5 feet, we arrive at estimates of sheet metal in the truss structures, concrete in the foundation and rolled steel for reinforcement. An NJDOT drawing is used for the dimensions.[50] Butterfly structures share the same types of cantilevers, but use twice the amount of metal for truss elements.

Section 512 – Steel post support – Units

Based on an NJDOT drawing, the weight of a 12' long support is determined to be 30 lb. Monotube supports are assumed to have the same weight.[51]

Section 512, 612 –Signs – Sq. Foot

Based on NJDOT specifications, the thickness of the aluminum plate is taken to be 0.1 inches[52]. Where the item specified includes the supports, it is assumed that signs are of size 30" x 30". The number of signs thus calculated, is multiplied by 30 lbs to obtain the weights of the supports.

Miscellaneous Items and Utilities

Section 601 –Corrugated Aluminum Pipes – Inches x Feet

Given the diameter and the length of the pipe, the nominal thickness of the pipe is used to estimate volume. Pipe bedding and embankments are not included in this estimate. From NJDOT specifications, it is determined that thickness for aluminum pipes must be at least 0.06 inches.[53] The use of nominal diameter assumes that the perimeter of a corrugated pipe would be the same as that of a smooth pipe.

[49] NJDOT Bridge Manual Standard Drawing Plates for Overhead Sign Support Structures (OH-G4)
[50] NJDOT Bridge Manual Standard Drawing Plates for Cantilever Sign Support Structures (CA-G3)
NJDOT Roadway construction Details (English Units) 2001; CD-619-5 (SHEET NO. 78)
[52] http://www.state.nj.us/transportation/eng/specs/2007/spec900.shtm#s911
[53] http://www.state.nj.us/transportation/eng/specs/2007/spec900.shtm#s9090204

Section 601 – Corrugated Steel/Metal Pipes – Inches x Feet

Given the diameter and the length of the pipe, the nominal thickness of the pipe is used to estimate volume. From NJDOT specifications, it is determined that thickness for steel pipes must be at least 0.079 inches.[54] Corrugated metal pipes are assumed to be made of steel. The use of nominal diameter assumes that the perimeter of a corrugated pipe would be the same as that of a smooth pipe.

Section 601 – Reinforced Concrete Pipes, Cured-in-place pipes – Inches x Feet

The weight of concrete to be used in manufacture of reinforced concrete pipes is obtained from the Concrete Pipe Design Manual published by the American Concrete Pipe Association.[55] Reinforcement is assumed to consist of 12 #5 rebars axially, and a spiral # 5 rebar for cross-sectional reinforcement which completes a circle at 6" intervals. The diameter of the spiral rebar is assumed to be the same as the nominal diameter of the pipe. It is assumed that the class of concrete does not impact the emission factors. Cured-in-place pipes maintain the same geometry, but have slightly different emission factors.

Section 601, 651, 652 – HDPE Pipes, PVC pipes, outlet drains, underdrains – Inches x Feet

For HDPE (high density polyethylene) and PVC (Polyvinyl chloride) pipes, we use emission factors for polypropylene as an approximation, since GREET does not report emissions for HDPE or PVC. Weights of various sizes of HDPE pipes are obtained from a manufacturer's brochure.[56] Underdrains are assumed to be identical to 6" HDPE pipes, and all other parts of underdrains are ignored in this estimation.[57] PVC pipes in Sections 601 and 651 have weights as specified in an online engineering source[58]and the weights of PVC sewer pipes in Section 652 is found in a product brochure and used with appropriate radius adjustment where necessary.[59] The radius adjustment accounts only for the increase in the diameter and not the increase in thickness of the pipe.

Section 601, 652 – Corrugated Aluminum/Steel/Metal Pipe Arch – Inches x Inches x Feet

We continue to use 0.06 inches thickness for aluminum pipes and 0.079 inches thickness for steel/metal pipes.[60] The perimeter of the pipe is approximated using Ramanujan's first approximation for an ellipse (Ramanujan 1914).

[54] http://www.state.nj.us/transportation/eng/specs/2007/spec900.shtm#s9090204
[55] Concrete Pipe Design Manual by American Concrete Pipe Association, 3rd Edition 1970, p. 67
[56] http://www.ads-pipe.com/pdf/en/Product_Note_3.108_N-12_Specification_for_Leachate.pdf
[57] http://www.state.nj.us/transportation/eng/CADD/v8/v8RoadwayDetails/pdf/034_CD-601-1Underdrains.pdf
[58] http://www.engineeringtoolbox.com/pvc-cpvc-pipes-dimensions-d_795.html
[59] http://www.pwpipe.com/literature/w/ucshort.pdf
[60] http://www.state.nj.us/transportation/eng/specs/2007/spec900.shtm#s9090204

Perimeter $\sim \pi * [3(a+b) - \sqrt{(3a+b)(a+3b)}]$

Where ‘a’ and ‘b’ are taken as half of the rise and span of the pipe arch.

Section 601 – Elliptical Reinforced Concrete Pipe – Inches x Inches x Feet

The weight of concrete to be used in manufacture of reinforced concrete pipes is obtained from the Concrete Pipe Design Manual published by the American Concrete Pipe Association(American Concrete Pipe Association 1970) (p.68). Reinforcement is assumed to consist of 12 #5 rebars axially, and a spiral # 5 rebar for cross-sectional reinforcement at 6” intervals. The estimation of the amount of steel is based on the “effective diameter” of the pipe as give in the above source. It is assumed that the class of concrete does not impact the emission factors.

Section 601, 651, 652 – Ductile Pipe – Inches x Feet

We use a volumetric method similar to that used for aluminum steel pipes. A product brochure specifies the appropriate thicknesses for ductile iron pipes of the 350 pressure class as a function of the diameter.[61] The same method is also used to estimate the amount of ductile iron in ductile iron water pipes (Section 651) and ductile iron sewer pipes (Section 652). We assume that ductile iron has the same emission factors as cast iron. The reinforcement is assumed to be 12 axial #5 rebars and one #5 spiral rebar at 6” intervals. At small sizes, this assumption possibly presumes an unrealistically high quantity of steel – however we continue to use this assumption for the sake of consistency.

Section 601 –Pipe end sections – Inches x Feet

Pipe end sections are estimated by making the unrealistic assumption that they maintain the same cross-section as a pipe of their diameter, and have a length as specified in the pipe end section drawings.[62]

Section 602 – Inlets – Number x Feet

The materials requirements of Inlets of various types are estimated based on the NJDOT drawings for inlets.[63] NJDOT requires the weight of the cast iron inlet cover (typically a bicycle-friendly grate) to be at least 325 lb. Similarly, the weights of the frame, the back and the curb are given in the drawings. Concrete requirements are estimated based on NJDOT requirements regarding the thickness of walls and the foundation.[64] Stage 2 of the foundation (the invert) is not included in the estimate. The

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[61] http://www.uspipe.com/Files/20047231412260.001DuctileIronPD.pdf, Table 2

[62] http://www.state.nj.us/transportation/eng/CADD/v8/v8RoadwayDetails/pdf/035_CD-601-2PipeEndSections.pdf

[63] NJDOT Roadway construction Details (English Units) 2001; CD-603-2 (SHEET NO. 25)
NJDOT Roadway construction Details (English Units) 2001; CD-603-3 (SHEET NO. 26)
NJDOT Roadway construction Details (English Units) 2001; CD-603-4 (SHEET NO. 27)
NJDOT Roadway construction Details (English Units) 2001; CD-603-5 (SHEET NO. 28)

[64] NJDOT Roadway construction Details (English Units) 2001; CD-603-1 (SHEET NO. 24)

depth of the inlet is accepted as an input, with a default value of 12 feet. Reinforcement for the concrete consists of #13 bars at 18" centre-to-centre for vertical rebars and a varying frequency for horizontal rebars.[65]

We assume that most inlets have similar geometries as the 8 inlet types listed in the left-hand column of the Table XXX given below. The table describes the base drawing, and lists the inlet types which are assumed to be equivalent to the given inlet types.

Table 33. Inlet geometry

Type	Other Types assumed to be similar	Dimensions	Casting Weight (lb)
A	A – Modified, Double A,	48 x 22	565
B	C, B- modified, Y, Double B, Double B modified, Special Type B, Type C infiltration, Drain inlet, B-W, BY, BY modified, Non-standard,	48 x 42	924
E	Es, Double E,	48 x 42	1085
B-1	B-1 modified, Double B-1 modified, Double B1, B1R, B1R Modified, BX, CX	48 x 54	924
B-2	D-2, B-2 modified, Double B-2, B2R, B3R, B2X, B-4, D-3, D-4, B2Y, D2Y2, B3, Double B2R,	48 x 66	924
D-1	D modified, D,	48 x 30	924
E-1	E1X, E1Y, S, EX	48 x 54	1085
E-2	E2, E5, E3W, E3X, E4, E4W, E5W,	48 x 66	1085

Section 602, 652 – Manholes – Number x Feet

The materials requirements of Inlets of various types are estimated based on the NJDOT drawings for inlets.[66] NJDOT requires the weight of the cast iron manhole cover and frame together to be at least 1030 lb. For the sake of simplicity, we assume all manholes to be made of concrete (manholes are sometimes made of brick) and perfectly cylindrical in shape (though part of the cross-section is conical). Only the first stage of the foundation is included in this estimate. For steel reinforcement, we use the same standards as used in the case of inlets.[67]For manholes of section 652, we assumed a height of 12'.

Section 603 –Concrete Slope Gutter/Slope Protection, Shotcrete – Sq. Yard x Inches

Concrete volume is estimated simply as the product of area and thickness. In the case of reinforced slope protection, the reinforcement steel estimate for concrete surface courses is used, i.e. 0.0089 cu. ft. per foot. Shotcrete is assumed to be similar to precast concrete in composition.

[65] NJDOT Roadway construction Details (English Units) 2001; CD-603-1 (SHEET NO. 24)
[66] NJDOT Roadway construction Details (English Units) 2001; CD-603-8 (SHEET NO. 31)
NJDOT Roadway construction Details (English Units) 2001; CD-603-9 (SHEET NO. 32)
[67] NJDOT Roadway construction Details (English Units) 2001; CD-603-1 (SHEET NO. 24)

Section 603 – Riprap Stone Slope/Channel Protection – Sq. Yard x Inches

The amount of aggregate (riprap) is estimated simply as the product of area and thickness. The coarse aggregate subbase layer and any possible geotextile requirements are not included. The emissions of cutting and laying granite (Granite Slope Protection) are also assumed to be the same as any aggregate. Emissions due to granite cutters may be included in the equipment stage.

Section 603 – Rock Backfill/Riprap Stone Scour Protection – Tons/ Cu. Yard– Direct

Section 603 – (Articulated) Concrete Block Matting – Sq. Yard x Inches

Specifications are obtained from a product manufacturer's brochure.[68] It is assumed as a default that open-cell matting is used. 6" blocks are estimated to weigh 49 lb per sq.ft, 4.75" blocks are estimated at 40 lb per sq. ft and 8.5" blocks are estimated to weigh 70 lb per sq. ft. For 6" block closed-cell matting, we estimate a weight of 59 lb per sq. ft. These estimates are based on the averages of the given ranges and in the case of 8.5" blocks, assume on a proportional increase in the weight of 6" blocks.

Section 604 – Gabion Wall/Mattress/Channel Lining – Cu. Yard

The volume of concrete is used directly. Any possible reinforcement steel requirements are not taken into account.

Section 606 – HMA Sidewalks/Driveways/Islands – Sq. Yard x Inches

The volume is estimated as the product of area and thickness, and converted into tons of HMA by multiplying with the density of a typical asphalt-aggregate mixture.

Section 606 – Concrete Sidewalks/Driveways/Islands, Concrete Pavers – Sq. Yard x Inches

The volume is estimated as the product of area and thickness. No reinforcement steel is included in this estimate. Tinted/Colored/White/Raised concrete sidewalks or islands are treated equivalent to the normal concrete surfaces.

Section 606 – Concrete Sidewalks/Driveways/Islands – Sq. Yard x Inches

The volume is estimated as the product of area and thickness. Reinforcement is assumed to be the same as for concrete surface courses.

[68] http://www.shoretec.com/shoreloc.php

Section 606 – Brick/Granite Pavers – Sq. Yard x Inches

The volume is estimated as the product of area and thickness. Both brick and granite are assumed to have the same emissions as plain aggregate. The emissions from brick kilns and granite cutting are ignored for the purpose of this estimation. Emissions from granite cutting might be included in the equipment stage.

Section 608 – Non-vegetative surface, HMA/Broken Stone – Sq. Yard x Inches

The volume is estimated as the product of area and thickness and then converted to tons of HMA using a density estimate of asphalt-aggregate mixtures. Porous, permeable, and color-coated asphalt are assumed to have the same emission factors as the usual asphalt-aggregate mixtures. Where the surface is made of stone, the volume is calculated assuming 3" thickness and converted to pounds of aggregate.

Section 608 – Non-vegetative surface, Polyester Matting – Sq. Yard

Polyester matting is assumed to have similar emission factors as a geotextile fabric and treated as such using the density of geotextiles as a reference.[69]

Section 609 –Beam Guide Rails – Feet

Rail elements and posts, which may also be listed as separate item numbers are calculated separately. We use an NJDOT drawing to estimate the volume of stamped steel used in beam guide rail.[70] We use separate galvanization factors for the additional weight of zinc on galvanized steel.[71] Wood in the spacer is also estimated volumetrically. Bridge and powder-coated beam guide rails are assumed to have the same emission factors.

Section 609 –Beam Guide Rails, Dual-faced – Feet

We use the same NJDOT drawing as for simple beam guide rails in this estimation too.[72] The only difference is that there is a requirement for twice as much of rail element.

Section 609 –Modified Thrie Beam Guide Rails (Single/Dual-faced) – Feet

Modified thrie beam guide rails have a different rail profile whose volume per feet is calculated using similar procedures as in the case of traditional beam guide rails.[73] Dual-faced thrie beam guide rails have twice as much of rail element.

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69 http://www.maine.gov/mdot/mlrc/geotextiles.php
70 NJDOT Roadway construction Details (English Units) 2001; CD-612-1 (SHEET NO. 43)
71 http://www.galvanizeit.org/aga/about-hot-dip-galvanizing/what-is-hot-dip-galvanizing/the-hdg-coating/zinc-coating/#inline
72 NJDOT Roadway construction Details (English Units) 2001; CD-612-2 (SHEET NO. 44)
73 NJDOT Roadway construction Details (English Units) 2001; CD-612-12 (SHEET NO. 54)

Section 609– Rub Rail – Feet

The material volumes are estimated using an NJDOT diagram.[74] Powder-coated rub-rail is assumed to have the same emission factors as rub rail.

Section 609– Beam guide rail anchorages, block-outs and terminals – Units

The material volumes are estimated using an NJDOT diagram.[75]For anchorages, we include only the rail element and not the cables or the foundation. All guide rail terminals (irrespective of their type) are assumed to consist of one beam guide rail anchorage and 41 ft of beam guide rail element. The stamped steel requirement for block-outs was obtained from a drawing of the NYSDOT.[76] Guide rail posts are assumed to be of the same dimensions, irrespective of the dimensions specified in the item.

Section 653– Gas Mains – Feet

The thickness of the mains is calculated using a "thickness calculator" prepared by a manufacturer of Gas Mains.[77] Gas Mains are assumed to be made exclusively of steel.

74 NJDOT Roadway construction Details (English Units) 2001; CD-612-3 (SHEET NO. 45)
75 NJDOT Roadway construction Details (English Units) 2001; CD-612-5 (SHEET NO. 47)
76 https://www.nysdot.gov/main/business-center/engineering/cadd-info/bridge-details-sheets-repostitory-usc/BD-RC4E.pdf
77 http://www.advancepipeliner.com/Resources/Calculators/ASMEWallThickness%201.01.php

APPENDIX G. DATA AND ASSUMPTIONS FOR RAIL CAPITAL PROJECTS[78]

This section describes the process and assumptions made in estimating lifecycle greenhouse emissions for components of a rail system including track, catenary systems, tunnels, bridges, stations, parking facilities, and rolling stock. We first make an inventory of material and energy inputs of these components identifying the materials and quantifying them by weight and by volume in the case of timber ties. The next step is to identify valid emission factors by unit weight or volume. The component emission factors are summarized as the product of weight or volume per unit, and emission factors by weight or volume. These emission factors include upstream and direct emissions for carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Our assumptions do not include all components of downstream emissions from materials disposal and recycling.

Material inputs were taken from a variety of sources including American Railway Engineering and Maintenance-of-Way Association AREMA literature and vendors' specifications for track. A European source (Network Rail) estimates catenary wire systems, tunnels, bridges, and rolling stock. Their estimation for passenger stations is not usable because it is on a per unit distance basis that is not generalizable to the United States. In addition, the estimate for energy use for passenger stations is based only on concrete and brick. However, they present reasonably valid and usable approximations for copper, wood, and brick, by weight. A doctoral dissertation *Life-cycle Environmental Inventory of Passenger Transportation in the United States* (Chester 2008) was consulted to address various gaps. From this monograph we extract light rail assumptions for track, and average specifications for heavy rail, commuter rail and light rail stations, and specifications for parking facilities including parking lots and parking garages. The rail portion of Chester is based on five rail systems including the Bay Area Rapid Transit system (BART), the Caltrain commuter line, The San Francisco Municipal Transportation Authority's Muni line, the Boston Green Line, and the design specifications for the California High Speed Rail (CAHSR) system.

Material emissions factors were taken from a variety of sources with somewhat divergent methodologies. Our method for accounting for greenhouse gas (GHG) emissions from material inputs to capital projects is to establish the energy consumption and fugitive emissions of those materials usually by weight, although it is also possible to do this by volume. This is done for every stage of the life of the material including extraction, transportation, refining and manufacturing, delivery, use or consumption, and disposal. GHG emissions from the use or disposal stage is referred to as direct emissions while everything before or after that stage is referred to as indirect emissions (Climate Registry 2008, Greenhalgh et al. 2005, Raganathan et al. 2009). Indirect emissions include upstream emissions, i.e. those emissions prior to consumption and downstream emissions, i.e. those associated with disposal or recycling. Electricity from the grid is generally considered indirect emissions because its production is outside of the consumer's control, hence consumers are not directly responsible for the emissions.

[78] The work for this portion of the project was partially funded by TCRP H41, "Assessing and Comparing Environmental Performance of Major Transit Investments".

Substantial effort was made to support high per unit weight emission factors for the copper used primarily for overhead catenary wire. It is estimated that for electrified rail systems 138 metric tons of copper are present for every route-kilometer (Network Rail). The steel in rails, the rail bed, and overhead structures and wires is estimated at 821 metric tons. The copper included in the combined rail and catenary systems amounts to 16.8% of the steel by weight. This is a substantial fraction of the total materials used in an electrical rail system, and thus must be accounted for in an emissions analysis.

The Components of Track

As described in AREMA's *Practical Guide to Railway Engineering* (Riley 2003), track consists of two parallel steel rails that sit on a supporting system that must restrict their movement under the heavy loads of trains of different types. Two rails are kept at a fixed distance from each other by ties that may either be precast pre-stressed reinforced concrete or pressure treated lumber. Concrete and timber ties are connected to rail with different hardware, which is addressed below. Rail segments are spliced with two steel joint bars that are bolted on either side of rail ends. Continuous rolling has increased maximum rail lengths to 1,600 feet, roughly 20 to 40 times what was possible previously. As a result the use of joint bars is diminished but not eliminated. Ballast on top of a stable base and subbase provide a medium for stabilizing track in relation to the ground. Rail anchors are attached to ties and held in place by ballast in areas subject to longitudinal motion because of changing temperature, grade, and because of traffic patterns or unusually high frequency of brake applications (Riley 2003).

This section presents the material inputs of the components of commonly used track sizes and a volumetric or weight-based assessment of the material inputs of a mile of track of 100 pounds per yard. We have gathered data for track of a variety of sizes but since the Denver case and the rail systems covered in Chester (Chester 2008) are based on 100 pound track it is convenient to use this size for illustrative purposes in this methodology.

<u>Rail</u>

Track is steel rolled in an inverse "T" shape with a massive rounded area on the end of the stem (Riley 2003). The bar of the inverted T shape provides stability while the more massive stem accommodates steel wheels of locomotives and rolling stock. A thinner section between the base and the running surface is called the web. Rail size is determined by its mass stated in terms of pounds per yard (lbs/yd) in the United States. Medium tonnage track is suitable for non-light rail transit purposes (Riley 2003). This track usually has a 5.5 inch base section and is rated 115 or 119 lbs/yd. Heavy tonnage track usually has a 6 inch base section and is rated 132, 133, 136, 140 and 141 lbs/yd. Actual weights per yard differ slightly from the nominal designations (AREMA 2000b). Light tonnage track, used for many light rail transit purposes are usually either 90 or 100 lbs/yd. Other rail sizes are discussed in the literature (Riley 2003) but will not be incorporated because their use is either rare or they are obsolete. New rail comes in 39 foot or 80 foot lengths, which may be welded together in lengths up to 1,600 ft (0.30303 miles).

To estimate the GHG emissions from rail alone, this model uses the assumptions from the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model (Argonne National Laboratory 2009) for rolled steel GHG emissions grams per ton and the calculated mass of the rail in tons using the following formula to determine mass:

$$Qty_{Steelrail} = Size * 2 * 1760 / 2000$$

Where $Qty_{Steelrail}$ is the mass of steel in the rail; Size is the track size in lbs/yd; 2 is the number of tracks; 1760 is the number of yards per mile; and 2000 is the number of pounds per ton. For example a mile of 100 lbs/yd track would weigh 100 * 2 * 1760 /2000 = 176 tons from the steel in the rails alone.

Ties

Track ties are made of pressure treated timber, pre-stressed precast concrete, steel, or alternative materials (Riley 2003). Ties made of steel and alternative materials are not in wide use and will not be included in this model. Based on Chester (Chester 2008) regional lines are assumed to use concrete ties as specified above and light-rail transit lines are assumed to use timber ties. BART, Caltrain, and CAHSR are heavy, commuter, and inter-city rail respectively, and use concrete ties with a volume of six cubic feet and are spaced every 24 inches from center to center. The Muni line and the Boston Green Line are both light-rail systems and use timber ties.[79]

Timber Ties

Timber ties may be hardwood or softwood. Softwood ties are more resistant to rot but are less sturdy than hardwood ties and are preferred for bridges over hardwood ties. Hardwood ties are preferred for most other types of track. Hardwood ties represent 92% of timber ties while softwood ties represent 8% (Smith, Bolin 2010). Commonly used timber tie sizes are 7 * 9 * 102 inches and 7 * 9 * 108 inches or 3.719 cubic feet and 3.938 cubic feet, respectively (Riley 2003).

Concrete Ties

An online concrete tie catalog[80] was reviewed and showed that concrete ties suitable for transit hold 100, 115, and 136 lbs/yd track and typically weigh 610 lbs per tie. Ties considered suitable for transit weighing 595 lbs and 700 lbs are considered outliers. It is assumed that all concrete ties modeled weigh 610 lbs. Concrete ties are precast and their composition is outside of the control of contractors. We assume that they are an

[79] Not all light-rail systems use timber ties; more modern systems likely use concrete ties.
[80] See http://www.lbfoster.com/cxt_ties/CXT_Concrete_Tie_Catalog.pdf.

architectural precast concrete with a mix of 16.4255% cement, 6.5532% water, and 77.0213% coarse and fine aggregates (Marceau, Nisbet & VanGeem 2007).

Tie Spacing

We assume that medium and light tonnage track (100 – 119 lbs/yd) has 22 ties per 39 feet and that heavy tonnage (132 lbs/yd or greater) has 24 ties per 39 feet (Riley 2003) or 21.25 inches and 19.5 inches respectively from tie center to tie center. This gives 2981.647 ties per mile of medium weight track and 3249.231 ties per mile of heavy weight track. GHG emissions for ties are the results of these constants and the per tie emission factors stated above.

Tie Hardware

Rail is usually attached to timber ties with a tie plate and spike system. Tie plates and spikes are made of stamped steel. According to one vendor[81] the tie plates for medium weight track weigh between 13.45 and 22.90 lbs. Tie plates for heavy weight track weigh between 14.94 and 23.32 lbs. The weight differences are quite small and the overlap of the two ranges is extensive. However 7.75x14 inch sizes are the most commonly used timber tie plates (Riley 2003). We assume their use for medium track and a slightly larger 7.75x14.75 inch tie plate for heavy track. Based on these assumptions individual tie plates weigh 22.90 lbs and 23.32 lbs for medium tonnage and heavy tonnage track, respectively.

Standard spikes come 244 to the 200 lb barrel or 13.115 oz each.[82] Typically tie plates have four holes and are spiked twice at opposite ends, i.e. inside right and outside left or outside right and inside left. The exception is at joint bars, in which case four spikes are driven. This applies typically to two ties under each rail splice. We assume two tie plates and four spikes for every timber tie. This means that the hardware for a timber tie consists of 49.079 lbs or 49.919 lbs of stamped steel for medium or heavy track respectively. In addition four spikes are used at every rail splice in both of two adjoining ties with a total additional stamped steel content of 6.5575 lbs.

Concrete ties have additional fastening surfaces embedded within them. These can be roughly accounted for by increasing the steel content beyond an allowance for reinforcing steel by no more than 50 lbs. According to a vendor[83] the hardware for concrete ties includes C Plate and C Clip systems, e 2063 clips, and J clips. These systems are applied to both sides of the rail and consist of stamped steel. The C plate and clip system weighs 3.1 lbs. The e and J clips weigh 1.6 lbs and 1.7 lbs, respectively. In addition a cushioning material, probably plastic is placed under the rail and insulation is added to rail that uses electricity as power (Riley 2003). Neither the cushioning material nor the insulation are addressed here, due to lack of sufficient information on their composition.

[81] See http://www.harmersteel.com/wp-content/catalog/cache/harmer-steel-catalog-2007/48.pdf.
[82] See http://www.sizes.com/tools/spikes_railroad.htm.
[83] See http://www.pandrolcanada.ca/literature/JointBarDateSheet.pdf.

Joint Bars

Rail joints connect two lengths of track. The splice is accomplished by bolting the track ends to stamped steel bars (Riley 2003). Joints are classified as standard, compromise, or insulated. Standard joint bars connect two rails of the same size. These may have four holes and measure 24 inches or six holes and measure 36 inches. Compromise joint bars are used to connect rails of different sizes. They have two holes and measure 24 inches. Insulated joints include insulating material that prevents current from passing between rail sections and is sold in the same dimensions as standard joint bars. Because we do not account for insulating material and to avoid making underestimates, it is assumed that all joint bars are 36 inch standard joint bars.

One vendor[84] sells joint bars weighing 80.3 lbs each for 100 lb/yd rail, 99.8 lbs for 155 lb/yd rail, and 106.5 lbs for rail sized 132 lb/yd or heavier. Medium track joint bars have 1-3/16 inch holes. Heavy track joint bars have 1-5/16 inch holes. Joint bar holes are pre-punched at the factory while track end holes are drilled on site. Joints are secured by bolts, square nuts, and spring washers. Based on one vendor,[85] bolts for medium track and heavy track are 6 inches and 5.75 inches in length respectively. Diameter is assumed to be the same as the holes. The weight of a bolt is calculated in cubic feet[86] using 490 lbs per cubic foot as the density, which is used in this model. Bolts for medium and heavy track weigh 0.5998 lbs and 0.7022, respectively. These estimates do not account for the greater size of the bolt heads. As pictured on a vendor website the bolt head is a half sphere with a radius that measures about 0.7 times the apparent diameter, based on visual inspection. No square nut specifications were found. A nut pictured on a vendor website[87] had sides measuring 1.4 times and thickness measuring 0.8 times the diameter of the bolt. If we assume these relationships to be constant, the weight [88] of individual nuts is 0.4462 lbs for medium track and 0.6025 lbs for heavy track. Assuming that washers have an outside diameter of 1.4 times the inner diameter as pictured, and arbitrarily assuming that the thickness is a constant 1/8 inch[89] washers weigh 0.0377 lbs and 0.0460 lbs for medium and heavy track, respectively.

Ballast

Ballast is used to stabilize track, preventing lateral, longitudinal and vertical movement (Riley 2003). Ballast should be hard, heavy, and well drained. Usually it consists of crushed stone, although recycled materials including open hearth and furnace slag are also used. Failure occurs as a result of settling, abrasion, and deposition of dirt and mud. Ballast is laid to a depth of 18 to 24 inches on a compacted subbase. The bed should extend at least 12 inches beyond the ties in both directions. We assume that a ballast bed is two feet high extending one foot beyond the ties and sloping roughly 45^o so that the base extends two feet horizontally beyond the top of the ballast bed. The

[84] See http://www.centralrailsupply.com/bars.htm.
[85] See http://www.crownrail.com/crownbolts.htm.
[86] $W_{bolt} = L \times 0.25\, d^2 \times 490 / 1728$
[87] See http://www.crownrail.com/crownbolts.htm.
[88] $W_{nut} = [(1.4d)^2 - \Pi(0.5d)^2] \times 0.8d \times 490 / 1728$
[89] $W_{washer} = \Pi\, [(0.5*1.4d)^2 - (0.5d)^2] \times 0.125 \times 490 / 1728$

density assumption for aggregate is 100 lbs per cubic foot. A linear foot of track supported by standard nine foot ties would need at a minimum to be supported by 22.4 cubic feet of ballast weighing 2,240 lbs.[90] A linear mile of track would need ballast weighing 118,272 lbs. These assumptions are not inconsistent with AREMA standards (AREMA 2000a). Emission factors for ballast are assumed to be the same as for aggregate.[91]

However our estimate of 22.4 cubic feet per linear foot is based on the AREMA minimum. If at a minimum we assume double track the minimum volume per linear foot is 44.8 cubic feet. Based on Chester (Chester 2008) we estimate roadbed ballast at 71 cubic feet per linear foot for two way heavy and commuter rail track and 50 cubic feet per linear foot for two way light-rail track. For single track we halve these estimates so that ballast is 35.5 cubic feet per linear foot for heavy and commuter rail track and 25 cubic feet per linear foot for light-rail track.

Anchors and Other Miscellaneous Items

The materials covered so far are the components that recur at regular intervals. As such they embody the largest share of GHG emissions and these emissions are readily estimated with some minor omissions. Other items such as rail anchors, switches, derails, gauge rods, sliding joints, miter rails and others mentioned in Riley (Riley 2003) are not included because of the difficulty of obtaining their composition and consequent emissions factors, and the diminishing benefit on their inclusion in any estimates. The vast majority of material-based GHG emissions are almost certainly captured in the procedure just outlined.

Assumptions for an Average Mile of Track

We attempt here to illustrate our estimate of the combined material inputs of a mile of track. In Table 34 we assume continuous 100 lb track with quarter mile (1320 ft) lengths. Light-rail transit is assumed to have timber ties, appropriate hardware and ballast at the rate of 25 cubic feet per linear foot of track. Heavy and commuter rail is assumed to have reinforced concrete ties, appropriate hardware, and ballast at the rate of 35.5 cubic feet per linear foot of track. Based on Table 34, a mile of 100 lb rail includes 202.50 tons of steel, 788.13 tons of concrete, and 9,372.00 tons of ballast. A mile of heavy or commuter rail includes 249.63 tons of steel, 73.17 tons of creosote treated timber and 6,600 tons of ballast. These figures are based on track that is 100% on the grade.

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[90] $W_{ballast} = [l_{ties} + 2 + 2(0.5 * h)] * h * l_{track} * 100$

[91] This work is cited in VTC report Review of Energy and Material inputs to Transportation Capital Construction Projects to NJDOT 7/30/2010.

Table 34. Inputs for One Mile of 100 lb Track with Continuous Rail.

	Material	Value	unit	tons / rt. mi.
Track	Steel	5,280.00	linear ft	176.00
timber ties (Light-rail transit)	creosote treated timber (9 ft.)	11,741.73	cubic ft	358.35
timber tie hardware, tie plate and spikes	stamped steel	2,981.65	pair of sets	73.17
Concrete ties (Heavy/commuter rail)	Concrete	10,620.84	cubic ft	788.13
	reinforcing steel	57.62	cubic ft	17.07
concrete tie hardware, J clips	stamped steel	5,280.00	pair	8.98
Joint bars, stamped steel, 1320 ft rail lengths	stamped steel	8.00	pair	0.46
Ballast, 1/2 * 50 cubic ft per linear ft (Light-rail transit)	crushed rock	13,200,000.00	cubic ft	6,600.00
Ballast, 1/2 * 71 cubic ft per linear ft (Heavy/commuter rail)	crushed rock	18,744,000.00	cubic ft	9,372.00

Grade

Based on Chester (Chester 2008) we make the following assumptions for additional structures for track that is above and below grade. Two types of elevated track are discussed, aerial track and retained fill tracks. Aerial track is supported by concrete or structural steel supports. For elevated track, based on BART we assume 2,400 cubic feet of reinforced concrete supports and footers spaced every 63.316 feet for concrete supports and 2,250 lbs of rolled steel per linear foot for structural steel supports based on the Green Line case. For retained fill tracks twelve foot reinforced concrete retaining walls, presumably with some sort of footer, support 54 cubic feet of ballast per foot of track. For CAHSR Chester’s estimate for a cross section of the retaining wall was 214 cubic feet per linear foot. The default assumptions for above grade track are 214 cubic feet per linear foot of reinforced concrete and 54 cubic feet per linear foot of track. Chester (Chester 2008) does not address excavation of below grade track or shoring up of the sides. We assume that greenhouse gas emissions from excavation and stabilization of excavated areas are one half the GHG emissions resulting from electricity consumption of tunneling and one half of the GHG emissions embodied in the concrete, soil and steel from stabilizing tunnels. These tunnel assumptions are taken from the Network Rail report (Network Rail).

Other Components of Rail Systems

Our assumptions for the other components of rail systems differ from our track assumptions in that we use abstract assumptions based on inventories that claim to approximate global averages (Network Rail , Chester 2008). As a result we use constant values to address each component. This approach suits the type of data that is likely available from transit agencies.[92] Rail stations are attributed status as either platforms or hubs. The attributes of parking facilities include parking garages or surface parking lots, and the number of parking spaces in each. Rolling stock is counted as vehicles and not described in any way. The system is described as electrified so we assume an overhead catenary system. No tunnels or bridges are included. As a result it is useful to use a bottom up approach in which we address an average mile of standard 100 lb track from its components (as done above in Table 34). We cannot vouch for the averages assumed in the other parts of the rail system because we don't know the variation that might exist in the other subsystems.

The Network Rail study (Network Rail) provides estimates of energy consumption for overhead catenary wire systems, bridges, tunnels, and rolling stock. There are significant limitations with our use of this study. The Network rail study is from the United Kingdom and should be used with care as a basis for generalization. We should be aware that there may be differences in construction practices, the overhead wire systems, and passenger station design and construction. The service life expectancy of any structure is likely to be affected by climate. There is enough variability of climate among places in the United States that have transportation systems that the validity of a single set of life expectancy estimates for the United States also becomes questionable. Life expectancy estimates based on the United Kingdom are not used. We chose to use this study because written documentation for US rail systems did not provide a basis for documenting material inputs. A doctoral dissertation by Mikhail Chester (Chester 2008) provides estimates for a basis for estimating the material inputs of passenger stations and parking facilities.

The material inputs taken from the Network Rail study (Network Rail) are presented in metric tons (tonnes) per route-kilometer, which we convert into short tons of material per route-mile. The Network Rail report assumes that 10% of the total length is made up of tunnels and 1% is made up of bridges. Units of distance of track are converted by dividing by these proportions.

- Catenary systems include 887 tons per mile of steel, 124.18 tons per mile of aluminum, and 244.81 tons of copper.
- Tunnels account for 478,979 tons per route mile of tunnel, as well as 78,056 tons per mile of concrete, 3,725.40 tons per mile of steel, and 19,521 MWh per mile of electricity.
- Bridges account for 157,886 tons of concrete per mile and 8,692.59 tons of steel per mile of bridge.

[92] The Denver case study for TCRP H41 lists total track length and apportions it among at grade, above grade and below grade track.

- The per vehicle material inputs of rolling stock are 43.53 tons of steel, 20.28 tons of aluminum, 1.93 tons of copper, 1.32 tons of glass, 1.01 lifetime tons of lubricating oil, 2.33 tons of wood, and 5.52 tons of rubber and plastic.

Passenger Station Assumptions

The Network Rail report (Network Rail) addresses passenger stations as a per route kilometer input. We are hesitant to generalize to the United States based on their estimates of materials consumption for passenger station construction. Their estimate includes twice the mass of bricks as concrete. Chester (Chester 2008) states that concrete is the primary material input for emissions and describes station designs; which bears this out. Based on his discussion, we assume that the BART system is typical of heavy rail passenger stations. Stations in the BART system include aerial platforms, surface stations, and underground stations. We assume that the passenger platforms of the Caltrain system is typical of commuter rail. The Caltrain system consists of concrete platforms over a subbase that we assume to be aggregate which we treat as equivalent to ballast. We assume that passenger stations of the Muni line are typical of light rail.

For our analysis it is assumed that unless otherwise stated, stations are at the surface level. For light rail, we assume a two type typology of stations based on size. There are large primary stations, which have more or less extensive parking facilities and may offer an opportunity to transfer to other modes of transportation. There are also smaller platform stations with less parking opportunities, and much simpler construction. This assumption is made based on one case, for Denver, which we received through the TCRP H-41 project. The case includes four primary stations and eight secondary ones. We do not have estimates for platform stations for heavy rail or large stations for commuter rail. Table 35 shows the material inputs for passenger stations. We assume that all concrete is reinforced with a default concrete to steel ratio of 85.39 lbs of steel per cubic yard of concrete based on NJDOT engineering drawings for pipe.[93] Smaller stations are assumed to be at grade and of the platform variety.

Parking Facilities

Off street parking is of two types, parking lots and parking garages (Chester 2008). We use Chester’s assumption that a parking space has 300 square feet of surface area and that an additional 30 square feet of surface are per parking space for access. Parking lots include a six-inch subbase, which is assumed to be aggregate, and two three-inch courses of asphalt concrete. Chester assumes that asphalt used in parking lots is 90% hot mix asphalt, 3% cutback, and 7% warm mix asphalt. We assume 100% hot mix asphalt. Because our data is at a high level of abstraction we are not able to model a user designed mix of asphalt pavements that would include warm mix or cutback asphalts.

[93] See http://flh.fhwa.dot.gov/resources/pse/standard/st60101.pdf.

Table 35. Material Inputs of Rail Passenger Stations.

Heavy Rail	BART	Total volume ft^3	Concrete volume ft^3	S tons	Steel volume ft^3	S tons
	Aerial	520,000	517,194	38,789.56	2,806	822.27
	Surface	440,000	437,626	32,821.93	2,374	695.77
	Underground	770,000	765,845	57,438.38	4,155	1,217.60
Commuter Rail	Caltrain	Total volume ft^3	Concrete volume ft^3	S tons	Steel volume ft^3	S tons
	Platforms	27,000	17,903	1,342.72	97	28.46
			Subbase volume ft^3	S tons		
			9,000	450.00		
Light Rail	Muni line	Total volume ft^3	Concrete volume ft^3	S tons	Steel volume ft^3	S tons
	Platforms	9,000	8,951	671.36	49	14.23
	Stations	310,000	308,327	23,124.54	1,673	490.20

Source: (Chester 2008)

Table 36. Material Inputs for One Parking Space of Garage Parking.

	4,400 m^2 building[1]		per parking space	
Steel structure building[1]	Kg	Lbs	Lbs	ft^3
Concrete	3,064,752.00	6,756,627.10	47,249.14	314.99
steel reinforcing bars	151,225.00	333,394.33	2,331.43	
structural steel	207,346.00	457,120.06	3,196.64	
Parking slab – Single parking space			Lbs	ft^3
Concrete slab 330 ft^2			49,232.90	328.22
steel reinforcing bars			1,043.66	1.78
Total Material inputs per space			Lbs	ft^3
Total			96,482.04	643.21
Concrete			6,571.73	
Steel			49,232.90	328.22

Source:[1] Taken from Guggemos and Horvath 2005.

Parking garages are complicated by the addition of a structure. Chester (Chester 2008) models parking garages as steel structures based on Guggemos and Horvath (Guggemos, Horvath 2005). The latter study compares environmental impacts between steel and concrete framed buildings. We model parking garages as a skeletal steel framed building with a reinforced concrete slab and nothing else. Guggemos and Horvath postulate two buildings, one is concrete framed and the other is steel framed. Both buildings have an area of 4,400 cubic meters spread over five stories. From Guggemos and Horvath we take the structural steel and reinforced concrete implied in a steel framed building and add a 12 inch reinforced concrete slab that has 330 square feet for every parking space. A 500 space lot has 165,000 square feet of area. Table 36 shows the calculations of material inputs per parking space in a parking garage. We begin with the material inputs based on Guggemos and Horvath's 4,400 square meter steel framed building. Metric weight and area units are converted to US standard. The area of the hypothetical building would accommodate roughly 143 parking spaces. The structural material inputs are divided by 143 to obtain the structural material inputs per parking space. Concrete is converted to cubic feet assuming density of 150 lbs per cubic foot. We then add 330 square feet of 12 inch reinforced concrete slab using a default ratio of steel to concrete to obtain the total estimate.

Estimation of Material and Electricity Emission Factors

Previous work reproduced here, has established greenhouse gas (GHG) emission factors for steel, aluminum, cement and concrete, asphalt concrete and coating materials, aggregate, process fuels solvents and lubricants, limited plastics, and equipment inputs. These emission factors include upstream and direct emissions for CO_2, CH_4, and N_2O. Emission factors for materials are stated as grams of GHG per unit weight of material supplied. New emission factors are presented for brick, copper, wood and pressure treated wood, as these are commonly used in rail systems.

We attempt to account for all GHG emissions that occur during the lifetime of the material from extraction to disposal. Process fuels are used in the production of the materials. We account for all stages of process fuels including extraction, transportation, refining, delivery, and combustion. Process emissions such as calcination of lime in cement making are accounted for as are fugitive emissions from such things as fuel or solvent evaporation or HFC leakage from cooling systems. Our model does substantially less well at accounting for downstream emissions.

Emission factors for specific process fuels are presented in Table 37 which is based primarily on the GREET Model developed by Argonne National Laboratory (Argonne National Laboratory 2009, Argonne National Laboratory 2007). Emission factors are presented as grams per million Btu (MMBtu). The GREET Model allows for the conversion of emission factors for fuels from an energy content basis a weight or volume basis and vice versa using lower heating values (LHV) or higher heating values

(HHV). Life cycle analyses (LCA) were sought that provide the provide process fuel information.

Table 37. GHG Emissions of Process Fuels in g/MMBtu.

Upstream Emissions of Process Fuels (g/MMBtu)							
	Coal[1]	Natural Gas[1]	Conv. Gasoline[1]	Distillate Fuel Oil[1]	Residual Oil[3]	LPG[1]	Petroleum Coke[2]
CO_2	1,648	12,693	16,812	15,487	7,326	9,195	22,427
CH_4	119.20	199.10	108.74	104.52	37.23	115.28	127.68
N_2O	0.0313	0.2610	1.1400	0.2483	0.1179	0.1583	0.3866
Combustion Emissions of Process Fuels (g/MMBtu)							
	Coal[1]	Natural Gas[1]	Conv. Gasoline[1]	Distillate Fuel Oil[1]	Residual Oil[1]	LPG[1] (Propane)	Petroleum Coke[1]
CO_2	108,363	59,379	75,645	78,169	85,045	68,024	104,716
CH_4	4.00	1.10	5.19	0.18	3.24	1.08	4.00
N_2O	1.0000	1.1000	2.4000	0.3900	0.3600	4.8600	1.0000
Upstream and Combustion Emissions of Process Fuels Combined (g/MMBtu)							
	Coal[2]	Natural Gas[2]	Conv. Gasoline[2]	Distillate Fuel Oil[2]	Residual Oil[2]	LPG[2] (Propane)	Petroleum Coke[2]
CO_2	110,012	72,072	92,457	93,656	92,370	77,218	127,143
CH_4	123.20	200.20	114	104.70	40.47	116.36	131.68
N_2O	1.0313	1.3610	3.5400	0.6383	0.4779	5.0183	1.3866

Sources:
1. GREET Fuel Cycle Model 1.8c (Argonne National Laboratory 2009).
2. Our Calculations for Crude Extraction and Refining Share - energy basis from Fuel Cycle model and Summation of Combined Emissions.

Table 38 shows the materials identified as components of a rail system with emission factors expressed as tonnes of GHG per short ton of material. The basis for these emission factors are documented below. Some materials, notably aluminum, glass, lubricating oil, plastic and steel were taken directly from the GREET Vehicle Cycle Model (Argonne National Laboratory 2007). These emissions factors were expressed as grams of GHG per short ton in the GREET Model. The GREET Model provides combined emission factors for steel but provides separate emission factors for virgin and recycled aluminum. Emissions of GHG from electricity are expressed as tonnes per MWh using default assumptions from the GREET Fuel Cycle Model (Argonne National Laboratory 2009) assuming the default mix of process fuels used in the United States. Emissions based on the mix of process fuels used in the United States are higher than those based on the Northeastern US mix. The United States mix was chosen because it better represents US transit systems.

Table 38. Material and Electricity Emission Factors

Material	CO_2 tonnes / short ton mat'l	CH_4 tonnes / short ton mat'l	N_2O tonnes / short ton mat'l
Aluminum[1]	5.575	1.063E-02	7.627E-05
Asphalt[10]	0.024	5.819E-05	3.876E-07
Ballast[9]	7.583E-03	5.680E-06	1.708E-05
Bricks[4]	0.618	5.539E-04	9.077E-06
Concrete[7,8]	0.224	2.022E-04	1.731E-05
Copper[6]	17.200	9.478E-03	2.254E-04
Glass[1]	1.242	6.601E-03	1.879E-05
Lubricating Oil[1]	3.929	4.040E-03	2.404E-05
Plastic[1]	3.258	5.272E-03	3.884E-05
Soil[5]	2.426E-03	2.712E-06	1.7E-08
Steel[1]	4.188	4.002E-03	2.203E-05
Timber Ties	-1.173	1.723E-02	2.501E-04
Wood (Plywood)[3]	0.202	4.644E-04	1.642E-03
Electricity (MWh)[2]	0.705	1.300E-05	9.100E-06

1. GREET Vehicle Cycle Model (Argonne National Laboratory 2009).
2. GREET Fuel Cycle Model (Argonne National Laboratory 2007).
3. Puettmann Wilson 2005 (Puettmann, Wilson 2005).
4. (EPA 2003).
5. (EPA 2003) Transportation emissions only.
6. (EPA 2005g).
7. Process fuels (Choate 2003).
8. Concrete precast mix specifications (Marceau, Nisbet & VanGeem 2007).
9. (BCS 2002a).
10. Estimates of average mix and heating requirements (Hunt 2010, Zapata, Gambatese 2005)

Brick and Soil

Emission factors for brick (EPA 2003) were estimated based on a life-cycle analysis paper published on the EPA website. This paper estimated combustion and *pre-combustion* energy per ton of brick produced in MMBtu. Emission factors for brick were estimated from the combustion energy numbers only. Upstream emissions were attributed from the factors listed in Table 37 to ensure consistency with the GREET Model. In descending order brick production uses natural gas (2.6724 MMBtu per short ton) electricity (2.0087 MMBtu per short ton) and diesel (0.1072 MMBtu per short ton). These figures include process and transportation energy. Emissions from soil as topsoil and clean fill are assumed to be identical to brick transportation emissions. This estimate does not account for the equipment used to extract, load and unload soil. However, soil emissions are not considered in this model. They are rather used to derive equipment and transportation factors input.

<u>Copper and Aluminum</u>

A similar process was used to estimate emissions from production and transportation of virgin and recycled copper wire. Embodied energy was estimated from a copper LCA paper (EPA 2005g). That paper includes estimates for all fuel types of energy inputs in MMBtu and GWP expressed as metric tons carbon equivalent (MTCE) per MMBtu for combustion CO_2 and fugitive CH_4. MTCE may be converted to GWP by dividing by the carbon fraction of CO_2 (12/44). Electricity is the largest source of energy consumption used in virgin (61.2%) and recycled (53.2%) copper wire production followed by natural gas (virgin 36.0%, recycled 39.9%). Our calculations of emissions based on energy inputs were consistently higher than those in the EPA LCA paper because the latter used a source that did not account for upstream emissions from process fuels. Copper is a convoluted, energy-intensive, and specifically electricity-intensive process for both virgin and recycled copper wire. Electricity use drastically increases GHG emissions because it uses process fuels, which adds a step to energy production with a necessary loss of efficiency. Although the model's estimated GHG emission factors are quite high they are not inconsistent with estimates from the GREET model.

Emission factors for aluminum are taken directly from the GREET Vehicle Cycle Model (Argonne National Laboratory 2007). As with copper above, the GREET Model estimates GHG emissions for virgin and recycled aluminum. The United States Geological Survey compiles primary and secondary production numbers for many materials including aluminum (Buckingham, Plunkert & Bray 2010) and copper (Edelstein 2011). Recycled metals accounted for 61.1% of aluminum production in 2009 and 16.3% of copper production in 2010. These proportions were used to weight the virgin and recycled emission factors for both metals. Steel is weighted within the GREET Vehicle Cycle Model.

<u>Wood as Plywood</u>

Emission factors for wood are taken from Puettmann and Wilson (Puettmann, Wilson 2005). They provide energy input from process fuels for plywood and other wood products that do not lend themselves to estimation of upstream GHG emissions as done in the GREET model. Emission factors were based on the authors' estimation of GHG emissions despite the fact that those estimates do not include upstream emissions from fossil fuels. For our model this was corrected by adding upstream emissions based on the reported energy from fossil fuels based on the GREET model--roughly half of the energy consumed in plywood production--to the estimates. We added emissions from process fuels including coal and natural gas as upstream emissions. Upstream emissions for crude oil were substituted for residual oil, which results in a slight overestimation. This overestimation is offset by omitted upstream emissions from uranium, hydropower, and a quite small amount of electricity. Any overestimation of

GHG emissions is exacerbated by omission of a credit for an upstream biomass GWP sink. Plywood was chosen as the basis for wood emission factor for stations.

Concrete

Emission factors for concrete were established from Choate (Choate 2003). Table 39 is based on the fuel inputs reported in that paper using emission factors for process fuels reported above. It shows direct and upstream emissions of GHGs assuming a wet concrete mixture of 12% cement, 82% aggregate, and 6% water. This method allows for adjustment to differences in mix specifications. The concrete industry's LCA analysis (Marceau, Nisbet & VanGeem 2007) does not allow these adjustments.
The adjustment process is straightforward with a known mix. All emissions from quarrying are divided by 82. Those from cement are divided by 12. Concrete manufacturing emissions are not adjusted. The result is a series of factors that will allow a user to estimate the GHG emissions of any mix specified in percentages. We assume that concrete is a typical precast made from a mix that is 16.41% cement, 77.02% aggregate, and 6.57% water. Emissions from aggregate are taken from an analysis of fuel consumption from limestone and crushed rock extraction (BCS 2002a). Greenhouse gas emissions are attributed based on the emission factors shown in Table 39. We assume that emission factors are the same for limestone, aggregate, and ballast rock.

Asphalt

This section is an abbreviated version of work we did previously. We assume an average mix for hot mix asphalt of 5% binder and 95% aggregate with moisture content of 4% in the aggregate (Zapata, Gambatese 2005). Upstream emissions of aggregate are taken from BCS (BCS 2002a). The upstream emissions from binder are similar to those from residual oil. We correct on an energy basis using LHV and refinery efficiencies based on Wang (Wang 2008). We estimate the heating requirement based on the specific heat of binder, aggregate, water and steam, and the latent heat required to convert water into steam (Hunt 2010). We then correct for imperfect heating efficiency using an average energy consumption estimate from Zapata et al. (VTC 2010).

Creosote Treated Timber

The life cycle of timber railroad ties includes four stages including production of green cut timbers, pressure treatment of timbers with creosote, active life and disposal. Smith and Bolin (Smith, Bolin 2010) address all four of these stages however we amend some of their assumptions to make our approach to timber ties consistent with other emission factors presented here. First, Smith and Bolin assume that the green timber contributes no GHG emissions because the carbon in it results from recent photosynthesis and not fossilized hydrocarbons. While the assumption is correct, this approach discounts emissions associated with harvesting, cutting and air drying the timber, and transportation. This error is corrected by supplementing from the life cycle analysis study of wood products, including green lumber, conducted by Puettmann & Wilson (Puettmann, Wilson 2005).

Table 39. Concrete GHG Emissions Assuming 12% Cement, 82% Aggregates, and 6% Water.

	Direct	Upstream	Direct	Upstream	Direct	Upstream
	CO_2 Production	CO_2 Production	CH_4 Production	CH_4 Production	N_2O Production	N_2O Production
	g/S ton Concrete	g/S ton Concrete	g/S ton Concrete	g/S ton Concrete	g/S ton Concrete	g/S ton Concrete
Quarrying (82%)						
cement raw materials	524	386	0.393	0.289	1.181	0.869
concrete raw materials	3,583	2,635	2.684	1.974	8.071	5.936
Cement Manufacturing (12%)						
energy consumption	62,012	3,657	2.140	81.986	0.681	0.067
kiln reactions (Calcination)	62,978					
Concrete Manufacturing (100%)						
raw material mixing	5,906	761	0.146	33.781	0.110	0.016
Transport	6,313	1,251	0.015	8.441	0.031	0.020
Total	141,316	8,690	5.377	126.471	10.074	6.908

Sources:

Table A.11 - Energy Use per Tonne Associated with U.S. Cement Manufacturing and Concrete Production from U.S. Cement (Choate 2003).
Source Table A.8 - Energy Consumed by Fuel Type in Cement Manufacturing (excluding Quarrying) (Choate 2003).
GREET Fuel Cycle Model 1.8c (Argonne National Laboratory 2009).

A green 8.5 foot timber tie measures 3.719 cubic feet or roughly 0.105 cubic meters, and weighs 252 pounds. If we assume that carbon monoxide (CO), and volatile organic compounds (VOCs) oxidize to CO_2, production of a cubic meter of green timber produces 27,579 grams of CO_2, 20 grams of CH_4, and 310 grams of N_2O (Puettmann, Wilson 2005). Production of a green 8.5 foot timber produces 2,905.158 grams of CO_2, 2.107 grams of CH_4, and 32.655 grams of N_2O. A green 9 foot timber produces 3,076.049 grams of CO_2, 2.231 grams of CH_4, and 34.576 grams of N_2O. We assume that the timber was air dried by the time it arrived at the pressure treating location. Total emissions are associated with farming, felling, and drying the timber. The wood life cycle analysis addresses energy consumption in processing wood (Smith, Bolin 2010). It does not give a credit for carbon sequestration as the GREET Model (Argonne National Laboratory 2009) does. This means the wood portion of a railroad tie should not contribute to GHG emissions so Smith and Bolin consider only emissions from the creosote.

Because Smith and Bolin do not estimate energy consumed in the pressure treating process or fugitive emissions resulting from evaporation, we cannot either. Most commercial creosote wood preservative products are diluted with solvents (IPCS 2004). As a result uncontrolled fugitive emissions may be substantial. The pressure treating process results in the loss of some of the water in the timber and addition of creosote (Smith, Bolin 2010). An 8.5 foot (102 inches) untreated tie weighs roughly 252 lbs of which 148 lbs are dry mass or 0.074 tons. The water weight of a green timber tie is 104 lbs. Coal tar creosote is a distillate of coal tar that is composed of aromatic hydrocarbons of a variety of densities, but lacking the heaviest materials found in coal tar (Agency for Toxic Substances and Disease Registry 2010)(Agency for Toxic Substances and Disease Registry 2010)(Agency for Toxic Substances and Disease Registry 2010). Coal tar is a byproduct of carbonization of coal to produce metallurgical coke or natural gas for gasification. The pressure treating process reduces the water weight of the tie to 59 lbs and adds 20 lbs of creosote to t(Agency for Toxic Substances and Disease Registry 2010)(Agency for Toxic Substances and Disease Registry 2010)he tie.

The carbon weight of the creosote is 10.637 lbs[94], so that the carbon fraction estimate of creosote is 0.818 (Smith, Bolin 2010). This is somewhat low but not unreasonable for solvent-diluted aromatic (cyclic) hydrocarbons with some minor replacement of carbon with oxygen, nitrogen, sulfur, and similar radicals found in such compounds as tar acids and bases, aromatic amines, phenolics, and nitrogen, sulfur, and oxygen heterocycles that make up 10% or slightly more of the weight of undiluted coal tar creosote (IPCS 2004). As 7 lbs of creosote are outgassed per tie, the resulting CO_2 would weigh 9,525 grams if all of the carbon is outgassed as CO_2 (Smith, Bolin 2010).

This approach has some gaps. Smith and Bolin assume that all decayed wood and lost creosote are released as VOCs, CO or CO_2 and that the non-CO_2 components quickly oxidize to CO_2 in the atmosphere (Smith, Bolin 2010). This assumption probably ignores a small amount of CH_4 and N_2O emissions from the wearing of timber ties. It also ignores scientific evidence that a significant part of commercial creosote solutions used as wood preservatives are released in rain runoff and not into the atmosphere (Tran et al. 2009). Therefore, these are minor shortcomings in our knowledge of creosote emissions. Smith and Bolin (Smith, Bolin 2010) estimate emissions for two disposal scenarios: recycling as fuel, and landfill disposal. Each tie offsets 1.4 million Btu (MMBtu) of energy from coal. It is assumed in the GREET Model (Argonne National Laboratory 2009) that combined upstream and direct emissions from burning 1.4 MMBtu of coal are 154,017 grams of CO_2, 172.480 grams of CH_4, and 1.444 grams of N_2O. These are the emissions that are saved as a result of burning used railroad ties instead of coal. Combustion of the wood in the ties is assumed to be carbon neutral since it is not fossil based. The 13 pounds of creosote remaining at the end of the service life of a railroad tie produce 17,690 grams of CO_2. Smith and Bolin assume no

[94] 39 * 12 / 44 = 10.637 where 12 / 44 is the proportion of CO_2 made up of Carbon by weight.

CH_4 or N_2O emissions from combustion of creosote, or wood. Based on our interpretation of this model, net emissions from burning used railroad ties as fuel is -136,327 grams of CO_2, -172.480 grams of CH_4, and -1.444 grams of N_2O.

Smith and Bolin (Smith, Bolin 2010) estimate CO_2 and CH_4 emissions for landfill disposal at 3,175 grams of fossil CO_2 and 2,354 grams of CH_4. These emissions are offset by 3.0 lbs or 1360.776 grams of captured natural gas, which could be used as fuel. Natural gas has a lower heating value of 983 Btu per cubic foot and a density of 22 grams per cubic foot. The fuel offset would produce 0.060802 MMBtu of heat and save 72,072 grams of CO_2 emissions, 200.20 grams of CH_4 emissions, and 1.361 grams of N_2O emissions. Smith and Bolin do not account for carbon sequestration of the wood portion of the railroad tie. They state that 77% of the ties' mass remains in the earth for an extended period. By applying this fraction to the dry weight of the wood in the used tie we obtain a result of 108.57 pounds or 49,247 grams. If we adopt a commonly used benchmark for carbon fraction of dry wood of 0.5 (Lamlon, Savidge 2006) the carbon content of the wood portion of a used tie is 24,624 grams, which would produce 90,288 grams of CO_2 sequestration. We estimate that net emissions from sending used railroad ties to the landfill are -159,185 grams of CO_2, 2,154 grams of CH_4, and -1.361 grams of N_2O. Smith and Bolin state that the purpose of their analysis is to compare differences in GHG emissions between two alternative approaches to disposal. As a result they do not intend to present a full life cycle analysis, they leave upstream emissions out of the analysis. We add upstream emissions from another source for wood and assume that as a byproduct of coal and coke production coal tar creosote has no upstream GHG emissions. This assumption neglects the upstream emissions of solvents used to cut creosote for wood preservation. Another gap is that there is no treatment of energy consumption or fugitive emissions in the pressure treating process. We assume that emissions during the service life consist only of the carbon content of fugitive emissions that are outgassed as CO_2. The CH_4 emissions from solvents are likely to be quite small and a N_2O component is likely non-existent. The large net savings with either disposal method are probably valid given the large fuel credits for coal substitution and the large credits for landfill sequestration of carbon in wood. However Smith and Bolin do not address CH_4 and N_2O emissions from combustion. Table 40 summarizes emission factors for one cubic foot of timber rail tie.

Smith and Bolin (Smith, Bolin 2010) recommend that ties be recycled as fuel at the end of their service life, which could provide an offset to other fuels. That study is biased against landfill disposal because it does not account for carbon sequestration in landfills. Carbon sequestration in landfills was our adjustment to the model. Although they cite EPA sources for their estimation of methane production in landfills, we have not looked at their work in depth. However, the methane levels they claim are quite high and bare further investigation. For our analysis we will assume that timber ties are disposed of in landfills.

Table 40. GHG Emission Factors for Creosote Pressure Treated Timber Railroad Ties

	CO_2 g/ft³	CH_4 g/ft³	N_2O g/ft³	GWP
Upstream Emissions	781	0.567	8.781	3,515
Pressure Treating	0	0	0	0
Fugitive Emissions	2,561	0	0	2,561
Disposal				
Use as Fuel	-36,656	-46.378	-0.388	-37,751
Landfill	-42,803	579.188	-0.366	-30,754
Total				
Fuel	-33,314	-45.812	8.392	-31,674
Landfill	-39,461	579.755	8.415	-24,677

Conclusion and Summary

Table 41 shows updated Emission factors for all rail system components. Overhead line equipment, tunnels, bridges, and rolling stock are taken from Network Rail (Network Rail). Rail stations and parking facilities are taken from Chester (Chester 2008) except for parking garages, which are based largely on Guggemos and Horvath (Guggemos, Horvath 2005) for the building structure and our conversion of Chester's flexible pavement to a rigid slab for the parking surface. We have added GHG emission factors for copper in order to adequately address catenary wire systems. By weight catenary wire systems have about one sixth as much copper as they have steel, yet the GHG emissions from copper wire production and rolled steel production are roughly equivalent. The catenary systems are massive with steel content larger than 132 pound track on reinforced concrete ties. Our model assumes 887 tons of steel per route-mile for catenary systems and 582 tons per route-mile for 132 pound track.

Other additions include wood as plywood and pressure treated timber, glass, lubricating oil, brick and soil. We cannot precisely estimate from the bottom up for many factors including catenary wires, bridges, tunnels, rolling stock,passenger stations or parking garages. It was designed to address the type of data likely to be available from transit agencies. Our analysis of a case-study for Denver (as part of TCRP H41) found that it included counts of miles of track, vehicles of rolling stock, primary hub rail stations and secondary feeder stations, and parking spaces for parking lots and parking garages.

The model will handle above and below grade track as well as at grade track. Although 100 pound track is shown for illustrative purposes, this model will handle other track sizes. A gap of some concern is that we do not account for HFC fugitive emissions for rolling stock or rail stations.

Table 41. Estimates of GHG Emissions for Rail System Components.

	Material	tonnes per rtkm	S tons per rtmi	CO_2 tonnes / mile	CH_4 tonnes / mile	N_2O tonnes / mile
Track (Com. rail)	Steel		202.50	848.070	0.810	0.004
100 lb/yd	Concrete		788.13	176.571	0.159	0.014
Continuous	ballast		9,372.00	71.067	0.053	0.160
Track (Mun. rail)	Steel		249.63	1,045.450	0.999	0.005
100 lb/yd	Timber		73.17	-463.340	6.807	0.099
continuous	ballast		6,600.00	50.047	0.037	0.113
Catenary[iii, 1]	Steel	500.00	887.00	3,714.752	3.550	0.020
	Aluminum	70.00	124.18	692.327	1.321	0.009
	Copper	138.00	244.81	4,210.848	2.320	0.055
Tunnels[i, 1]	Soil	270,000.00	478,979.49	1,161.856	1.299	0.008
	Concrete	44,000.00	78,055.92	17,487.491	15.783	1.351
	Steel	2,100.00	3,725.40	15,601.958	14.910	0.082
	Electricity	12,130.00	19,521.34	13,762.546	0.254	0.178
Bridges[ii, 1]	Concrete	89,000.00	157,885.83	35,372.426	31.925	2.732
	Steel	4,900.00	8,692.59	36,404.570	34.790	0.192
Rail Stations[2]		Ft^3 per unit	S tons per unit	CO_2 tonnes / unit	CH_4 tonnes / unit	N_2O tonnes / unit
Heavy Rail						
Aerial	Concrete	517,194	38,789.56	8,690.328	7.843	0.671
	Steel	2,806	822.27	3,443.681	3.291	0.018
Surface	Concrete	437,626	32,821.93	7,353.354	6.637	0.568
	Steel	2,374	695.77	2,913.884	2.785	0.015
Underground	Concrete	765,845	57,438.38	12,868.370	11.614	0.994
	Steel	4,155	1,217.60	5,099.297	4.873	0.027
Commuter Rail						
Platforms	Concrete	17,903	1,343	300.819	0.272	0.023
	Steel	97	28	119.204	0.114	0.001
	Subbase	9,000	450	3.412	0.003	0.008
Light Rail						
Platforms	Concrete	8,951	671	150.410	0.136	0.012
	Steel	49	14	59.602	0.057	0.000
Stations	Concrete	308,327	23,125	5,180.772	4.676	0.400
	Steel	1,673	490	2,052.964	1.962	0.011

Table 41. Non-Track Estimates of GHG Emissions--Continued.

Parking Facilities	Material	Ft^3 per parking space	S tons per parking space	CO2 tonnes / parking space	CH4 tonnes / parking space	N2O tonnes / parking space
Parking Garage[2,3]	Concrete		48.24	10.808	0.010	8.35×10^{-4}
	Steel		3.29	13.761	0.013	7.2×10^{-5}
	Total	330	51.53	24.569	0.023	9.07×10^{-4}
Parking Lot[2]	Hot Mix Asphalt	165	7.69	0.187	4.47×10^{-4}	3×10^{-6}
	Aggregate	165	8.25	0.063	4.7×10^{-5}	1.41×10^{-4}
	Total	330	15.94	0.250	4.94×10^{-4}	1.44×10^{-4}
Rolling Stock[1]	Material	tonnes per vehicle	S tons per vehicle	CO_2 tonnes / vehicle	CH_4 tonnes / vehicle	N_2O tonnes / vehicle
	Steel	27.05	29.82	124.876	0.119	6.57×10^{-4}
	Aluminum	12.60	13.89	77.435	0.148	0.001
	Copper	1.20	1.32	22.752	0.013	2.98×10^{-4}
	Glass	0.82	0.90	1.122	0.006	1.7×10^{-5}
	Lubricating Oil	0.63	0.69	2.729	0.003	1.7×10^{-5}
	Wood (Plywood)	1.45	1.60	0.354	0.002	0.002
	Plastic and Rubber	3.43	3.78	12.317	0.020	1.47×10^{-4}

i. per unit distance of tunnels
ii. per unit distance of bridges
iii. per unit distance of track

Sources:
1. Network Rail. n.d. Comparing Environmental Impact of Conventional and High Speed Rail.
2. Chester. 2008. Life-Cycle Environmental Inventory of Passenger Transportation in the United States.
3. Guggemos, A.A.; Horvath, A. 2005. Comparison of Environmental Effects of Steel- and Concrete-Framed Buildings.

An important limitation of the model is that we often do not account for equipment activity. Where we have this information it is through the LCA studies we cite. The Choate study (Choate 2003) on concrete and the BCS study (BCS 2002a) on aggregate and ballast account for equipment activity fairly well, although their assumptions may be outdated. Our asphalt assumptions are based on a heating model (Hunt 2010) and industry averages (Zapata, Gambatese 2005). Direct equipment emissions are accounted for abstractly in these cases. The GREET Model (Argonne National Laboratory 2009, Argonne National Laboratory 2007) would address equipment activity data at least as well these other models already mentioned, except that it does not address installation of materials by a contractor. Where we do not account for activity well at all is where there is no LCA or only a poor LCA available. The EPA reports for copper and brick (EPA 2003, EPA 2005g) do not address upstream emissions completely. We use GREET process fuel emission factors from Table 37 to correct for this. Again, we do not address installation of these materials. The wood study (Puettmann, Wilson 2005) addresses upstream equipment but like GREET, it does not address installation. We do not have activity data for track installation, building construction, or demolition. A similar limitation is that we do not address disposal or recycling and the end of the life cycle.

APPENDIX H: GASCAP CASE STUDIES

Introduction

This section summarizes four case studies based on inputting DOT bid sheet information into GASCAP. Various assumptions were made to estimate equipment activity. We identify various omissions in GASCAP and potential procedures for use of the software. The results, however, are indicative of the variation in emissions that different projects will produce.

We establish the inputs for each contract based on the item numbers in the bid sheets. Some item numbers are excluded from the analysis for a variety of reasons. These items include administrative components, including the development and management of development and management of construction layouts and progress schedules, testing procedures, setting up and maintaining a field office, price adjustments, and obtaining the required performance and payment bonds and liability insurance are excluded. Training activities are noted but not quantified. Temporary reusable items such as breakaway barricades, cones, drums, and construction signs and other temporary signage are also not included, as are services such as towing or use of traffic directors. Material inputs do not include Division 700 – Electronics and Division 800 – Landscaping. Many of these items either have no impact on greenhouse gas emissions (e.g. liability insurance) or are minor. Further research can develop procedures for additional bid sheet items, if needed.

Equipment activities are included indirectly. Some equipment activities are noted explicitly such as site clearing, excavation, concrete and hot mix asphalt (HMA) milling, and final cleanup. Other examples include saw cutting, setting of materials accounted for elsewhere, such as inlets, and pile driving. Other equipment activities are implied by material inputs such as laying concrete, paving, spraying, and placing structures. There are no specifics in the bid sheets about mobilization, which is generally covered as a lump sum. We make an attempt to estimate equipment activity input from the contract items, but must make assumptions about specifically what equipment is used, the duration of use, the power rating, and the fuel used by the equipment. Staging and lighting assumptions are made in a similar way.

Some assumptions are made to demonstrate the Recyclables module for contracts 135083070 and 003048072.

Other than as described above, material inputs are discussed with a focus on which materials are included and which are missing. Omissions are discussed in some detail. Quantified greenhouse gas emissions are presented for each module in tabular form. Following this introduction, each contract is presented. GASCAP output is then attached for each contract followed by the best three bids for each contract from the bid-sheets for reference.

Contract 001093740: Grove Street (CR623) over Route 46, Clifton City, Passaic County

This contract addresses road and bridge reconstruction where Grove Street, Clifton, Passaic County passes over NJ Route 46 at milepost 61.09. The contract was awarded 7/23/2009 with a scheduled completion date of 11/19/2009. If we assume that work on the project begins on the let date the project's duration is 119 days. We assume that all work is completed during daylight hours.

The roadway component of this project uses soil aggregate, aggregate subbase and a concrete base course all expressible in cubic yards. Roughly 600 square yards of existing HMA pavement is milled to a depth of 3 inches. A tack coat is applied, which is presumed not to include cutback agents. HMA intermediate and surface courses are applied, accounting for 340 tons of material. HMA and concrete sidewalks and an HMA driveway of known depth are presented in square yards. A concrete vertical curve of known height and thickness and ductile water pipe of known diameter are presented in linear feet. Epoxy traffic stripes are not included. A temporary chain link fence is not included because it is presumed to be reusable. A fire hydrant could not be included as this item is not in GASCAP. A gas main including bridge and non-bridge components were included as were backfilling, bedding, and installation using coarse aggregate.

The bridge component includes concrete wing walls, abutment walls, pier column and cap, and bridge deck expressed in cubic yards, and epoxy-coated reinforcement steel expressed in pounds. Concrete bridge sidewalk and parapet are expressed in linear feet. Structural steel is expressed as a lump sum. We allow 50,000 pounds for structural steel. A permanent chain-link aluminum-coated steel fence of known height is expressed in linear feet. Missing items include temporary shielding and sheeting, epoxy waterproofing, reinforced elastomeric bearing assembly units, shear connectors, and strip seal expansion joint assemblies. An item for 100 square feet of concrete repair could not be addressed because it is not in GASCAP.

An erosion control system including silt fencing, inlet filters, concrete washout systems and an oil only emergency spill kit are not covered. Landscaping including topsoiling, fertilizing and seeding, and straw mulching was also not covered.

In addition to site clearing and final clean up, equipment activity includes 198 cubic yards of unclassified excavation and 75 cubic yards of gas line excavation, 606 square yards of HMA milling to a depth of three inches, 75 square yards of underlayer preparation, resetting of 2 castings, one manhole, one gas valve box, removal of erosion control sediment, various HMA and concrete paving and pavement repairs, and various installations. Cleaning of 495 feet of pipe and 8 drains is noted. Training activities consisting of 28,000 hours of training are noted as well.

Contract 135083070: Route 9 over Main Street, Bridge Superstructre Replacement, Township of Woodbridge, Middlesex County

This contract addresses bridge superstructure replacement in Woodbridge Township, Middlesex County. The contract was awarded 3/8/2010 and has a scheduled completion date of 1/9/2011. Using the let date as the start date the contract duration is 307 days. We assume that night work occurs over 30 days of the contract. Lighting is provided by generators.

The roadway component uses dense graded aggregate of known depths for the base course. Tack coat and prime coat are expressed in gallons. We assume that the prime coat uses cutbacks, but the tack coat does not. We are not able to address polymerized joint adhesive expressed in linear feet, although a volumetric input would be easier to estimate. HMA base, intermediate and surface courses account for 1,250 tons of material that does not include 513 square feet of non-vegetative surface, which is estimated separately. We assume that 25% of the weight (312.5 tons) of the HMA is substituted with recycled asphalt pavement (RAP). Concrete sidewalk and driveway of known depth are expressed in square yards and concrete vertical curbs of known height and thickness are expressed in linear feet. Guide rails and rub rails are estimated based on linear feet. One controlled release terminal and 15 bicycle safe grates are included on a per unit basis. Epoxy traffic stripes are not included, nor are traffic markings, raised permanent markes (RPM), sewer connections, and crash cushions.

The bridge component includes concrete footings, wing walls, abutment walls, sidewalks and parapets, and curbs. Notable omissions include 162 linear feet of header reconstruction and the bridge deck waterproof surface course. Epoxy coated reinforcing steel is expressed in pounds. Beam guide rails are expressed in linear feet. The bridge component does not include epoxy waterproofing, which is expressed as a lump sum, temporary shoring, prefabricated superstructure units, asphaltic joint systems, and rigid metallic conduits.

The landscaping section including topsoiling, fertilizing and seeding, topsoil stabilization and straw mulching is not covered. The erosion control section is largely not covered, including the silt fencing and inlet filter system; however the inlet faceplates are covered.

In addition to site clearing and final clean up, equipment activity includes various types of excavation totaling 837 cubic yards, and removal of 3,178 square yards of pavement, 2 tons of acid producing soil, and 26 cubic yards of erosion control sediment. Other equipment activity includes milling of 740 square yards of HMA pavement to a depth of three inches, sawing and sealing HMA joints, various HMA and concrete paving and pavement repairs, removal of erosion sediments, and setting of various components. This contract includes 1,000 hours of training.

Contract 003048072: Route US 22 Resurfacing and County Route 519 Intersection Improvements, from Phillipsburg Mall Entrance to Vicinity of Greenwich

This contract addresses resurfacing of US Route 22 and intersection improvements to County Route 519 in Greenwich and Pohatcong Townships in Warren County. The contract was awarded 2/1/2011 and is scheduled for completion 9/12/2011. The time from let date to completion date is 223 days, which we assume to be the active phase of the contract. We assume that night work occurs throughout the contract. Lighting is provided by grid electricity.

The roadway component includes dense-graded aggregate and concrete base courses of various depths, 12,920 gallons of tack and prime coat, 10,990 tons of HMA base, intermediate, and surface courses, 213 linear feet of reinforced concrete pipe, various inlets, a four foot manhole, curb pieces, a HMA driveway, concrete island, concrete vertical curbs, an HMA non-vegetative surface, various guide and rub rails, and signage. Not included were HMA pavement repair, 26,500 linear feet of polymerized joint adhesive, 8,100 linear feet of joint sealing in concrete pavement, epoxy traffic stripes, thermoplastic traffic markings, RPMs of various specifications, and a concrete handicap ramp. We assume substitution of recycled material in concrete including 50 cubic yards of RCM (7,500 lbs) and 50 lbs of coal fly ash.

The bridge component of the project is limited to a caste-in-place retaining wall of 354 square feet. GASCAP does not include this item code.

The erosion control component includes silt fencing, hay bales, inlet filters, concrete washout systems and oil emergency spill kits. The electronics component includes 135 linear feet of rigid metallic conduit, 1,737 linear feet of ground wire, foundations, and traffic signal boxes and mast arms of aluminum and steel. The landscaping component includes tree removal, topsoiling to various depths, turf application, fertilizing and seeding, mulching with hardwood bark, planting of ground cover and various itemized trees and shrubs, and building of a stone wall. These items and construction monuments are not covered by GASCAP.

In addition to site clearing and final clean up, equipment activity includes 244 cubic yards of excavation, 670 square yards of pavement removal, HMA milling to various depths, various HMA and concrete paving and pavement repairs, pipe cleaning, and setting and resetting of various items. This contract had no provision for training.

Contract 045093060: Route 1 & 9 North Avenue to Haynes Avenue Resurfacing, Mill and pave, City of Newark and Elizabeth (Essex and Union Counties)

This contract covers milling and paving of sites in Newark, Essex County and Elizabeth, Union County. The contract was awarded 2/8/2011 and has a scheduled completion date of 1/21/2012. As with the previous three contracts we assume that work began on the project let date and will continue until the completion date, which gives the project a duration period of 347 days. We assume that all work is completed during daylight hours.

This contract has no bridge component. The roadway component includes 3,628 cubic yards of subbase, 20,658 gallons of tack and prime coat, and more than 48,000 tons of HMA including 11,190 tons of binder rich intermediate course (Item No. 409003P). This last item was entered HMA intermediate course (Item No. 401066M) with binder content specified at 7%. This contract also includes three types of inlet, bicycle safe grates, curb pieces, inlet face plates, 160 square yards of four inch thick concrete island, concrete vertical curbs, and signage. Items not included were 194 square yards of HMA pavement repair, epoxy traffic stripes, thermoplastic traffic markings, RPMs and rumble strips.

The erosion control component of this contract includes silt fencing, inlet filters of various types, a concrete washout system, and an oil emergency spill kit. The landscaping component includes topsoiling, fertilizing and seeding, and straw mulching.

Beyond site clearing and final cleanup, equipment activities include excavation of 7,519 cubic yards, HMA and concrete milling to various depths of more than 175,000 square yards of pavement, paving and various HMA and concrete pavement repairs, erosion sediment removal, pipe and drain cleaning, and placing, setting, and installing various items. Training in this contract consists of 740 hours.

Lessons learned from case studies

These case studies have demonstrated the capability and the shortcomings of GASCAP. Our estimates of greenhouse gas emissions likely cover about 90% of the total construction life-cycle emissions associated with these projects, assuming our assumptions on equipment activity are correct. The lack of detailed construction equipment activity is the major shortcoming, and there is a need to develop methods to estimate the equipment activity for a variety of projects.

As part of GASCAP development, we included detailed specifications for over 1000 bid sheet items. Despite this, the case studies identified various omissions of bid sheet items that were missing from the bid lists we surveyed. One item also had inadequate information on size and dimensions to calculate a volumetric measure. Some items also are reported as lump sums making it impossible to disentangle the individual components of the item. DOT should consider requiring additional detail in bid sheets to allow a full estimation of the emissions from these items.

GASCAP will benefit from feedback from DOT staff who begin to explore the capabilities of GASCAP. We recommend that missing items be identified as well as any other assumptions that are made while entering bid sheet items.

NJDOT Contract Num 001093740 Contract ID 09151

SECTION 1:	Materials	
Direct CO2	7.13	(mt)
Direct CH4	0.00	(mt)
Direct N2O	0.00	(mt)
Direct CO2 Equivalent	**7.17**	**(mt)**
Upstream CO2	5,686.34	(mt)
Upstream CH4	5.19	(mt)
Upstream N2O	0.80	(mt)
Upstream CO2 Equivalent	**6,043.51**	**(mt)**
Combined CO2 Equivalent	**6,050.68**	**(mt)**

SECTION 2:	Equipment	
Direct CO2	50.23	(mt)
Direct CH4	0.00	(mt)
Direct N2O	0.00	(mt)
Direct PMBC	0.01	(mt)
Direct CO2 Equiv. from HFCs	0.00	(mt)
Direct CO2 Equivalent	**50.45**	**(mt)**
Upstream CO2	9.88	(mt)
Upstream CH4	0.19	(mt)
Upstream N2O	0.00	(mt)
Upstream PMBC	0.00	(mt)
Upstream CO2 Equivalent	**14.00**	**(mt)**
Combined CO2 Equivalent	**64.45**	**(mt)**

SECTION 3:	Recyclables Credits	
CO2	0.00	(mt)
CH4	0.00	(mt)
N2O	0.00	(mt)
Total CO2 Equivalent	**0.00**	**(mt)**

SECTION 4:	Lifecycle Maintenance	
Direct CO2	0.00	(mt)
Direct CH4	0.00	(mt)
Direct N2O	0.00	(mt)
Direct PMBC	0.00	(mt)
Direct CO2 Equivalent	**0.00**	**(mt)**
Upstream CO2	0.00	(mt)
Upstream CH4	0.00	(mt)
Upstream N2O	0.00	(mt)
Upstream PMBC	0.00	(mt)
Upstream CO2 Equivalent	**0.00**	**(mt)**
Combined CO2 Equivalent	**0.00**	**(mt)**

SECTION 6:	Lighting	
Direct CO2	0.00	(mt)
Direct CH4	0.00	(mt)
Direct N2O	0.00	(mt)
Direct CO2 Equivalent	**0.00**	**(mt)**

OVERALL RESULTS

CO2	5,758.73	(mt)
CH4	5.39	(mt)
N2O	0.80	(mt)
PMBC	0.01	(mt)
Total CO2 Equivalent	6,120.94	(mt)

Fuel Consumption

Gasoline (10% Ethanol RFG)	0.00	gallons
Gasoline	740.07	gallons
20% Biodiesel	0.00	gallons
Diesel	7,937.85	gallons
Liquified Petroleum Gas	0.00	gallons
Compressed Natural Gas	0.00	GGE

Fuel Costs

Gasoline (10% Ethanol RFG)	$ per gallon
Gasoline	$ per gallon
20% Biodiesel	$ per gallon
Diesel	$ per gallon
Liquified Petroleum Gas	$ per gallon
Compressed Natural Gas	$ per GGE

Total Fuel Cost $34,711.69

SECTION 5:	Staging	
Direct CO2	4.28	(mt)
Direct CH4	0.00	(mt)
Direct N2O	0.00	(mt)
Direct CO2 Equiv. from HFCs	0.46	(mt)
Direct CO2 Equivalent	**4.80**	**(mt)**
Upstream CO2	0.87	(mt)
Upstream CH4	0.01	(mt)
Upstream N2O	0.00	(mt)
Upstream CO2 Equivalent	**1.01**	**(mt)**
Combined CO2 Equivalent	**5.81**	**(mt)**

SECTION 7:	Rail	
Direct CO2	0.00	(mt)
Upstream and Disposal CO2	0.00	(mt)
Upstream and Disposal CH4	0.00	(mt)
Upstream and Disposal N2O	0.00	(mt)
Total CO2 Equivalent	**0.00**	**(mt)**

Materials

Item Code	Description	Value	Unit	Cement Ratio	Aggregate Ratio	Heating Temp.	% Binder	% Moisture	Cutback	Depth (feet)
509078P	Chain-Link Fence, Aluminum-Coated Steel, Bridge, 6' 3"	460.00	Feet	N/A	N/A	N/A	N/A	N/A	Non-Solvent-N/A	N/A
507039P	Concrete Bridge Parapet, Hpc	460.00	Feet	0.15	0.80	N/A	N/A	N/A	Non-Solvent-N/A	N/A
507033P	Concrete Bridge Sidewalk, Hpc	44.00	Cu. Yards	0.15	0.80	N/A	N/A	N/A	Non-Solvent-N/A	N/A
507024P	Concrete Bridge Deck, Hpc	209.00	Cu. Yards	0.15	0.80	N/A	N/A	N/A	Non-Solvent-N/A	N/A
506003P	Structural Steel	50,000.00	Pounds	N/A	N/A	N/A	N/A	N/A	Non-Solvent-N/A	N/A
504027P	Concrete Pier Column And Cap	4.00	Cu. Yards	0.15	0.80	N/A	N/A	N/A	Non-Solvent-N/A	N/A
504024P	Concrete Abutment Wall	200.00	Cu. Yards	0.15	0.80	N/A	N/A	N/A	Non-Solvent-N/A	N/A
504018P	Concrete Wing Wall	36.00	Cu. Yards	0.15	0.80	N/A	N/A	N/A	Non-Solvent-N/A	N/A
504006P	Reinforcement Steel, Epoxy-Coated	83,745.00	Pounds	N/A	N/A	N/A	N/A	N/A	Non-Solvent-N/A	N/A
653107M	Gas Main Installation, Coarse Aggregate, #57	10.00	Cu. Yards	N/A	N/A	N/A	N/A	N/A	Non-Solvent-N/A	N/A
653093M	Gas Line Bedding	37.00	Cu. Yards	N/A	N/A	N/A	N/A	N/A	Non-Solvent-N/A	N/A
653092M	Gas Main Installation, Backfill	37.00	Cu. Yards	N/A	N/A	N/A	N/A	N/A	Non-Solvent-N/A	N/A
653057P	12" Gas Main, Bridge	153.00	Feet	N/A	N/A	N/A	N/A	N/A	Non-Solvent-N/A	N/A
653018P	12" Gas Main	80.00	Feet	N/A	N/A	N/A	N/A	N/A	Non-Solvent-N/A	N/A
651058P	8" Ductile Iron Water Pipe, Class 54	413.00	Feet	N/A	N/A	N/A	N/A	N/A	Non-Solvent-N/A	N/A
651051P	4" Ductile Iron Water Pipe, Class 52	80.00	Feet	N/A	N/A	N/A	N/A	N/A	Non-Solvent-N/A	N/A
607024P	9" X 20" Concrete Vertical Curb	581.00	Feet	0.15	0.80	N/A	N/A	N/A	Non-Solvent-N/A	N/A
606036P	Hot Mix Asphalt Driveway, 4" Thick	25.00	Sq. Yard	N/A	N/A	N/A	0.04	0.04	Non-Solvent-N/A	N/A
606012P	Concrete Sidewalk, 4" Thick	136.00	Sq. Yard	0.15	0.80	N/A	N/A	N/A	Non-Solvent-N/A	N/A
606006P	Hot Mix Asphalt Sidewalk, 5" Thick	136.00	Sq. Yard	N/A	N/A	N/A	0.04	0.04	Non-Solvent-N/A	N/A
401087M	HMA - Intermediate Course	159.00	Tons	N/A	N/A	325.00	0.04	0.04	Non-Solvent-N/A	N/A
401045M	HMA - Surface Course	181.00	Tons	N/A	N/A	325.00	0.05	0.04	Non-Solvent-N/A	N/A
401030M	Tack Coat	160.00	Gallons	N/A	N/A	145.00	N/A	N/A	Non-Solvent-0	N/A
304009P	Concrete Base Course, 10" Thick	75.00	Sq. Yards	0.15	0.80	N/A	N/A	N/A	Non-Solvent-N/A	N/A
301006P	Subbase	26.00	Cu. Yards	N/A	N/A	N/A	N/A	N/A	Non-Solvent-N/A	N/A
203021P	I-14 Soil Aggregate	3.00	Cu. Yards	N/A	N/A	N/A	N/A	N/A	Non-Solvent-N/A	N/A

Item Code	Description	Direct CO_2 (g)	Direct CH_4 (g)	Direct N_2O (g)	Direct CO_2 Equiv. (g)	Upstream CO_2 (g)	Upstream CH_4 (g)	Upstream N_2O (g)	Upstream CO_2 Equiv. (g)
509078P	Chain-Link Fence, Aluminum-Coated Steel, Bridge, 6' 3"	0.00	0.00	0.00	0.00	9,066,841.39	11,044.18	59.74	9,317,288.23
507039P	Concrete Bridge Parapet, Hpc	0.00	0.00	0.00	0.00	190,312,770.90	202,510.05	2,994.16	195,493,672.89
507033P	Concrete Bridge Sidewalk, Hpc	0.00	0.00	0.00	0.00	28,018,947.74	24,165.46	1,590.04	29,019,335.51
507024P	Concrete Bridge Deck, Hpc	0.00	0.00	0.00	0.00	138,232,764.75	124,021.50	7,608.49	143,195,849.50
506003P	Structural Steel	0.00	0.00	0.00	0.00	71,264,715.22	77,707.03	437.01	73,032,037.41
504027P	Concrete Pier Column And Cap	0.00	0.00	0.00	0.00	1,360,901.99	895.49	139.02	1,422,803.25
504024P	Concrete Abutment Wall	0.00	0.00	0.00	0.00	68,045,099.54	44,774.53	6,950.96	71,140,162.44
504018P	Concrete Wing Wall	0.00	0.00	0.00	0.00	12,248,117.92	8,059.42	1,251.17	12,805,229.24
504006P	Reinforcement Steel, Epoxy-Coated	0.00	0.00	0.00	0.00	119,361,271.53	130,151.51	731.96	122,321,359.45
653107M	Gas Main Installation, Coarse Aggregate, #57	0.00	0.00	0.00	0.00	102,369.51	76.69	230.60	175,466.88
653093M	Gas Line Bedding	0.00	0.00	0.00	0.00	378,767.20	283.74	853.23	649,227.44
653092M	Gas Main Installation, Backfill	0.00	0.00	0.00	0.00	378,767.20	283.74	853.23	649,227.44
653057P	12" Gas Main, Bridge	0.00	0.00	0.00	0.00	24,548,280.33	31,216.26	164.80	25,254,908.44
653018P	12" Gas Main	0.00	0.00	0.00	0.00	12,835,702.13	16,322.23	86.17	13,205,180.88
651058P	8" Ductile Iron Water Pipe, Class 54	0.00	0.00	0.00	0.00	4,879,872,754.77	3,598,438.41	16,472.17	4,960,546,332.71
651051P	4" Ductile Iron Water Pipe, Class 52	0.00	0.00	0.00	0.00	91,550,005.07	67,509.35	309.03	93,063,500.78
607024P	9" X 20" Concrete Vertical Curb	0.00	0.00	0.00	0.00	12,666,737.44	767,290.77	757,461.27	263,592,836.25
606036P	Hot Mix Asphalt Driveway, 4" Thick	67,745.90	2.67	1.03	68,120.15	107,779.49	648.18	1.76	121,936.68
606012P	Concrete Sidewalk, 4" Thick	0.00	0.00	0.00	0.00	5,141,185.30	3,382.96	525.18	5,375,034.50
606006P	Hot Mix Asphalt Sidewalk, 5" Thick	460,672.09	18.13	6.98	463,216.99	732,900.53	4,407.60	11.97	829,169.44
401087M	HMA - Intermediate Course	3,082,002.10	121.29	46.71	3,099,028.08	4,903,272.89	29,487.83	80.05	5,547,334.06
401045M	HMA - Surface Course	3,518,789.34	138.22	53.33	3,538,222.94	7,342,246.68	43,461.56	119.58	8,292,009.75
401030M	Tack Coat	4,744.94	0.07	0.07	4,768.70	479,641.79	2,683.98	7.75	538,406.84
304009P	Concrete Base Course, 10" Thick	0.00	0.00	0.00	0.00	7,088,031.20	4,664.01	724.06	7,410,433.59
301006P	Subbase	0.00	0.00	0.00	0.00	266,160.73	199.39	599.57	456,213.88
203021P	I-14 Soil Aggregate	0.00	0.00	0.00	0.00	30,710.85	23.01	69.18	52,640.06

Equipment

Year	Description	Fuel Type	Power Rating	Hours	Air Conditioning	Direct CO_2 (g)	Direct CH_4 (g)	Direct N_2O (g)	Direct PM_{BC} (g)	Direct CO_2 Equiv. from HFCs(g)	Direct CO_2 Equiv. (g)
2004	Sprayers	Gasoline (4 Stroke)	100	50.00	No	2995674.705	308.443	21.614	46.698	0.00	3008852.257
2008	Cranes	Gasoline (4 Stroke)	75	40.00	No	956990.256	35.162	9.605	20.325	0.00	960706.169
1996	Pavers	Diesel	600	200.00	No	24509886.591	162.077	337.841	5432.451	0.00	24618020.953
2004	Paving Equipment	Diesel	175	75.00	No	3119370.497	33.815	42.994	610.903	0.00	3133408.815
2008	Excavators	Diesel	100	125.00	No	4030625.095	25.118	50.029	1485.820	0.00	4046661.525
2005	Crawler Tractors	Diesel	1000	50.00	No	14618503.799	135.579	201.491	2393.723	0.00	14683813.130

Year	Description	Fuel Type	Power Rating	Hours	Upstream CO_2 (g)	Upstream CH_4 (g)	Upstream N_2O (g)	Upstream PM_{BC} (g)	Upstream CO_2 Equiv. (g)	Fuel Use	Fuel Unit
2004	Sprayers	Gasoline (4 Stroke)	100	50.00	461870.808	2818.828	7.068	14.137	523257.367	348.585	gallons
2008	Cranes	Gasoline (4 Stroke)	75	40.00	205248.997	1252.648	3.141	6.282	232528.334	214.232	gallons
1996	Pavers	Diesel	600	200.00	5966601.641	128304.242	85.195	198.789	8687401.297	4058.056	gallons
2004	Paving Equipment	Diesel	175	75.00	452478.234	9729.974	6.461	15.075	658810.531	516.435	gallons
2008	Excavators	Diesel	100	125.00	671411.439	6372.086	15.978	31.956	810178.474	668.068	gallons
2005	Crawler Tractors	Diesel	1000	50.00	2120525.057	45599.217	30.278	70.650	3087494.899	2420.254	gallons

Staging

Item	Year	Fuel Type	Distance (miles)	Number of Trips	Number of Vehicles	Direct CO2 (g)	Direct CH4 (g)	Direct N2O (g)	Direct CO2 Equiv. from HFCs(g)	Direct CO2 Equiv. (g)	Upstream CO2 (g)	Upstream CH4 (g)	Upstream N2O (g)	Upstream CO2 Equiv. (g)	Fuel Use (gal)
Combination Short-haul Truck	2001	Diesel Fuel	45	12	1	1,114,182.02	1.43	1.33	51,212.39	1,165,837.38	226,354.14	1,528.07	3.93	259,662.00	111.21
Light Commercial Truck	2006	Reformulated Gasoline	23	40	3	1,526,838.44	218.44	149.40	153,637.18	1,731,378.09	305,552.79	2,201.89	60.83	370,648.43	177.26
Single Unit Short-haul Truck	2003	Diesel Fuel	15	6	3	301,075.96	0.83	0.89	153,637.18	455,006.87	61,165.86	412.92	1.06	70,166.38	30.05
Single Unit Short-haul Truck	2008	Diesel Fuel	50	12	2	1,340,189.36	26.66	4.04	102,424.79	1,444,426.23	272,269.44	1,838.04	4.73	312,333.70	133.77

TABULATION OF BIDS

CALL ORDER : 151
LETTING DATE : 07/23/09 10:00AM
CONTRACT ID : 09151
DISTRICT : N1
CONTRACT TIME : 11/19/09 COMPLETION DATE
COUNTIES : PASSAIC
CONTRACT DESCRIPTION : URBAN
PROJECT(S) : FS-8112(138)
GROVE STREET (CR623) OVER ROUTE 46, MILEPOST 61.09
CLIFTON CITY, PASSAIC COUNTY ,CONTRACT NO. 001093740

SET-ASIDE :

VENDOR RANKING :

RANK	VENDOR NO.	NAME		TOTAL BID	% OVER LOW BID
1	R4689	RITACCO CONSTRUCTION INC	$	2,787,000.00	100.0000%
2	F2743	FERREIRA CONSTRUCTION CO INC	$	3,197,891.00	114.7431%
3	C7279	J.F.CREAMER & SON JOINT VENTURE WITH JOSEPH M. SANZARI,INC	$	3,215,994.59	115.3927%
4	S1082	SCAFAR CONTRACTING INC	$	3,285,348.00	117.8812%
5	S7025	SPARWICK CONTR INC	$	3,391,792.00	121.7005%
6	R6685	ROSANGELA CONTRACTING CO INC	$	3,565,086.00	127.9184%
7	H3415	H&G CONTRACTORS INC	$	3,675,915.60	131.8951%
8	C7698	CRUZ ENTERPRISES, LLC	$	3,807,627.75	136.6210%

LINE NO / ITEM CODE / ALT ITEM DESCRIPTION	QUANTITY		(1) R4689 RITACCO CONSTRUCTION INC UNIT PRICE	AMOUNT	(2) F2743 FERREIRA CONSTRUCTION CO INC UNIT PRICE	AMOUNT	(3) C7279 J.F.CREAMER J-V J.M. SANZARI UNIT PRICE	AMOUNT
SECTION 0001 ROADWAY								
0004 153003P PROGRESS SCHEDULE		LUMP	10000.00000	10000.00	3276.00000	3276.00	10000.00000	10000.00
0005 153006P PROGRESS SCHEDULE UPDATE	6.000	U	200.00000	1200.00	655.00000	3930.00	500.00000	3000.00
0006 153012P TRAINEES	2800.000	HOUR	1.00000	2800.00	0.01000	28.00	1.00000	2800.00
0007 154003P MOBILIZATION		LUMP	280000.00000	280000.00	396000.00000	396000.00	300000.00000	300000.00
0011 157003M CONSTRUCTION LAYOUT		LUMP	20000.00000	20000.00	40000.00000	40000.00	45000.00000	45000.00
0017 159003M BREAKAWAY BARRICADE	25.000	U	100.00000	2500.00	200.00000	5000.00	100.00000	2500.00
0018 159006M DRUM	25.000	U	80.00000	2000.00	200.00000	5000.00	75.00000	1875.00
0019 159009M TRAFFIC CONE	25.000	U	15.00000	375.00	50.00000	1250.00	25.00000	625.00

CALL ORDER : 151
LETTING DATE : 07/23/09 10:00AM
CONTRACT ID : 09151
DISTRICT : N1
COUNTIES : PASSAIC

SET-ASIDE :

LINE NO / ITEM CODE / ALT ITEM DESCRIPTION	QUANTITY		(1) R4689 RITACCO CONSTRUCTION INC UNIT PRICE	AMOUNT	(2) F2743 FERREIRA CONSTRUCTION CO INC UNIT PRICE	AMOUNT	(3) C7279 J.F.CREAMER J-V J.M. SANZARI UNIT PRICE	AMOUNT
0020 159012M CONSTRUCTION SIGNS	584.000	SF	12.00000	7008.00	20.00000	11680.00	13.00000	7592.00
0021 159014M CONSTRUCTION IDENTIFICATION SIGN, 6'6" X 7'	2.000	U	1000.00000	2000.00	1500.00000	3000.00	3000.00000	6000.00
0022 159021P CONSTRUCTION BARRIER CURB	895.000	LF	40.00000	35800.00	200.00000	179000.00	150.00000	134250.00
0023 159027M FLASHING ARROW BOARD, 4' X 8'	6.000	U	1000.00000	6000.00	506.00000	3036.00	500.00000	3000.00
0024 159031M VARIABLE MESSAGE SIGN ASSEMBLY	4.000	U	1000.00000	4000.00	6000.00000	24000.00	500.00000	2000.00
0025 159042M TEMPORARY CRASH CUSHION, INERTIAL BARRIER SYSTEM, 10 MODULES	2.000	U	2000.00000	4000.00	4158.00000	8316.00	6000.00000	12000.00
0026 159054M TEMPORARY CRASH CUSHION, INERTIAL BARRIER SYSTEM, 14 MODULES	2.000	U	2000.00000	4000.00	3924.00000	7848.00	7500.00000	15000.00
0027 159108M TRAFFIC CONTROL TRUCK WITH MOUNTED CRASH CUSHION	4.000	U	1000.00000	4000.00	15000.00000	60000.00	1000.00000	4000.00
0028 159126M TEMPORARY TRAFFIC STRIPES, 4"	7508.000	LF	0.25000	1877.00	1.00000	7508.00	0.26000	1952.08
0029 159144M EMERGENCY TOWING SERVICE	1.000	U	150.00000	150.00	315.00000	315.00	1000.00000	1000.00
0030 161003P FINAL CLEANUP		LUMP	5000.00000	5000.00	6324.00000	6324.00	3000.00000	3000.00
0031 201003P CLEARING SITE		LUMP	40000.00000	40000.00	40000.00000	40000.00	40000.00000	40000.00
0032 202009P EXCAVATION, UNCLASSIFIED	198.000	CY	50.00000	9900.00	45.00000	8910.00	150.00000	29700.00
0033 203021P I-14 SOIL AGGREGATE	3.000	CY	60.00000	180.00	555.00000	1665.00	150.00000	450.00
0034 301006P SUBBASE	26.000	CY	80.00000	2080.00	79.00000	2054.00	75.00000	1950.00
0035 304009P CONCRETE BASE COURSE, 10" THICK	75.000	SY	50.00000	3750.00	84.00000	6300.00	125.00000	9375.00
0036 401009P HMA MILLING, 3" OR LESS	606.000	SY	15.00000	9090.00	17.00000	10302.00	10.00000	6060.00
0037 401030M TACK COAT	160.000	GAL	3.00000	480.00	3.00000	480.00	1.00000	160.00

TABULATION OF BIDS

CALL ORDER : 151
LETTING DATE : 07/23/09 10:00AM
CONTRACT ID : 09151
DISTRICT : N1
COUNTIES : PASSAIC

SET-ASIDE :

LINE NO / ITEM CODE / ALT ITEM DESCRIPTION	QUANTITY	(1) R4689 RITACCO CONSTRUCTION INC UNIT PRICE	AMOUNT	(2) F2743 FERREIRA CONSTRUCTION CO INC UNIT PRICE	AMOUNT	(3) C7279 J.F.CREAMER J-V J.M. SANZARI UNIT PRICE	AMOUNT
0038 401045M HOT MIX ASPHALT 9.5 H 64 SURFACE COURSE	181.000 T	95.00000	17195.00	114.00000	20634.00	80.00000	14480.00
0039 401087M HOT MIX ASPHALT 19 H 64 INTERMEDIATE COURSE	159.000 T	88.00000	13992.00	117.00000	18603.00	80.00000	12720.00
0040 405003P UNDERLAYER PREPARATION	75.000 SY	7.00000	525.00	9.00000	675.00	7.00000	525.00
0042 602099M RESET EXISTING CASTING	2.000 U	500.00000	1000.00	311.00000	622.00	400.00000	800.00
0044 605183P TEMPORARY CHAIN-LINK FENCE, 6' HIGH	250.000 LF	4.00000	1000.00	26.00000	6500.00	20.00000	5000.00
0045 606006P HOT MIX ASPHALT SIDEWALK, 5" THICK	153.000 SY	25.00000	3825.00	37.00000	5661.00	50.00000	7650.00
0046 606012P CONCRETE SIDEWALK, 4" THICK	136.000 SY	37.00000	5032.00	51.00000	6936.00	55.00000	7480.00
0047 606036P HOT MIX ASPHALT DRIVEWAY, 4" THICK	25.000 SY	65.00000	1625.00	105.00000	2625.00	75.00000	1875.00
0048 607024P 9" X 20" CONCRETE VERTICAL CURB	581.000 LF	20.00000	11620.00	20.00000	11620.00	25.00000	14525.00
0049 610003M TRAFFIC STRIPES, LONG LIFE, EPOXY RESIN 4"	5342.000 LF	0.50000	2671.00	0.80000	4273.60	0.46000	2457.32
0050 651051P 4" DUCTILE IRON WATER PIPE, CLASS 52	80.000 LF	100.00000	8000.00	105.00000	8400.00	70.00000	5600.00
0051 651058P 8" DUCTILE IRON WATER PIPE, CLASS 54	413.000 LF	125.00000	51625.00	215.00000	88795.00	150.00000	61950.00
0052 651246M FIRE HYDRANT	1.000 U	5000.00000	5000.00	7875.00000	7875.00	5500.00000	5500.00
0053 651261M INSERTION VALVES AND BOXES	2.000 U	9000.00000	18000.00	5250.00000	10500.00	12000.00000	24000.00
0054 652432M RESET MANHOLE, SANITARY SEWER, USING EXISTING CASTING	1.000 U	500.00000	500.00	569.00000	569.00	500.00000	500.00
0055 653015M GAS MAIN, TIE-IN ASSISTANCE	24.000 MH	550.00000	13200.00	567.00000	13608.00	500.00000	12000.00
0056 653018P 12" GAS MAIN	80.000 LF	90.00000	7200.00	368.00000	29440.00	165.00000	13200.00
0057 653057P 12" GAS MAIN, BRIDGE	153.000 LF	200.00000	30600.00	352.00000	53856.00	125.00000	19125.00

TABULATION OF BIDS

CALL ORDER : 151 CONTRACT ID : 09151 COUNTIES : PASSAIC
LETTING DATE : 07/23/09 10:00AM DISTRICT : N1

SET-ASIDE :

LINE NO / ITEM CODE / ALT ITEM DESCRIPTION	QUANTITY	(1) R4689 RITACCO CONSTRUCTION INC UNIT PRICE	AMOUNT	(2) F2743 FERREIRA CONSTRUCTION CO INC UNIT PRICE	AMOUNT	(3) C7279 J.F.CREAMER J-V J.M. SANZARI UNIT PRICE	AMOUNT
0058 653084M RESET GAS VALVE BOX	1.000 U	185.00000	185.00	210.00000	210.00	500.00000	500.00
0059 653090M GAS LINE EXCAVATION, UNCLASSIFIED	75.000 CY	200.00000	15000.00	89.00000	6675.00	275.00000	20625.00
0060 653092M GAS MAIN INSTALLATION, BACKFILL	30.000 CY	13.00000	390.00	36.00000	1080.00	28.00000	840.00
0061 653093M GAS LINE BEDDING	37.000 CY	14.00000	518.00	38.00000	1406.00	30.00000	1110.00
0062 653096M GAS EXPANSION CHAMBER	1.000 U	2600.00000	2600.00	16800.00000	16800.00	15000.00000	15000.00
0063 653106M GAS MAIN INSTALLATION, EXCAVATION FOR TEST PITS	4.000 CY	90.00000	360.00	420.00000	1680.00	400.00000	1600.00
0064 653107M GAS MAIN INSTALLATION, COARSE AGGREGATE #57	10.000 CY	22.00000	220.00	34.00000	340.00	28.00000	280.00
0065 653108M FABRICATE TIE-IN PIECE	2.000 U	1500.00000	3000.00	1260.00000	2520.00	2400.00000	4800.00
0066 702054M TEMPORARY TRAFFIC SIGNAL SYSTEM, LOCATION NO. ___ GROVE STREET	LUMP	50000.00000	50000.00	60000.90000	60000.90	71000.00000	71000.00
SECTION TOTALS		$	723,073.00	$	1,217,126.50	$	968,431.40
SECTION 0002 CONSTRUCTION ENGINEERING							
0008 155006M FIELD OFFICE TYPE B SET UP	1.000 U	25000.00000	25000.00	21000.00000	21000.00	30000.00000	30000.00
0009 155024M FIELD OFFICE TYPE B MAINTENANCE	16.000 MO	500.00000	8000.00	2000.00000	32000.00	1000.00000	16000.00
0010 155039M TELEPHONE SERVICE	LUMP	4000.00000	4000.00	4000.00000	4000.00	4000.00000	4000.00
SECTION TOTALS		$	37,000.00	$	57,000.00	$	50,000.00
SECTION 0003 NON PARICIPATING							
0001 151003M PERFORMANCE BOND AND PAYMENT BOND	LUMP	15000.00000	15000.00	6300.00000	6300.00	22000.00000	22000.00
0002 152003P OWNER'S AND CONTRACTOR'S PROTECTIVE LIABILITY INSURANCE	LUMP	10000.00000	10000.00	15135.00000	15135.00	10000.00000	10000.00

CALL ORDER : 151
LETTING DATE : 07/23/09 10:00AM

CONTRACT ID : 09151
DISTRICT : N1

COUNTIES : PASSAIC

SET-ASIDE :

LINE NO / ITEM CODE / ALT ITEM DESCRIPTION	QUANTITY	(1) R4689 RITACCO CONSTRUCTION INC UNIT PRICE	AMOUNT	(2) F2743 FERREIRA CONSTRUCTION CO INC UNIT PRICE	AMOUNT	(3) C7279 J.F.CREAMER J-V J.M. SANZARI UNIT PRICE	AMOUNT
0003 152009P POLLUTION LIABILITY INSURANCE	LUMP	15000.00000	15000.00	1.00000	1.00	100.00000	100.00
0041 601670M CLEANING EXISTING PIPE, 12" TO 24" DIAMETER	495.000 LF	5.00000	2475.00	6.00000	2970.00	8.00000	3960.00
0043 602216M CLEANING DRAINAGE STRUCTURE	8.000 U	750.00000	6000.00	263.00000	2104.00	300.00000	2400.00
SECTION TOTALS		$	48,475.00	$	26,510.00	$	38,460.00
SECTION 0004 EROSION CONTROL							
0012 158012M HEAVY DUTY SILT FENCE, BLACK	218.000 LF	4.00000	872.00	9.00000	1962.00	6.00000	1308.00
0013 158027M INLET FILTER TYPE 1	56.000 SF	33.00000	1848.00	38.00000	2128.00	12.00000	672.00
0014 158063P CONCRETE WASHOUT SYSTEM	LUMP	5000.00000	5000.00	6300.00000	6300.00	1500.00000	1500.00
0015 158072M OIL ONLY EMERGENCY SPILL KIT, TYPE 1	1.000 U	800.00000	800.00	786.00000	786.00	1000.00000	1000.00
0016 158084M EROSION CONTROL SEDIMENT REMOVAL	2.000 CY	200.00000	400.00	666.00000	1332.00	100.00000	200.00
SECTION TOTALS		$	8,920.00	$	12,508.00	$	4,680.00
SECTION 0005 GENERAL LANDSCAPE							
0067 804006P TOPSOILING, 4" THICK	175.000 SY	5.00000	875.00	5.00000	875.00	7.00000	1225.00
0068 804009P TOPSOILING, 6" THICK	114.000 SY	6.00000	684.00	7.00000	798.00	7.00000	798.00
0069 806006P FERTILIZING AND SEEDING, TYPE A-3	289.000 SY	2.00000	578.00	2.00000	578.00	2.00000	578.00
0070 809003M STRAW MULCHING	289.000 SY	2.00000	578.00	2.00000	578.00	0.46000	132.94
SECTION TOTALS		$	2,715.00	$	2,829.00	$	2,733.94
SECTION 0006 BRIDGE							
0071 201006P CLEARING SITE, BRIDGE (___) GROVE STREE	LUMP	100000.00000	100000.00	100000.00000	100000.00	100000.00000	100000.00

TABULATION OF BIDS

CALL ORDER : 151
LETTING DATE : 07/23/09 10:00AM
CONTRACT ID : 09151
DISTRICT : N1
COUNTIES : PASSAIC

SET-ASIDE :

LINE NO / ITEM CODE / ALT ITEM DESCRIPTION	QUANTITY	(1) R4689 RITACCO CONSTRUCTION INC UNIT PRICE	AMOUNT	(2) F2743 FERREIRA CONSTRUCTION CO INC UNIT PRICE	AMOUNT	(3) C7279 J.F.CREAMER J-V J.M. SANZARI UNIT PRICE	AMOUNT
0072 201039P TEMPORARY SHIELDING	LUMP	250000.00000	250000.00	183488.00000	183488.00	400000.00000	400000.00
0073 501003P TEMPORARY SHEETING	150.000 SF	100.00000	15000.00	50.00000	7500.00	200.00000	30000.00
0074 504006P REINFORCEMENT STEEL, EPOXY-COATED	83745.000 LB	1.50000	125617.50	1.50000	125617.50	1.65000	138179.25
0075 504018P CONCRETE WING WALL	36.000 CY	1500.00000	54000.00	1240.00000	44640.00	1900.00000	68400.00
0076 504024P CONCRETE ABUTMENT WALL	200.000 CY	1000.00000	200000.00	798.00000	159600.00	1300.00000	260000.00
0077 504027P CONCRETE PIER COLUMN AND CAP	4.000 CY	3000.00000	12000.00	4453.00000	17812.00	6000.00000	24000.00
0078 504036P EPOXY WATERPROOFING	82.000 SY	40.00000	3280.00	49.00000	4018.00	70.00000	5740.00
0079 506003P STRUCTURAL STEEL	LUMP	614819.50000	614819.50	600000.00000	600000.00	550000.00000	550000.00
0080 506006P REINFORCED ELASTOMERIC BEARING ASSEMBLY	30.000 U	2000.00000	60000.00	1935.00000	58050.00	1300.00000	39000.00
0081 506012P SHEAR CONNECTOR	3600.000 U	4.00000	14400.00	4.00000	14400.00	4.20000	15120.00
0082 507015P STRIP SEAL EXPANSION JOINT ASSEMBLY	210.000 LF	250.00000	52500.00	371.00000	77910.00	375.00000	78750.00
0083 507024P CONCRETE BRIDGE DECK, HPC	209.000 CY	1500.00000	313500.00	1358.00000	283822.00	1400.00000	292600.00
0084 507033P CONCRETE BRIDGE SIDEWALK, HPC	44.000 CY	350.00000	15400.00	415.00000	18260.00	600.00000	26400.00
0085 507039P CONCRETE BRIDGE PARAPET, HPC	460.000 LF	200.00000	92000.00	236.00000	108560.00	150.00000	69000.00
0086 509078P CHAIN-LINK FENCE, ALUMINUM-COATED STEEL BRIDGE, 6' 3" HIGH, CURVED TOP	460.000 LF	80.00000	36800.00	94.00000	43240.00	75.00000	34500.00
0087 555003M SUBSTRUCTURE CONCRETE REPAIR	100.000 SF	75.00000	7500.00	350.00000	35000.00	200.00000	20000.00
SECTION TOTALS		$	1,966,817.00	$	1,881,917.50	$	2,151,689.25
CONTRACT TOTALS		$	2,787,000.00	$	3,197,891.00	$	3,215,994.59

I CERTIFY THAT THE ABOVE IS AN EXACT TRANSCRIPT OF THE ORIGINAL BID PROPOSAL, EXCEPT THAT ERRORS, IF ANY, IN EXTENSION AND ADDITIONS HAVE BEEN CORRECTED.

SIGNED,

Results

NJDOT Contract Num 135083070 Contract ID 10101

SECTION 1:	Materials	
Direct CO2	26.53	(mt)
Direct CH4	0.00	(mt)
Direct N2O	0.00	(mt)
Direct CO2 Equivalent	**26.67**	**(mt)**
Upstream CO2	529.24	(mt)
Upstream CH4	2.45	(mt)
Upstream N2O	1.72	(mt)
Upstream CO2 Equivalent	**1,112.77**	**(mt)**
Combined CO2 Equivalent	**1,139.44**	**(mt)**

SECTION 2:	Equipment	
Direct CO2	129.64	(mt)
Direct CH4	0.00	(mt)
Direct N2O	0.00	(mt)
Direct PMBC	0.02	(mt)
Direct CO2 Equiv. from HFCs	0.13	(mt)
Direct CO2 Equivalent	**130.35**	**(mt)**
Upstream CO2	2.02	(mt)
Upstream CH4	0.27	(mt)
Upstream N2O	0.00	(mt)
Upstream PMBC	0.00	(mt)
Upstream CO2 Equivalent	**8.79**	**(mt)**
Combined CO2 Equivalent	**139.14**	**(mt)**

SECTION 3:	Recyclables Credits	
CO2	2.12	(mt)
CH4	0.00	(mt)
N2O	0.00	(mt)
Total CO2 Equivalent	**3.64**	**(mt)**

OVERALL RESULTS		
CO2	696.33	(mt)
CH4	2.74	(mt)
N2O	1.72	(mt)
PMBC	0.02	(mt)
Total CO2 Equivalent	1,287.45	(mt)

Fuel Consumption		
Gasoline (10% Ethanol RFG)	272.33	gallons
Gasoline	484.90	gallons
20% Biodiesel	22,685.44	gallons
Diesel	0.00	gallons
Liquified Petroleum Gas	0.00	gallons
Compressed Natural Gas	0.00	GGE

Fuel Costs	
Gasoline (10% Ethanol RFG)	$ per gallon
Gasoline	$ per gallon
20% Biodiesel	$ per gallon
Diesel	$ per gallon
Liquified Petroleum Gas	$ per gallon
Compressed Natural Gas	$ per GGE
Total Fuel Cost	$88,099.30

SECTION 4:	Lifecycle Maintenance	
Direct CO2	0.00	(mt)
Direct CH4	0.00	(mt)
Direct N2O	0.00	(mt)
Direct PMBC	0.00	(mt)
Direct CO2 Equivalent	**0.00**	**(mt)**
Upstream CO2	0.00	(mt)
Upstream CH4	0.00	(mt)
Upstream N2O	0.00	(mt)
Upstream PMBC	0.00	(mt)
Upstream CO2 Equivalent	**0.00**	**(mt)**
Combined CO2 Equivalent	**0.00**	**(mt)**

SECTION 5:	Staging	
Direct CO2	10.09	(mt)
Direct CH4	0.00	(mt)
Direct N2O	0.00	(mt)
Direct CO2 Equiv. from HFCs	0.92	(mt)
Direct CO2 Equivalent	**11.18**	**(mt)**
Upstream CO2	0.94	(mt)
Upstream CH4	0.01	(mt)
Upstream N2O	0.00	(mt)
Upstream CO2 Equivalent	**1.32**	**(mt)**
Combined CO2 Equivalent	**12.51**	**(mt)**

SECTION 6:	Lighting	
Direct CO2	0.00	(mt)
Direct CH4	0.00	(mt)
Direct N2O	0.00	(mt)
Direct CO2 Equivalent	**0.00**	**(mt)**

SECTION 7:	Rail	
Direct CO2	0.00	(mt)
Upstream and Disposal CO2	0.00	(mt)
Upstream and Disposal CH4	0.00	(mt)
Upstream and Disposal N2O	0.00	(mt)
Total CO2 Equivalent	**0.00**	**(mt)**

Materials

Item Code	Description	Value	Unit	Cement Ratio	Aggregate Ratio	Heating Temp.	% Binder	% Moisture	Cutback	Depth (feet)
609004M	Beam Guide Rail, Bridge	160.00	Feet	N/A	N/A	N/A	N/A	N/A	Non-Solvent-N/A	N/A
507047M	21" By 36" Concrete Barrier Curb, Bridge, Precast	172.00	Feet	0.15	0.80	N/A	N/A	N/A	Non-Solvent-N/A	N/A
507039P	Concrete Bridge Parapet, Hpc	292.00	Feet	0.15	0.80	N/A	N/A	N/A	Non-Solvent-N/A	N/A
507033P	Concrete Bridge Sidewalk, Hpc	25.00	Cu. Yards	0.15	0.80	N/A	N/A	N/A	Non-Solvent-N/A	N/A
504024P	Concrete Abutment Wall	290.00	Cu. Yards	0.15	0.80	N/A	N/A	N/A	Non-Solvent-N/A	N/A
504018P	Concrete Wing Wall	15.00	Cu. Yards	0.15	0.80	N/A	N/A	N/A	Non-Solvent-N/A	N/A
504015P	Concrete Footing	115.00	Cu. Yards	0.15	0.80	N/A	N/A	N/A	Non-Solvent-N/A	N/A
504006P	Reinforcement Steel, Epoxy-Coated	24,700.00	Pounds	N/A	N/A	N/A	N/A	N/A	Non-Solvent-N/A	N/A
602214M	Inlet Face Plate	15.00	Units	N/A	N/A	N/A	N/A	N/A	Non-Solvent-N/A	N/A
602210M	Bicycle Safe Grate	15.00	Units	N/A	N/A	N/A	N/A	N/A	Non-Solvent-N/A	N/A
609033M	Controlled Release Terminal	1.00	Units	N/A	N/A	N/A	N/A	N/A	Non-Solvent-N/A	N/A
609021M	Rub Rail	795.00	Feet	N/A	N/A	N/A	N/A	N/A	Non-Solvent-N/A	N/A
609006M	Beam Guide Rail, Dual-Faced	471.00	Feet	N/A	N/A	N/A	N/A	N/A	Non-Solvent-N/A	N/A
609003M	Beam Guide Rail	1,940.00	Feet	N/A	N/A	N/A	N/A	N/A	Non-Solvent-N/A	N/A
608003P	Nonvegetative Surface, Hot Mix Asphalt	513.00	Sq. Yard	N/A	N/A	N/A	0.04	0.04	Non-Solvent-N/A	N/A
607021P	9" X 18" Concrete Vertical Curb	359.00	Feet	0.15	0.80	N/A	N/A	N/A	Non-Solvent-N/A	N/A
607018P	9" X 16" Concrete Vertical Curb	490.00	Feet	0.15	0.80	N/A	N/A	N/A	Non-Solvent-N/A	N/A
606051P	Concrete Driveway, 6" Thick	32.00	Sq. Yard	0.15	0.80	N/A	N/A	N/A	Non-Solvent-N/A	N/A
606012P	Concrete Sidewalk, 4" Thick	181.00	Sq. Yard	0.15	0.80	N/A	N/A	N/A	Non-Solvent-N/A	N/A
401099M	HMA - Base Course	170.00	Tons	N/A	N/A	325.00	0.04	0.04	Non-Solvent-N/A	N/A
401093M	HMA - Intermediate Course	560.00	Tons	N/A	N/A	325.00	0.04	0.04	Non-Solvent-N/A	N/A
401063M	HMA - Surface Course	520.00	Tons	N/A	N/A	325.00	0.05	0.04	Non-Solvent-N/A	N/A
401036M	Prime Coat, Cut-Back Asphalt	425.00	Gallons	N/A	N/A	120.00	N/A	N/A	MC-0.3	N/A
401030M	Tack Coat	900.00	Gallons	N/A	N/A	145.00	N/A	N/A	Non-Solvent-0	N/A
302036P	Dense-Graded Aggregate Base Course, 6" Thick	1,124.00	Sq. Yards	N/A	N/A	N/A	N/A	N/A	Non-Solvent-N/A	N/A
302033P	Dense-Graded Aggregate Base Course, 4" Thick	181.00	Sq. Yards	N/A	N/A	N/A	N/A	N/A	Non-Solvent-N/A	N/A

		Direct CO_2 (g)	Direct CH_4 (g)	Direct N_2O (g)	Direct CO_2 Equiv. (g)	Upstream CO_2 (g)	Upstream CH_4 (g)	Upstream N_2O (g)	Upstream CO_2 Equiv. (g)
609004M	Beam Guide Rail, Bridge	0.00	0.00	0.00	0.00	3,949,423.12	5,252.53	27.98	4,068,398.84
507047M	21" By 36" Concrete Barrier Curb, Bridge, Precast	0.00	0.00	0.00	0.00	14,480,514.56	762,977.86	751,149.13	263,359,281.10
507039P	Concrete Bridge Parapet, Hpc	0.00	0.00	0.00	0.00	120,807,237.18	128,549.86	1,900.64	124,095,983.66
507033P	Concrete Bridge Sidewalk, Hpc	0.00	0.00	0.00	0.00	15,919,856.67	13,730.38	903.43	16,488,258.81
504024P	Concrete Abutment Wall	0.00	0.00	0.00	0.00	98,665,394.34	64,923.07	10,078.89	103,153,235.54
504018P	Concrete Wing Wall	0.00	0.00	0.00	0.00	5,103,382.47	3,358.09	521.32	5,335,512.18
504015P	Concrete Footing	0.00	0.00	0.00	0.00	39,125,932.24	25,745.35	3,996.80	40,905,593.40
504006P	Reinforcement Steel, Epoxy-Coated	0.00	0.00	0.00	0.00	35,204,769.32	38,387.27	215.89	36,077,826.48
602214M	Inlet Face Plate	0.00	0.00	0.00	0.00	5,453,670.74	4,021.56	18.41	5,543,830.29
602210M	Bicycle Safe Grate	0.00	0.00	0.00	0.00	5,453,670.74	4,021.56	18.41	5,543,830.29
609033M	Controlled Release Terminal	0.00	0.00	0.00	0.00	338,343.69	453.16	2.45	348,620.62
609021M	Rub Rail	0.00	0.00	0.00	0.00	44,359,444.09	57,032.63	302.74	45,650,978.83
609006M	Beam Guide Rail, Dual-Faced	0.00	0.00	0.00	0.00	16,302,850.16	21,830.94	116.02	16,797,267.56
609003M	Beam Guide Rail	0.00	0.00	0.00	0.00	47,886,755.32	63,686.91	339.21	49,329,335.90
608003P	Nonvegetative Surface, Hot Mix Asphalt	1,390,145.77	54.71	21.07	1,397,825.39	2,211,635.12	13,300.57	36.11	2,502,140.73
607021P	9" X 18" Concrete Vertical Curb	0.00	0.00	0.00	0.00	7,056,932.11	427,475.42	421,999.17	146,853,659.65
607018P	9" X 16" Concrete Vertical Curb	0.00	0.00	0.00	0.00	8,668,821.89	525,116.04	518,388.96	180,396,835.39
606051P	Concrete Driveway, 6" Thick	0.00	0.00	0.00	0.00	1,814,535.99	1,193.99	185.36	1,897,071.00
606012P	Concrete Sidewalk, 4" Thick	0.00	0.00	0.00	0.00	6,842,312.79	4,502.33	698.96	7,153,538.56
401099M	HMA - Base Course	3,295,222.37	129.68	49.94	3,313,426.25	5,242,493.03	31,527.87	85.59	5,931,111.89
401093M	HMA - Intermediate Course	10,854,850.17	427.17	164.50	10,914,815.87	17,269,388.81	103,856.51	281.95	19,537,780.35
401063M	HMA - Surface Course	10,109,229.06	397.09	153.20	10,165,060.37	21,093,747.36	124,861.93	343.55	23,822,348.46
401036M	Prime Coat, Cut-Back Asphalt	850,536.53	0.12	0.12	850,577.44	1,169,093.78	6,536.31	18.88	1,312,208.77
401030M	Tack Coat	26,690.29	0.39	0.40	26,823.96	2,697,985.06	15,097.40	43.57	3,028,538.49
302036P	Dense-Graded Aggregate Base Course, 6" Thick	0.00	0.00	0.00	0.00	1,917,722.20	1,436.60	4,319.96	3,287,079.47
302033P	Dense-Graded Aggregate Base Course, 4" Thick	0.00	0.00	0.00	0.00	205,876.46	154.23	463.77	352,883.38

Equipment

Year	Description	Fuel Type	Power Rating	Hours	Air Conditioning	Direct CO2 (g)	Direct CH4 (g)	Direct N2O (g)	Direct PMBC (g)	Direct CO2 Equiv. from HFCs(g)	Direct CO2 Equiv. (g)
2007	Cement & Mortar Mixers	20% Biodiesel	175	120	No	3,532,268.17	21.34	49.22	514.35	0.00	3,547,974.19
2010	Generator Sets	20% Biodiesel	100	404.1	No	9,973,817.74	49.55	111.13	1,845.93	0.00	10,009,307.87
2005	Cranes	20% Biodiesel	100	25	No	559,446.57	6.30	7.01	118.19	0.00	561,752.45
2006	Cranes	20% Biodiesel	600	60	No	5,644,980.39	30.27	78.66	558.02	0.00	5,670,000.34
2009	Concrete/Industrial Saws	20% Biodiesel	100	35	No	1,002,998.10	6.20	12.45	329.28	0.00	1,006,987.71
1995	Asphalt Pavers	4 Stroke Gasoline (10% Ethanol RFG)	75	45	No	2,329,923.68	1,430.45	13.72	34.81	0.00	2,364,215.19
1996	Pavers	20% Biodiesel	300	150	No	10,505,487.56	105.87	144.80	3,049.63	0.00	10,552,598.30
2006	Paving Equipment	20% Biodiesel	175	50	No	2,079,577.49	22.42	28.66	360.51	0.00	2,088,933.79
2003	Excavators	20% Biodiesel	100	300	No	9,674,785.42	148.13	120.07	5,158.23	0.00	9,715,117.74
2008	Crawler Tractors	20% Biodiesel	1200	250	Yes	84,333,496.90	506.66	1,162.45	9,190.63	132,119.37	84,836,614.90

Year	Description	Fuel Type	Power Rating	Hours	Upstream CO2 (g)	Upstream CH4 (g)	Upstream N2O (g)	Upstream PMBC (g)	Upstream CO2 Equiv. (g)	Fuel Use	Fuel Unit
2007	Cement & Mortar Mixers	20% Biodiesel	175	120	42,132.71	9,814.42	60.05	58.95	266,850.69	803.16	gallons
2010	Generator Sets	20% Biodiesel	100	404.1	221,217.70	51,530.78	314.79	309.50	1,400,950.15	2,015.88	gallons
2005	Cranes	20% Biodiesel	100	25	6,672.56	1,554.31	9.51	9.34	42,261.15	127.20	gallons
2006	Cranes	20% Biodiesel	600	60	67,333.89	15,684.80	95.97	94.21	426,464.25	1,283.56	gallons
2009	Concrete/Industrial Saws	20% Biodiesel	100	35	20,281.40	4,724.36	28.91	28.38	128,453.80	166.25	gallons
1995	Asphalt Pavers	4 Stroke Gasoline (10% Ethanol RFG)	75	45	309,831.36	2,232.74	61.68	14.58	375,838.91	272.33	gallons
1996	Pavers	20% Biodiesel	300	150	212,186.70	49,426.92	302.41	296.88	1,343,900.40	1,739.28	gallons
2006	Paving Equipment	20% Biodiesel	175	50	24,781.35	5,772.58	35.32	34.67	156,954.52	344.29	gallons
2003	Excavators	20% Biodiesel	100	300	115,407.16	26,883.02	164.48	161.47	730,939.92	1,603.36	gallons
2008	Crawler Tractors	20% Biodiesel	1200	250	1,005,031.74	103,324.68	2,387.33	2,008.85	3,914,923.08	13,963.01	gallons

SECTION 3: RECYCLING CREDIT

NJDOT Contract Num 135083070 Contract ID 10101

Recycled Asphalt Pavement (RAP):	625,000	lb
Reclaimed Concrete Material (RCM):		lb
Foundry Sand:		lb
Coal Bottom Ash:		lb
Glass Cullet/CRCG:		lb
Ground Bituminous Shingle Material:		lb
Remediated Petroleum Contaminated Soil Aggregate:		lb
Blast Furnace Slag:		lb
Coal Fly Ash:		lb
Ground Granulated Blast Furnace Slag:		lb
Other Industrial Waste Products:		lb

RECYCLED MATERIALS CREDIT

CO_2	=	2.12	(mt)
CH_4	=	0.00	(mt)
N_2O	=	0.00	(mt)
Total CO_2 Equivalen	=	3.64	(mt)

Staging

Item	Year	Fuel Type	Distance (miles)	Number of Trips	Number of Vehicles	Direct CO2 (g)	Direct CH4 (g)	Direct N2O (g)	Direct CO2 Equiv. from HFCs(g)	Direct CO2 Equiv. (g)	Upstream CO2 (g)	Upstream CH4 (g)	Upstream N2O (g)	Upstream CO2 Equiv. (g)	Fuel Use (gal)
Light Commercial Truck	2004	Reformulated Gasoline	38	100	2	4,176,730.30	666.59	480.79	264,238.73	4,604,012.65	835,854.79	6,023.38	166.39	1,013,927.12	484.90
Combination Short-haul Truck	2002	BD20	37	24	2	3,665,072.33	4.65	4.39	264,238.73	3,930,769.46	62,723.89	4,586.90	108.71	192,747.96	396.24
Single Unit Short-haul Truck	2005	BD20	42	16	3	2,249,672.55	5.82	6.71	396,358.10	2,648,232.14	38,500.72	2,815.50	66.73	118,311.15	243.22

TABULATION OF BIDS

CALL ORDER : 101 CONTRACT ID : 10101 COUNTIES : MIDDLESEX
LETTING DATE : 03/18/10 10:00AM DISTRICT : C1
CONTRACT TIME : 01/09/11 COMPLETION DATE
CONTRACT DESCRIPTION : URBAN PROJECT(S) : BR-0001(250)
ROUTE 9 OVER MAIN STREET
BRIDGE SUPERSTRUCTURE REPLACEMENT
TOWNSHIP OF WOODBRIDGE, MIDDLESEX COUNTY
CONTRACT NO. 135083070

SET-ASIDE :

VENDOR RANKING :

RANK	VENDOR NO.	NAME		TOTAL BID	% OVER LOW BID
1	C7279	J.F.CREAMER & SON JOINT VENTURE WITH JOSEPH M. SANZARI,INC	$	2,737,987.25	100.0000%
2	I2943	IEW CONSTR GP	$	2,916,862.26	106.5331%
3	F2743	FERREIRA CONSTRUCTION CO INC	$	2,985,898.25	109.0545%
4	H3415	H&G CONTRACTORS INC	$	2,988,525.75	109.1505%
5	R4689	RITACCO CONSTRUCTION INC	$	2,994,775.85	109.3787%
6	M0545	MARBRO INC	$	3,043,520.13	111.1590%
7	S1082	SCAFAR CONTRACTING INC	$	3,099,001.52	113.1854%
8	M2685	MERCO INC T/A MERCO INC OF NJ	$	4,181,469.00	152.7205%

LINE NO / ITEM CODE / ALT ITEM DESCRIPTION	QUANTITY		(1) C7279 J.F.CREAMER J-V J.M. SANZARI UNIT PRICE	AMOUNT	(2) I2943 IEW CONSTR GP UNIT PRICE	AMOUNT	(3) F2743 FERREIRA CONSTRUCTION CO INC UNIT PRICE	AMOUNT
SECTION 0001 ROADWAY ITEMS								
0001 151003M PERFORMANCE BOND AND PAYMENT BOND		LUMP	25000.00000	25000.00	18816.77000	18816.77	27325.00000	27325.00
0004 153003P PROGRESS SCHEDULE		LUMP	8000.00000	8000.00	0.01000	0.01	3100.00000	3100.00
0005 153012P TRAINEES	1000.000	HOUR	1.00000	1000.00	0.01000	10.00	0.01000	10.00
0006 154003P MOBILIZATION		LUMP	273500.00000	273500.00	287642.66000	287642.66	298397.00000	298397.00
0010 157003M CONSTRUCTION LAYOUT		LUMP	30000.00000	30000.00	24416.72000	24416.72	57000.00000	57000.00
0013 158063P CONCRETE WASHOUT SYSTEM		LUMP	5000.00000	5000.00	14199.79000	14199.79	3000.00000	3000.00
0014 158072M OIL ONLY EMERGENCY SPILL KIT, TYPE 1	2.000	U	1100.00000	2200.00	1104.21000	2208.42	500.00000	1000.00
0016 159003M BREAKAWAY BARRICADE	120.000	U	100.00000	12000.00	59.08000	7089.60	106.00000	12720.00
0017 159006M DRUM	350.000	U	55.00000	19250.00	32.82000	11487.00	55.00000	19250.00

TABULATION OF BIDS

CALL ORDER : 101 CONTRACT ID : 10101 COUNTIES : MIDDLESEX
LETTING DATE : 03/18/10 10:00AM DISTRICT : C1

SET-ASIDE :

LINE NO / ITEM CODE / ALT ITEM DESCRIPTION	QUANTITY		(1) C7279 J.F.CREAMER J-V J.M. SANZARI UNIT PRICE	AMOUNT	(2) I2943 IEW CONSTR GP UNIT PRICE	AMOUNT	(3) F2743 FERREIRA CONSTRUCTION CO INC UNIT PRICE	AMOUNT
0018 159009M TRAFFIC CONE	400.000	U	12.00000	4800.00	3.92000	1568.00	6.00000	2400.00
0019 159012M CONSTRUCTION SIGNS	3550.000	SF	8.50000	30175.00	7.81000	27725.50	19.00000	67450.00
0020 159015M CONSTRUCTION IDENTIFICATION SIGN, 4' X 8'	4.000	U	1100.00000	4400.00	697.10000	2788.40	702.00000	2808.00
0021 159021P CONSTRUCTION BARRIER CURB	1450.000	LF	74.00000	107300.00	124.41000	180394.50	37.00000	53650.00
0022 159027M FLASHING ARROW BOARD, 4' X 8'	6.000	U	2100.00000	12600.00	0.01000	0.06	506.00000	3036.00
0023 159030M PORTABLE VARIABLE MESSAGE SIGN	8.000	U	8000.00000	64000.00	749.62000	5996.96	4045.00000	32360.00
0024 159108M TRAFFIC CONTROL TRUCK WITH MOUNTED CRASH CUSHION	2.000	U	11000.00000	22000.00	0.01000	0.02	5618.00000	11236.00
0025 159120M TEMPORARY PAVEMENT MARKING TAPE, 4"	2500.000	LF	1.80000	4500.00	1.51000	3775.00	3.00000	7500.00
0026 159138M HMA PATCH	40.000	T	150.00000	6000.00	223.07000	8922.80	500.00000	20000.00
0027 159141M TRAFFIC DIRECTOR, FLAGGER	500.000	HOUR	1.00000	500.00	82.84000	41420.00	58.00000	29000.00
0028 160003M FUEL PRICE ADJUSTMENT		LUMP	500.00000	500.00	500.00000	500.00	500.00000	500.00
0029 161003P FINAL CLEANUP		LUMP	3000.00000	3000.00	15282.47000	15282.47	12000.00000	12000.00
0030 201003P CLEARING SITE		LUMP	40000.00000	40000.00	39500.00000	39500.00	30000.00000	30000.00
0031 202006M EXCAVATION, TEST PIT	10.000	CY	300.00000	3000.00	187.40000	1874.00	251.00000	2510.00
0032 202009P EXCAVATION, UNCLASSIFIED	357.000	CY	125.00000	44625.00	20.84000	7439.88	60.00000	21420.00
0033 202018P EXCAVATION, ACID PRODUCING SOIL	20.000	CY	25.00000	500.00	51.72000	1034.40	77.00000	1540.00
0034 202021P REMOVAL OF PAVEMENT	3178.000	SY	12.00000	38136.00	4.18000	13284.04	5.00000	15890.00
0035 202033M SOIL SAMPLING AND ANALYSES, ACID PRODUCING SOIL	2.000	U	50.00000	100.00	892.29000	1784.58	524.00000	1048.00

TABULATION OF BIDS

CALL ORDER : 101
LETTING DATE : 03/18/10 10:00AM
CONTRACT ID : 10101
DISTRICT : C1
COUNTIES : MIDDLESEX

SET-ASIDE :

LINE NO / ITEM CODE / ALT ITEM DESCRIPTION	QUANTITY	(1) C7279 J.F.CREAMER J-V J.M. SANZARI UNIT PRICE	AMOUNT	(2) I2943 IEW CONSTR GP UNIT PRICE	AMOUNT	(3) F2743 FERREIRA CONSTRUCTION CO INC UNIT PRICE	AMOUNT
0036 202036P ACID PRODUCING SOIL REMEDIATION	13.000 SY	5.00000	65.00	57.66000	749.58	133.00000	1729.00
0037 202039M DISPOSAL OF ACID PRODUCING SOIL	2.000 T	15.00000	30.00	66.92000	133.84	212.00000	424.00
0038 302033P DENSE-GRADED AGGREGATE BASE COURSE, 4" THICK	181.000 SY	13.00000	2353.00	15.87000	2872.47	8.00000	1448.00
0039 302036P DENSE-GRADED AGGREGATE BASE COURSE, 6" THICK	1124.000 SY	17.00000	19108.00	14.60000	16410.40	19.00000	21356.00
0040 401009P HMA MILLING, 3" OR LESS	740.000 SY	7.00000	5180.00	3.07000	2271.80	4.00000	2960.00
0041 401027M POLYMERIZED JOINT ADHESIVE	3100.000 LF	1.10000	3410.00	0.56000	1736.00	0.55000	1705.00
0042 401030M TACK COAT	900.000 GAL	2.50000	2250.00	2.45000	2205.00	2.00000	1800.00
0043 401036M PRIME COAT	425.000 GAL	0.01000	4.25	5.58000	2371.50	0.01000	4.25
0044 401063M HOT MIX ASPHALT 12.5 H 76 SURFACE COURS	520.000 T	130.00000	67600.00	98.38000	51157.60	93.00000	48360.00
0045 401093M HOT MIX ASPHALT 19 H 76 INTERMEDIATE COURSE	560.000 T	120.00000	67200.00	95.59000	53530.40	90.00000	50400.00
0046 401099M HOT MIX ASPHALT 25 M 64 BASE COURSE	170.000 T	100.00000	17000.00	223.07000	37921.90	314.00000	53380.00
0047 401105M SAWING AND SEALING JOINTS IN HOT MIX ASPHALT OVERLAY	3200.000 LF	1.40000	4480.00	5.58000	17856.00	3.00000	9600.00
0048 602105M SET INLET TYPE B, CASTING	1.000 U	1500.00000	1500.00	1191.23000	1191.23	971.00000	971.00
0049 606012P CONCRETE SIDEWALK, 4" THICK	181.000 SY	60.00000	10860.00	60.23000	10901.63	59.00000	10679.00
0050 606051P CONCRETE DRIVEWAY, 6" THICK	32.000 SY	65.00000	2080.00	66.92000	2141.44	67.00000	2144.00
0051 606084P DETECTABLE WARNING SURFACE	1.000 SY	220.00000	220.00	223.07000	223.07	209.00000	209.00
0052 607018P 9" X 16" CONCRETE VERTICAL CURB	490.000 LF	22.00000	10780.00	20.97000	10275.30	20.00000	9800.00
0053 607021P 9" X 18" CONCRETE VERTICAL CURB	359.000 LF	24.00000	8616.00	22.53000	8088.27	22.00000	7898.00

CALL ORDER : 101
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CONTRACT ID : 10101
DISTRICT : C1
COUNTIES : MIDDLESEX

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LINE NO / ITEM CODE / ALT ITEM DESCRIPTION	QUANTITY	(1) C7279 J.F.CREAMER J-V J.M. SANZARI UNIT PRICE	AMOUNT	(2) I2943 IEW CONSTR GP UNIT PRICE	AMOUNT	(3) F2743 FERREIRA CONSTRUCTION CO INC UNIT PRICE	AMOUNT
0054 608003P NONVEGETATIVE SURFACE, HOT MIX ASPHALT	513.000 SY	26.00000	13338.00	30.32000	15554.16	37.00000	18981.00
0055 609003M BEAM GUIDE RAIL	1940.000 LF	20.00000	38800.00	24.39000	47316.60	17.00000	32980.00
0056 609006M BEAM GUIDE RAIL, DUAL-FACED	471.000 LF	35.00000	16485.00	24.44000	11511.24	29.00000	13659.00
0057 609021M RUB RAIL	795.000 LF	6.00000	4770.00	8.59000	6829.05	7.00000	5565.00
0058 609033M CONTROLLED RELEASE TERMINAL	1.000 U	1000.00000	1000.00	1070.71000	1070.71	1250.00000	1250.00
0059 610003M TRAFFIC STRIPES, LONG LIFE, EPOXY RESIN 4"	2500.000 LF	1.00000	2500.00	0.78000	1950.00	0.45000	1125.00
0060 610009M TRAFFIC MARKINGS, THERMOPLASTIC	90.000 SF	5.00000	450.00	16.73000	1505.70	4.00000	360.00
0061 610012M RPM, MONO-DIRECTIONAL, WHITE LENS	21.000 U	50.00000	1050.00	68.32000	1434.72	27.00000	567.00
0062 652417M SANITARY SEWER SERVICE CONNECTION	1.000 U	5500.00000	5500.00	15409.85000	15409.85	5998.00000	5998.00
0086 159066M TEMPORARY CRASH CUSHION, QUADGUARD 4 BAYS X 24" WIDE	1.000 U	12000.00000	12000.00	20411.15000	20411.15	6030.00000	6030.00
0087 602210M BICYCLE SAFE GRATE	15.000 U	325.00000	4875.00	1528.96000	22934.40	413.00000	6195.00
SECTION TOTALS		$	1,085,590.25	$	1,087,126.59	$	1,053,727.25
SECTION 0002 CONSTRUCTION ENGINEERING ITEMS							
0007 155006M FIELD OFFICE TYPE B SET UP	1.000 U	30000.00000	30000.00	45802.34000	45802.34	20000.00000	20000.00
0008 155024M FIELD OFFICE TYPE B MAINTENANCE	9.000 MO	1500.00000	13500.00	2007.65000	18068.85	2200.00000	19800.00
0009 155039M TELEPHONE SERVICE	LUMP	3250.00000	3250.00	3250.00000	3250.00	3250.00000	3250.00
SECTION TOTALS		$	46,750.00	$	67,121.19	$	43,050.00
SECTION 0003 NON-PARTICIPATING ITMES (ROADWAY)							
0002 152003P OWNER'S AND CONTRACTOR'S PROTECTIVE LIABILITY INSURANCE	LUMP	9500.00000	9500.00	5668.83000	5668.83	15300.00000	15300.00

TABULATION OF BIDS

CALL ORDER : 101 CONTRACT ID : 10101 COUNTIES : MIDDLESEX
LETTING DATE : 03/18/10 10:00AM DISTRICT : C1

SET-ASIDE :

LINE NO / ITEM CODE / ALT ITEM DESCRIPTION	QUANTITY	(1) C7279 J.F.CREAMER J-V J.M. SANZARI UNIT PRICE	AMOUNT	(2) I2943 IEW CONSTR GP UNIT PRICE	AMOUNT	(3) F2743 FERREIRA CONSTRUCTION CO INC UNIT PRICE	AMOUNT
0003 152009P POLLUTION LIABILITY INSURANCE	LUMP	1000.00000	1000.00	0.01000	0.01	1.00000	1.00
SECTION TOTALS		$	10,500.00	$	5,668.84	$	15,301.00
SECTION 0004 EROSION CONTROL							
0011 158012M HEAVY DUTY SILT FENCE, BLACK	407.000 LF	8.00000	3256.00	6.18000	2515.26	5.00000	2035.00
0012 158030M INLET FILTER TYPE 2, 2' X 4'	15.000 U	150.00000	2250.00	90.35000	1355.25	150.00000	2250.00
0015 158084M EROSION CONTROL SEDIMENT REMOVAL	26.000 CY	75.00000	1950.00	117.56000	3056.56	150.00000	3900.00
0088 602214M INLET FACE PLATE	15.000 U	200.00000	3000.00	298.94000	4484.10	270.00000	4050.00
SECTION TOTALS		$	10,456.00	$	11,411.17	$	12,235.00
SECTION 0005 GENERAL LANDSCAPE ITEMS							
0063 804006P TOPSOILING, 4" THICK	301.000 SY	2.50000	752.50	5.58000	1679.58	4.00000	1204.00
0064 806006P FERTILIZING AND SEEDING, TYPE A-3	301.000 SY	1.50000	451.50	0.84000	252.84	2.00000	602.00
0065 806018P FERTILIZING AND SEEDING, TYPE F	30.000 SY	1.50000	45.00	1.12000	33.60	0.60000	18.00
0066 807003M TOPSOIL STABILIZATION, TYPE 1 MAT	147.000 SY	5.00000	735.00	5.02000	737.94	4.00000	588.00
0067 809003M STRAW MULCHING	198.000 SY	1.50000	297.00	0.84000	166.32	1.50000	297.00
SECTION TOTALS		$	2,281.00	$	2,870.28	$	2,709.00
SECTION 0006 ROUTE 9 BRIDGE (STRUCTURE NO. 1210-150)							
0068 201006P CLEARING SITE, BRIDGE (___) STR. NO. 1210-150	LUMP	180000.00000	180000.00	179500.00000	179500.00	166000.00000	166000.00
0069 202009P EXCAVATION, UNCLASSIFIED	450.000 CY	125.00000	56250.00	73.56000	33102.00	57.00000	25650.00
0070 504006P REINFORCEMENT STEEL, EPOXY-COATED	24700.000 LB	2.00000	49400.00	3.92000	96824.00	2.00000	49400.00

TABULATION OF BIDS

CALL ORDER : 101
LETTING DATE : 03/18/10 10:00AM
CONTRACT ID : 10101
DISTRICT : C1
COUNTIES : MIDDLESEX

SET-ASIDE :

LINE NO / ITEM CODE / ALT ITEM DESCRIPTION	QUANTITY		(1) C7279 J.F.CREAMER J-V J.M. SANZARI UNIT PRICE	AMOUNT	(2) I2943 IEW CONSTR GP UNIT PRICE	AMOUNT	(3) F2743 FERREIRA CONSTRUCTION CO INC UNIT PRICE	AMOUNT
0071 504015P CONCRETE FOOTING	115.000	CY	600.00000	69000.00	536.02000	61642.30	323.00000	37145.00
0072 504018P CONCRETE WING WALL	15.000	CY	1800.00000	27000.00	2477.83000	37167.45	1550.00000	23250.00
0073 504024P CONCRETE ABUTMENT WALL	290.000	CY	600.00000	174000.00	598.89000	173678.10	800.00000	232000.00
0074 504036P EPOXY WATERPROOFING	70.000	SY	50.00000	3500.00	62.27000	4358.90	59.00000	4130.00
0075 504061P TEMPORARY SHORING		LUMP	1500.00000	1500.00	41271.43000	41271.43	50000.00000	50000.00
0076 505063P PREFABRICATED SUPERSTRUCTURE UNITS	5420.000	SF	151.00000	818420.00	154.79000	838961.80	182.00000	986440.00
0077 507020P ASPHALTIC BRIDGE JOINT SYSTEM	125.000	LF	140.00000	17500.00	131.37000	16421.25	210.00000	26250.00
0078 507027M DATE PANEL	2.000	U	1200.00000	2400.00	767.12000	1534.24	1200.00000	2400.00
0079 507033P CONCRETE BRIDGE SIDEWALK, HPC	25.000	CY	450.00000	11250.00	0.01000	0.25	780.00000	19500.00
0080 507039P CONCRETE BRIDGE PARAPET, HPC	292.000	LF	250.00000	73000.00	256.53000	74906.76	240.00000	70080.00
0081 507047M 21" BY 36" CONCRETE BARRIER CURB, BRIDGE, PRECAST	172.000	LF	220.00000	37840.00	503.70000	86636.40	391.00000	67252.00
0082 551021M HEADER RECONSTRUCTION	162.000	LF	160.00000	25920.00	219.29000	35524.98	295.00000	47790.00
0083 555006M BRIDGE DECK WATERPROOF SURFACE COURSE	55.000	T	210.00000	11550.00	446.15000	24538.25	419.00000	23045.00
0084 609004M BEAM GUIDE RAIL, BRIDGE	160.000	LF	120.00000	19200.00	125.20000	20032.00	116.00000	18560.00
0085 701021P 3" RIGID METALLIC CONDUIT	312.000	LF	15.00000	4680.00	53.09000	16564.08	32.00000	9984.00
SECTION TOTALS			$	1,582,410.00	$	1,742,664.19	$	1,858,876.00
CONTRACT TOTALS			$	2,737,987.25	$	2,916,862.26	$	2,985,898.25

I CERTIFY THAT THE ABOVE IS AN EXACT TRANSCRIPT OF THE ORIGINAL BID PROPOSAL, EXCEPT THAT ERRORS, IF ANY, IN EXTENSION AND ADDITIONS HAVE BEEN CORRECTED.

SIGNED,

NJDOT Contract Num 045093060 Contract ID 10113

SECTION 1:	Materials	
Direct CO2	947.78	(mt)
Direct CH4	0.04	(mt)
Direct N2O	0.01	(mt)
Direct CO2 Equivalent	**952.96**	**(mt)**
Upstream CO2	2,755.35	(mt)
Upstream CH4	13.94	(mt)
Upstream N2O	1.52	(mt)
Upstream CO2 Equivalent	**3,520.25**	**(mt)**
Combined CO2 Equivalent	**4,473.21**	**(mt)**

SECTION 2:	Equipment	
Direct CO2	107.30	(mt)
Direct CH4	0.00	(mt)
Direct N2O	0.00	(mt)
Direct PMBC	0.01	(mt)
Direct CO2 Equiv. from HFCs	0.15	(mt)
Direct CO2 Equivalent	**107.91**	**(mt)**
Upstream CO2	24.40	(mt)
Upstream CH4	0.52	(mt)
Upstream N2O	0.00	(mt)
Upstream PMBC	0.00	(mt)
Upstream CO2 Equivalent	**35.53**	**(mt)**
Combined CO2 Equivalent	**143.44**	**(mt)**

SECTION 3:	Recyclables Credits	
CO2	0.00	(mt)
CH4	0.00	(mt)
N2O	0.00	(mt)
Total CO2 Equivalent	**0.00**	**(mt)**

SECTION 4:	Lifecycle Maintenance	
Direct CO2	0.00	(mt)
Direct CH4	0.00	(mt)
Direct N2O	0.00	(mt)
Direct PMBC	0.00	(mt)
Direct CO2 Equivalent	**0.00**	**(mt)**
Upstream CO2	0.00	(mt)
Upstream CH4	0.00	(mt)
Upstream N2O	0.00	(mt)
Upstream PMBC	0.00	(mt)
Upstream CO2 Equivalent	**0.00**	**(mt)**
Combined CO2 Equivalent	**0.00**	**(mt)**

SECTION 6:	Lighting	
Direct CO2	0.00	(mt)
Direct CH4	0.00	(mt)
Direct N2O	0.00	(mt)
Direct CO2 Equivalent	**0.00**	**(mt)**

OVERALL RESULTS

CO2	3,852.34	(mt)
CH4	14.53	(mt)
N2O	1.54	(mt)
PMBC	0.02	(mt)
Total CO2 Equivalent	4,636.23	(mt)

Fuel Consumption

Gasoline (10% Ethanol RFG)	0.00	gallons
Gasoline	514.30	gallons
20% Biodiesel	0.00	gallons
Diesel	21,614.33	gallons
Liquified Petroleum Gas	0.00	gallons
Compressed Natural Gas	0.00	GGE

Fuel Costs

Gasoline (10% Ethanol RFG)	$ per gallon
Gasoline	$ per gallon
20% Biodiesel	$ per gallon
Diesel	$ per gallon
Liquified Petroleum Gas	$ per gallon
Compressed Natural Gas	$ per GGE

Total Fuel Cost $88,514.53

SECTION 5:	Staging	
Direct CO2	14.56	(mt)
Direct CH4	0.00	(mt)
Direct N2O	0.00	(mt)
Direct CO2 Equiv. from HFCs	1.34	(mt)
Direct CO2 Equivalent	**16.14**	**(mt)**
Upstream CO2	2.94	(mt)
Upstream CH4	0.02	(mt)
Upstream N2O	0.00	(mt)
Upstream CO2 Equivalent	**3.44**	**(mt)**
Combined CO2 Equivalent	**19.57**	**(mt)**

SECTION 7:	Rail	
Direct CO2	0.00	(mt)
Upstream and Disposal CO2	0.00	(mt)
Upstream and Disposal CH4	0.00	(mt)
Upstream and Disposal N2O	0.00	(mt)
Total CO2 Equivalent	**0.00**	**(mt)**

Materials

Item Code	Description	Value	Unit	Cement Ratio	Aggregate Ratio	Heating Temp.	% Binder	% Moisture	Cutback	Depth (feet)
612009P	Guide Sign, Type Ga, Breakaway Supports	12.00	Sq. Feet	N/A	N/A	N/A	N/A	N/A	Non-Solvent-N/A	N/A
607018P	9" X 16" Concrete Vertical Curb	1,308.00	Feet	0.15	0.80	N/A	N/A	N/A	Non-Solvent-N/A	N/A
606075P	Concrete Island, 4" Thick	160.00	Sq. Yard	0.15	0.80	N/A	N/A	N/A	Non-Solvent-N/A	N/A
602214M	Inlet Face Plate	134.00	Units	N/A	N/A	N/A	N/A	N/A	Non-Solvent-N/A	N/A
602213M	Curb Piece	25.00	Units	N/A	N/A	N/A	N/A	N/A	Non-Solvent-N/A	15.00
602210M	Bicycle Safe Grate	35.00	Units	N/A	N/A	N/A	N/A	N/A	Non-Solvent-N/A	N/A
602159M	Reconstructed Inlet, Type E, Using New Casting	20.00	Units	0.15	0.80	N/A	N/A	N/A	Non-Solvent-N/A	15.00
602153M	Reconstructed Inlet, Type B, Using New Casting	60.00	Units	0.15	0.80	N/A	N/A	N/A	Non-Solvent-N/A	15.00
602150M	Reconstructed Inlet, Type A, Using New Casting	20.00	Units	0.15	0.80	N/A	N/A	N/A	Non-Solvent-N/A	15.00
401066M	HMA - Intermediate Course	11,190.00	Tons	N/A	N/A	325.00	0.07	0.04	Non-Solvent-N/A	N/A
404003M	Stone Matrix Asphalt 9.5mm Surface Course	22,388.00	Tons	N/A	N/A	325.00	0.05	0.04	Non-Solvent-N/A	N/A
401099M	HMA - Base Course	10,320.00	Tons	N/A	N/A	325.00	0.04	0.04	Non-Solvent-N/A	N/A
401066M	HMA - Intermediate Course	4,270.00	Tons	N/A	N/A	325.00	0.04	0.04	Non-Solvent-N/A	N/A
401036M	Prime Coat, Cut-Back Asphalt	5,441.00	Gallons	N/A	N/A	120.00	N/A	N/A	MC-0.3	N/A
401030M	Tack Coat	15,217.00	Gallons	N/A	N/A	145.00	N/A	N/A	Non-Solvent-0	N/A
301006P	Subbase	3,628.00	Cu. Yards	N/A	N/A	N/A	N/A	N/A	Non-Solvent-N/A	N/A

		Direct CO_2 (g)	Direct CH_4 (g)	Direct N_2O (g)	Direct CO_2 Equiv. (g)	Upstream CO_2 (g)	Upstream CH_4 (g)	Upstream N_2O (g)	Upstream CO_2 Equiv. (g)
612009P	Guide Sign, Type Ga, Breakaway Supports	0.00	0.00	0.00	0.00	144,254.19	213.40	1.30	149,137.46
607018P	9" X 16" Concrete Vertical Curb	0.00	0.00	0.00	0.00	23,140,447.01	1,401,738.34	1,383,781.13	481,549,103.46
606075P	Concrete Island, 4" Thick	0.00	0.00	0.00	0.00	6,048,453.29	3,979.96	617.86	6,323,569.99
602214M	Inlet Face Plate	0.00	0.00	0.00	0.00	48,719,458.63	35,925.93	164.45	49,524,883.95
602213M	Curb Piece	0.00	0.00	0.00	0.00	4,670,579.56	3,444.10	15.77	4,747,793.12
602210M	Bicycle Safe Grate	0.00	0.00	0.00	0.00	12,725,231.73	9,383.64	42.95	12,935,604.02
602159M	Reconstructed Inlet, Type E, Using New Casting	0.00	0.00	0.00	0.00	125,609,886.00	111,364.57	4,585.31	129,369,987.45
602153M	Reconstructed Inlet, Type B, Using New Casting	0.00	0.00	0.00	0.00	376,829,657.99	334,093.72	13,755.92	388,109,962.34
602150M	Reconstructed Inlet, Type A, Using New Casting	0.00	0.00	0.00	0.00	102,602,051.18	90,550.02	3,495.27	105,587,136.43
401066M	HMA - Intermediate Course	218,395,721.14	8,557.37	3,309.72	219,601,439.64	599,043,647.71	3,502,475.20	9,738.22	675,614,475.02
404003M	Stone Matrix Asphalt 9.5mm Surface Course	435,241,192.52	17,096.11	6,595.92	437,644,945.22	908,166,953.48	5,375,786.16	14,791.17	1,025,643,725.47
401099M	HMA - Base Course	200,039,381.74	7,872.08	3,031.51	201,144,463.90	318,250,165.18	1,913,927.15	5,195.95	360,053,380.73
401066M	HMA - Intermediate Course	82,768,232.56	3,257.15	1,254.32	83,225,471.01	131,679,089.66	791,905.90	2,149.88	148,975,575.17
401036M	Prime Coat, Cut-Back Asphalt	10,888,868.83	1.52	1.59	10,889,392.62	14,967,151.19	83,680.09	241.70	16,799,359.82
401030M	Tack Coat	451,273.45	6.55	6.85	453,533.62	45,616,931.76	255,263.47	736.75	51,205,855.81
301006P	Subbase	0.00	0.00	0.00	0.00	37,139,659.02	27,821.89	83,662.79	63,659,382.47

Equipment

Year	Description	Fuel Type	Power Rating	Hours	Air Conditioning	Direct CO2 (g)	Direct CH4 (g)	Direct N2O (g)	Direct PMBC (g)
2009	Cement & Mortar Mixers	Diesel	750	250	No	40,230,641.85	210.35	560.59	3,297.86
2009	Cranes	Diesel	600	60	No	5,645,000.90	29.59	78.66	490.37
2003	Pavers	Diesel	600	150	No	18,382,177.81	99.06	253.38	2,303.07
2007	Excavators	Diesel	100	550	No	17,735,966.97	195.89	220.13	4,275.28
2004	Crawler Tractors	Diesel	1200	75	Yes	25,301,231.93	235.35	348.73	4,318.99

Year	Description	Direct CO2 Equiv. from HFCs(g)	Direct CO2 Equiv. (g)	Upstream CO2 (g)	Upstream CH4 (g)	Upstream N2O (g)	Upstream PMBC (g)	Upstream CO2 Equiv. (g)	Fuel Use	Fuel Unit
2009	Cement & Mortar Mixers	0.00	40,408,841.81	13,584,466.84	292,116.82	193.97	452.59	19,779,050.45	9,147.71	gallons
2009	Cranes	0.00	5,670,006.57	1,906,104.84	40,988.38	27.22	63.51	2,775,298.01	1,283.56	gallons
2003	Pavers	0.00	18,462,806.22	2,666,623.44	57,342.37	38.08	88.84	3,882,616.82	3,043.54	gallons
2007	Excavators	0.00	17,808,320.05	2,575,465.42	55,382.14	36.77	85.81	3,749,890.30	2,939.50	gallons
2004	Crawler Tractors	149,333.62	25,563,615.44	3,670,139.52	78,921.72	52.40	122.28	5,343,741.17	4,188.90	gallons

Staging

Item	Year	Fuel Type	Distance (miles)	Number of Trips	Number of Vehicles	Direct CO2 (g)	Direct CH4 (g)	Direct N2O (g)	Direct CO2 Equiv. from HFCs(g)	Direct CO2 Equiv. (g)	Upstream CO2 (g)	Upstream CH4 (g)	Upstream N2O (g)	Upstream CO2 Equiv. (g)	Fuel Use (gal)
Combination Short-haul Truck	2008	Diesel Fuel	60	16	3	5,948,342.23	34.35	7.21	448,000.85	6,399,300.58	1,208,450.66	8,158.01	20.98	1,386,273.34	593.74
Single Unit Short-haul Truck	2003	Diesel Fuel	25	50	3	4,181,610.60	11.48	12.38	448,000.85	4,633,690.95	849,525.89	5,734.98	14.75	974,533.04	417.39
Light Commercial Truck	2000	Reformulated Gasoline	34	80	3	4,429,997.82	876.41	675.32	448,000.85	5,105,754.02	886,538.22	6,388.61	176.48	1,075,408.26	514.30

TABULATION OF BIDS

CALL ORDER : 113
LETTING DATE : 02/08/11 10:00AM
CONTRACT ID : 10113
DISTRICT :
CONTRACT TIME : 01/21/12 COMPLETION DATE
COUNTIES : HUDSON
CONTRACT DESCRIPTION : URBAN
PROJECT(S) : NHS-0033(280)

ROUTE 1&9 NORTH AVENUE TO HAYNES AVENUE RESURFACING
(M.P. 45.5 TO 47.6) CONTRACT NO. 045093060,MILL AND PAVE
CITY OF NEWARK, CITY OF ELIZABETH,COUNTY OF ESSEX,
COUNTY OF UNION

SET-ASIDE :

VENDOR RANKING :

RANK	VENDOR NO.	NAME		TOTAL BID	% OVER LOW BID
1	D2395	DELLA PELLO PAVING INC	$	6,375,750.69	100.0000%
2	T4306	TILCON NEW YORK INC	$	6,588,000.00	103.3290%
3	I5980	INTERCOUNTY PAVING ASSOC LLC	$	6,993,888.23	109.6951%
4	S0503	JOSEPH M SANZARI INC	$	7,144,273.21	112.0538%
5	S1389	SCHIFANO CONSTRUCTION CORP	$	7,195,394.22	112.8556%
6	S8162	.STAVOLA CONTRACTING CO., INC.	$	7,294,770.88	114.4143%
7	C7444	CRISDEL GROUP, INC	$	7,676,785.00	120.4060%
8	N2943	NEW PRINCE CONCRETE CONSTRUCTION CO	$	8,400,236.16	131.7529%

LINE NO / ITEM CODE / ALT ITEM DESCRIPTION	QUANTITY		(1) D2395 DELLA PELLO PAVING INC UNIT PRICE	AMOUNT	(2) T4306 TILCON NEW YORK INC UNIT PRICE	AMOUNT	(3) I5980 INTERCOUNTY PAVING ASSOC LLC UNIT PRICE	AMOUNT
SECTION 0001 ROADWAY								
0001 151003M PERFORMANCE BOND AND PAYMENT BOND		LUMP	31645.00000	31645.00	19620.76000	19620.76	37500.00000	37500.00
0004 153003P PROGRESS SCHEDULE		LUMP	3500.00000	3500.00	1000.00000	1000.00	11500.00000	11500.00
0005 153006P PROGRESS SCHEDULE UPDATE	4.000	U	632.50000	2530.00	600.00000	2400.00	630.00000	2520.00
0006 153012P TRAINEES	740.000	HOUR	3.00000	2220.00	1.00000	740.00	0.01000	7.40
0007 154003P MOBILIZATION		LUMP	323845.00000	323845.00	496507.00000	496507.00	499811.97000	499811.97
0011 157003M CONSTRUCTION LAYOUT		LUMP	10000.00000	10000.00	1.00000	1.00	7250.00000	7250.00
0018 159003M BREAKAWAY BARRICADE	100.000	U	1.00000	100.00	1.00000	100.00	115.00000	11500.00
0019 159006M DRUM	250.000	U	1.00000	250.00	1.00000	250.00	1.00000	250.00

TABULATION OF BIDS

CALL ORDER : 113 CONTRACT ID : 10113 COUNTIES : HUDSON
LETTING DATE : 02/08/11 10:00AM DISTRICT :

SET-ASIDE :

LINE NO / ITEM CODE / ALT ITEM DESCRIPTION	QUANTITY		(1) D2395 DELLA PELLO PAVING INC UNIT PRICE	AMOUNT	(2) T4306 TILCON NEW YORK INC UNIT PRICE	AMOUNT	(3) I5980 INTERCOUNTY PAVING ASSOC LLC UNIT PRICE	AMOUNT
0020 159009M TRAFFIC CONE	200.000	U	1.00000	200.00	20.00000	4000.00	14.00000	2800.00
0021 159012M CONSTRUCTION SIGNS	2739.000	SF	1.00000	2739.00	1.00000	2739.00	11.00000	30129.00
0022 159027M FLASHING ARROW BOARD, 4' X 8'	2.000	U	6000.00000	12000.00	2000.00000	4000.00	1300.00000	2600.00
0023 159029M PORTABLE VARIABLE MESSAGE SIGN W/REMOTE COMMUNICATION	6.000	U	4000.00000	24000.00	8000.00000	48000.00	8300.00000	49800.00
0024 159108M TRAFFIC CONTROL TRUCK WITH MOUNTED CRASH CUSHION	4.000	U	10000.00000	40000.00	6000.00000	24000.00	55000.00000	220000.00
0025 159126M TEMPORARY TRAFFIC STRIPES, 4"	96000.000	LF	0.77000	73920.00	0.19000	18240.00	0.18000	17280.00
0026 159132M TEMPORARY PAVEMENT MARKINGS	3600.000	SF	2.15000	7740.00	1.00000	3600.00	1.00000	3600.00
0027 159138M HMA PATCH	100.000	T	50.00000	5000.00	50.00000	5000.00	82.25000	8225.00
0028 159144M EMERGENCY TOWING SERVICE	10.000	U	150.00000	1500.00	150.00000	1500.00	0.01000	0.10
0029 160003M FUEL PRICE ADJUSTMENT		LUMP	10500.00000	10500.00	10500.00000	10500.00	10500.00000	10500.00
0030 160006M ASPHALT PRICE ADJUSTMENT		LUMP	27100.00000	27100.00	27100.00000	27100.00	27100.00000	27100.00
0031 161003P FINAL CLEANUP		LUMP	5000.00000	5000.00	5000.00000	5000.00	6000.00000	6000.00
0032 201003P CLEARING SITE		LUMP	5000.00000	5000.00	10000.00000	10000.00	3750.00000	3750.00
0033 202009P EXCAVATION, UNCLASSIFIED	7519.000	CY	23.60000	177448.40	35.00000	263165.00	41.00000	308279.00
0034 301006P SUBBASE	3628.000	CY	1.00000	3628.00	1.00000	3628.00	1.00000	3628.00
0035 401009P HMA MILLING, 3" OR LESS	148616.000	SY	2.75000	408694.00	3.75000	557310.00	3.75000	557310.00
0036 401012P HMA MILLING, MORE THAN 3" TO 6"	24339.000	SY	3.25000	79101.75	4.50000	109525.50	3.50000	85186.50
0037 401015P CONCRETE MILLING	3000.000	SY	11.00000	33000.00	3.50000	10500.00	1.00000	3000.00
0038 401021M HOT MIX ASPHALT PAVEMENT REPAIR	194.000	SY	22.00000	4268.00	75.00000	14550.00	1.00000	194.00

CALL ORDER : 113 CONTRACT ID : 10113 COUNTIES : HUDSON
LETTING DATE : 02/08/11 10:00AM DISTRICT :

SET-ASIDE :

LINE NO / ITEM CODE / ALT ITEM DESCRIPTION	QUANTITY	(1) D2395 DELLA PELLO PAVING INC UNIT PRICE	AMOUNT	(2) T4306 TILCON NEW YORK INC UNIT PRICE	AMOUNT	(3) I5980 INTERCOUNTY PAVING ASSOC LLC UNIT PRICE	AMOUNT
0039 401030M TACK COAT	15217.000 GAL	0.01000	152.17	0.01000	152.17	2.50000	38042.50
0040 401036M PRIME COAT	5441.000 GAL	0.01000	54.41	0.01000	54.41	0.01000	54.41
0041 401066M HOT MIX ASPHALT 9.5 M 64 INTERMEDIATE COURSE	4270.000 T	58.80000	251076.00	75.00000	320250.00	63.00000	269010.00
0042 401099M HOT MIX ASPHALT 25 M 64 BASE COURSE	10320.000 T	60.70000	626424.00	65.00000	670800.00	68.00000	701760.00
0043 401108M CORE SAMPLES, HOT MIX ASPHALT	108.000 U	80.00000	8640.00	25.00000	2700.00	60.00000	6480.00
0044 404003M STONE MATRIX ASPHALT 9.5 MM SURFACE COURSE	22388.000 T	97.60000	2185068.80	92.25000	2065293.00	100.00000	2238800.00
0045 409003P BINDER RICH INTERMEDIATE COURSE, 4.75MM	11190.000 T	108.85000	1218031.50	100.00000	1119000.00	113.75000	1272862.50
0046 453006M FULL DEPTH CONCRETE PAVEMENT REPAIR, HM	722.000 SY	225.00000	162450.00	175.00000	126350.00	150.00000	108300.00
0049 602099M RESET EXISTING CASTING	50.000 U	600.00000	30000.00	247.74000	12387.00	575.00000	28750.00
0050 602150M RECONSTRUCTED INLET, TYPE A, USING NEW CASTING	20.000 U	1400.00000	28000.00	1728.96000	34579.20	700.00000	14000.00
0051 602153M RECONSTRUCTED INLET, TYPE B, USING NEW CASTING	60.000 U	1500.00000	90000.00	1335.47000	80128.20	700.00000	42000.00
0052 602159M RECONSTRUCTED INLET, TYPE E, USING NEW CASTING	20.000 U	1575.00000	31500.00	2075.46000	41509.20	700.00000	14000.00
0053 602210M BICYCLE SAFE GRATE	35.000 U	245.00000	8575.00	353.49000	12372.15	300.00000	10500.00
0054 602213M CURB PIECE	25.000 U	285.00000	7125.00	403.35000	10083.75	325.00000	8125.00
0055 602214M INLET FACE PLATE	134.000 U	225.00000	30150.00	418.34000	56057.56	300.00000	40200.00
0057 606075P CONCRETE ISLAND, 4" THICK	160.000 SY	66.00000	10560.00	103.85000	16616.00	93.00000	14880.00
0058 607018P 9" X 16" CONCRETE VERTICAL CURB	1308.000 LF	80.00000	104640.00	45.00000	58860.00	46.00000	60168.00

TABULATION OF BIDS

CALL ORDER : 113 CONTRACT ID : 10113 COUNTIES : HUDSON
LETTING DATE : 02/08/11 10:00AM DISTRICT :

SET-ASIDE :

LINE NO / ITEM CODE / ALT ITEM DESCRIPTION	QUANTITY	(1) D2395 DELLA PELLO PAVING INC UNIT PRICE	AMOUNT	(2) T4306 TILCON NEW YORK INC UNIT PRICE	AMOUNT	(3) I5980 INTERCOUNTY PAVING ASSOC LLC UNIT PRICE	AMOUNT
0059 610006M TRAFFIC STRIPES, LONG LIFE, EPOXY RESIN 6"	87429.000 LF	0.84000	73440.36	0.33000	28851.57	0.36000	31474.44
0060 610007M TRAFFIC STRIPES, LONG LIFE, EPOXY RESIN 8"	8505.000 LF	0.66000	5613.30	0.58000	4932.90	0.46000	3912.30
0061 610009M TRAFFIC MARKINGS, THERMOPLASTIC	3698.000 SF	2.50000	9245.00	3.00000	11094.00	3.00000	11094.00
0062 610012M RPM, MONO-DIRECTIONAL, WHITE LENS	1085.000 U	27.00000	29295.00	24.00000	26040.00	23.10000	25063.50
0063 610018M RPM, MONO-DIRECTIONAL, AMBER LENS	551.000 U	27.00000	14877.00	24.00000	13224.00	23.10000	12728.10
0064 610024M REMOVAL OF RPM	1638.000 U	4.00000	6552.00	0.01000	16.38	3.75000	6142.50
0065 610033M RUMBLE STRIP	37485.000 LF	0.48000	17992.80	0.25000	9371.25	0.20000	7497.00
0066 612009P GUIDE SIGN, TYPE GA, BREAKAWAY SUPPORTS	12.000 SF	321.00000	3852.00	40.00000	480.00	39.50000	474.00
SECTION TOTALS		$	6,248,243.49	$	6,364,179.00	$	6,876,039.22
SECTION 0002 CONSTRUCTION ENGINEERING							
0008 155009M FIELD OFFICE TYPE C SET UP	1.000 U	19100.00000	19100.00	23465.00000	23465.00	28500.00000	28500.00
0009 155027M FIELD OFFICE TYPE C MAINTENANCE	8.000 MO	2800.00000	22400.00	2372.00000	18976.00	3500.00000	28000.00
0010 155039M TELEPHONE SERVICE	LUMP	3200.00000	3200.00	3200.00000	3200.00	3200.00000	3200.00
SECTION TOTALS		$	44,700.00	$	45,641.00	$	59,700.00
SECTION 0003 NON-PARTICIPATING (ROADWAY)							
0002 152003P OWNER'S AND CONTRACTOR'S PROTECTIVE LIABILITY INSURANCE	LUMP	1.00000	1.00	500.00000	500.00	4100.00000	4100.00
0003 152009P POLLUTION LIABILITY INSURANCE	LUMP	100.00000	100.00	500.00000	500.00	0.01000	0.01
0047 601670M CLEANING EXISTING PIPE, 12" TO 24" DIAMETER	13127.000 LF	3.35000	43975.45	7.50000	98452.50	1.00000	13127.00

TABULATION OF BIDS

CALL ORDER : 113
LETTING DATE : 02/08/11 10:00AM
CONTRACT ID : 10113
DISTRICT :
COUNTIES : HUDSON

SET-ASIDE :

LINE NO / ITEM CODE / ALT ITEM DESCRIPTION	QUANTITY	(1) D2395 DELLA PELLO PAVING INC UNIT PRICE	AMOUNT	(2) T4306 TILCON NEW YORK INC UNIT PRICE	AMOUNT	(3) I5980 INTERCOUNTY PAVING ASSOC LLC UNIT PRICE	AMOUNT
0048 601672M CLEANING EXISTING PIPE, OVER 24" TO 48" DIAMETER	473.000 LF	6.75000	3192.75	12.50000	5912.50	7.40000	3500.20
0056 602216M CLEANING DRAINAGE STRUCTURE	130.000 U	125.00000	16250.00	225.00000	29250.00	135.00000	17550.00
SECTION TOTALS		$	63,519.20	$	134,615.00	$	38,277.21
SECTION 0004 EROSION CONTROL							
0012 158006M SILT FENCE	1056.000 LF	2.50000	2640.00	2.00000	2112.00	3.25000	3432.00
0013 158030M INLET FILTER TYPE 2, 2' X 4'	201.000 U	20.00000	4020.00	125.00000	25125.00	15.00000	3015.00
0014 158033M INLET FILTER TYPE 2, 4' X 4'	44.000 U	30.00000	1320.00	150.00000	6600.00	15.00000	660.00
0015 158063P CONCRETE WASHOUT SYSTEM	LUMP	1000.00000	1000.00	2500.00000	2500.00	2750.00000	2750.00
0016 158072M OIL ONLY EMERGENCY SPILL KIT, TYPE 1	2.000 U	200.00000	400.00	500.00000	1000.00	500.00000	1000.00
0017 158084M EROSION CONTROL SEDIMENT REMOVAL	10.000 CY	50.00000	500.00	18.00000	180.00	1.00000	10.00
SECTION TOTALS		$	9,880.00	$	37,517.00	$	10,867.00
SECTION 0005 GENERAL LANDSCAPE							
0067 804006P TOPSOILING, 4" THICK	1344.000 SY	5.00000	6720.00	3.00000	4032.00	5.00000	6720.00
0068 806006P FERTILIZING AND SEEDING, TYPE A-3	1344.000 SY	1.00000	1344.00	0.75000	1008.00	0.85000	1142.40
0069 809003M STRAW MULCHING	1344.000 SY	1.00000	1344.00	0.75000	1008.00	0.85000	1142.40
SECTION TOTALS		$	9,408.00	$	6,048.00	$	9,004.80
CONTRACT TOTALS		$	6,375,750.69	$	6,588,000.00	$	6,993,888.23

I CERTIFY THAT THE ABOVE IS AN EXACT TRANSCRIPT OF THE ORIGINAL BID PROPOSAL, EXCEPT THAT ERRORS, IF ANY, IN EXTENSION AND ADDITIONS HAVE BEEN CORRECTED.

SIGNED,

NJDOT Contract Num 003048072 Contract ID 10421

SECTION 1:	Materials	
Direct CO2	223.16	(mt)
Direct CH4	0.01	(mt)
Direct N2O	0.00	(mt)
Direct CO2 Equivalent	**224.39**	**(mt)**
Upstream CO2	627.34	(mt)
Upstream CH4	3.93	(mt)
Upstream N2O	1.19	(mt)
Upstream CO2 Equivalent	**1,079.12**	**(mt)**
Combined CO2 Equivalent	**1,303.51**	**(mt)**

SECTION 2:	Equipment	
Direct CO2	90.12	(mt)
Direct CH4	0.00	(mt)
Direct N2O	0.00	(mt)
Direct PMBC	0.01	(mt)
Direct CO2 Equiv. from HFCs	0.00	(mt)
Direct CO2 Equivalent	**90.51**	**(mt)**
Upstream CO2	13.32	(mt)
Upstream CH4	0.28	(mt)
Upstream N2O	0.00	(mt)
Upstream PMBC	0.00	(mt)
Upstream CO2 Equivalent	**19.26**	**(mt)**
Combined CO2 Equivalent	**109.77**	**(mt)**

SECTION 3:	Recyclables Credits	
CO2	0.04	(mt)
CH4	0.00	(mt)
N2O	0.00	(mt)
Total CO2 Equivalent	**0.05**	**(mt)**

SECTION 4:	Lifecycle Maintenance	
Direct CO2	0.00	(mt)
Direct CH4	0.00	(mt)
Direct N2O	0.00	(mt)
Direct PMBC	0.00	(mt)
Direct CO2 Equivalent	**0.00**	**(mt)**
Upstream CO2	0.00	(mt)
Upstream CH4	0.00	(mt)
Upstream N2O	0.00	(mt)
Upstream PMBC	0.00	(mt)
Upstream CO2 Equivalent	**0.00**	**(mt)**
Combined CO2 Equivalent	**0.00**	**(mt)**

SECTION 6:	Lighting	
Direct CO2	1.30	(mt)
Direct CH4	0.00	(mt)
Direct N2O	0.00	(mt)
Direct CO2 Equivalent	**1.31**	**(mt)**

OVERALL RESULTS

CO2	973.01	(mt)
CH4	4.24	(mt)
N2O	1.20	(mt)
PMBC	0.01	(mt)
Total CO2 Equivalent	1,433.96	(mt)

Fuel Consumption		
Gasoline (10% Ethanol RFG)	0.00	gallons
Gasoline	1,184.21	gallons
20% Biodiesel	0.00	gallons
Diesel	15,657.97	gallons
Liquified Petroleum Gas	0.00	gallons
Compressed Natural Gas	0.00	GGE

Fuel Costs	
Gasoline (10% Ethanol RFG)	$ per gallon
Gasoline	$ per gallon
20% Biodiesel	$ per gallon
Diesel	$ per gallon
Liquified Petroleum Gas	$ per gallon
Compressed Natural Gas	$ per GGE

Total Fuel Cost $67,368.74

SECTION 5:	Staging	
Direct CO2	15.07	(mt)
Direct CH4	0.00	(mt)
Direct N2O	0.00	(mt)
Direct CO2 Equiv. from HFCs	0.86	(mt)
Direct CO2 Equivalent	**16.14**	**(mt)**
Upstream CO2	2.75	(mt)
Upstream CH4	0.02	(mt)
Upstream N2O	0.00	(mt)
Upstream CO2 Equivalent	**3.29**	**(mt)**
Combined CO2 Equivalent	**19.43**	**(mt)**

SECTION 7:	Rail	
Direct CO2	0.00	(mt)
Upstream and Disposal CO2	0.00	(mt)
Upstream and Disposal CH4	0.00	(mt)
Upstream and Disposal N2O	0.00	(mt)
Total CO2 Equivalent	**0.00**	**(mt)**

Materials

Item Code	Description	Value	Unit	Cement Ratio	Aggregate Ratio	Heating Temp.	% Binder	% Moisture	Cutback	Depth (feet)
612006P	Guide Sign, Type Ga, Steel "U" Post Supports	23.00	Sq. Feet	N/A	N/A	N/A	N/A	N/A	Non-Solvent-N/A	N/A
612003P	Regulatory And Warning Sign	406.00	Sq. Feet	N/A	N/A	N/A	N/A	N/A	Non-Solvent-N/A	N/A
609039M	Beam Guide Rail Anchorage	2.00	Units	N/A	N/A	N/A	N/A	N/A	Non-Solvent-N/A	N/A
609027M	Tangent Guide Rail Terminal	1.00	Units	N/A	N/A	N/A	N/A	N/A	Non-Solvent-N/A	N/A
609024M	Flared Guide Rail Terminal	1.00	Units	N/A	N/A	N/A	N/A	N/A	Non-Solvent-N/A	N/A
609021M	Rub Rail	650.00	Feet	N/A	N/A	N/A	N/A	N/A	Non-Solvent-N/A	N/A
609003M	Beam Guide Rail	825.00	Feet	N/A	N/A	N/A	N/A	N/A	Non-Solvent-N/A	N/A
608004P	Nonvegetative Surface, Porous Hot Mix Asphalt, 4" Thick	673.00	Sq. Yard	N/A	N/A	N/A	0.04	0.04	Non-Solvent-N/A	N/A
607069P	9" X Variable Height Concrete Vertical Curb	2,800.00	Feet	0.15	0.80	N/A	N/A	N/A	Non-Solvent-N/A	N/A
607018P	9" X 16" Concrete Vertical Curb	923.00	Feet	0.15	0.80	N/A	N/A	N/A	Non-Solvent-N/A	N/A
606075P	Concrete Island, 4" Thick	93.00	Sq. Yard	0.15	0.80	N/A	N/A	N/A	Non-Solvent-N/A	N/A
606039P	Hot Mix Asphalt Driveway, 6" Thick	475.00	Sq. Yard	N/A	N/A	N/A	0.04	0.04	Non-Solvent-N/A	N/A
602213M	Curb Piece	24.00	Units	N/A	N/A	N/A	N/A	N/A	Non-Solvent-N/A	15.00
602054M	Manhole, 4' Diameter	1.00	Units	0.15	0.80	N/A	N/A	N/A	Non-Solvent-N/A	15.00
602013M	Inlet, Type Double B	1.00	Units	0.15	0.80	N/A	N/A	N/A	Non-Solvent-N/A	15.00
602012M	Inlet, Type B	9.00	Units	0.15	0.80	N/A	N/A	N/A	Non-Solvent-N/A	15.00
601122P	15" Reinforced Concrete Pipe	213.00	Feet	N/A	N/A	N/A	N/A	N/A	Non-Solvent-N/A	N/A
401099M	HMA - Base Course	385.00	Tons	N/A	N/A	325.00	0.04	0.04	Non-Solvent-N/A	N/A
401078M	HMA - Intermediate Course	6,660.00	Tons	N/A	N/A	325.00	0.04	0.04	Non-Solvent-N/A	N/A
401072M	HMA - Intermediate Course	220.00	Tons	N/A	N/A	325.00	0.04	0.04	Non-Solvent-N/A	N/A
401048M	HMA - Surface Course	4,000.00	Tons	N/A	N/A	325.00	0.05	0.04	Non-Solvent-N/A	N/A
401036M	Prime Coat, Cut-Back Asphalt	220.00	Gallons	N/A	N/A	120.00	N/A	N/A	MC-0.3	N/A
401030M	Tack Coat	12,700.00	Gallons	N/A	N/A	145.00	N/A	N/A	Non-Solvent-0	N/A
304012P	Concrete Base Course, 12" Thick	17.00	Sq. Yards	0.15	0.80	N/A	N/A	N/A	Non-Solvent-N/A	N/A
304009P	Concrete Base Course, 10" Thick	284.00	Sq. Yards	0.15	0.80	N/A	N/A	N/A	Non-Solvent-N/A	N/A
302042P	Dense-Graded Aggregate Base Course, 8" Thick	670.00	Sq. Yards	N/A	N/A	N/A	N/A	N/A	Non-Solvent-N/A	N/A
302036P	Dense-Graded Aggregate Base Course, 6" Thick	187.00	Sq. Yards	N/A	N/A	N/A	N/A	N/A	Non-Solvent-N/A	N/A

Item Code	Description	Direct CO_2 (g)	Direct CH_4 (g)	Direct N_2O (g)	Direct CO_2 Equiv. (g)	Upstream CO_2 (g)	Upstream CH_4 (g)	Upstream N_2O (g)	Upstream CO_2 Equiv. (g)
612006P	Guide Sign, Type Ga, Steel "U" Post Supports	0.00	0.00	0.00	0.00	276,487.19	409.01	2.49	285,846.79
612003P	Regulatory And Warning Sign	0.00	0.00	0.00	0.00	4,880,599.98	7,219.89	43.87	5,045,817.25
609039M	Beam Guide Rail Anchorage	0.00	0.00	0.00	0.00	51,883.18	69.49	0.38	53,459.14
609027M	Tangent Guide Rail Terminal	0.00	0.00	0.00	0.00	338,343.69	453.16	2.45	348,620.62
609024M	Flared Guide Rail Terminal	0.00	0.00	0.00	0.00	338,343.69	453.16	2.45	348,620.62
609021M	Rub Rail	0.00	0.00	0.00	0.00	36,268,727.87	46,630.45	247.52	37,324,699.68
609003M	Beam Guide Rail	0.00	0.00	0.00	0.00	20,364,212.96	27,083.35	144.25	20,977,681.50
608004P	Nonvegetative Surface, Porous Hot Mix Asphalt, 4" Thick	1,823,719.50	71.77	27.64	1,833,794.32	2,901,423.85	17,448.90	47.37	3,282,535.50
607069P	9" X Variable Height Concrete Vertical Curb	0.00	0.00	0.00	0.00	1,835,151.18	6,711.57	4,746.19	3,447,411.69
607018P	9" X 16" Concrete Vertical Curb	0.00	0.00	0.00	0.00	16,329,229.81	989,147.16	976,475.52	339,808,732.79
606075P	Concrete Island, 4" Thick	0.00	0.00	0.00	0.00	3,515,663.48	2,313.35	359.13	3,675,575.06
606039P	Hot Mix Asphalt Driveway, 6" Thick	1,930,758.02	75.98	29.26	1,941,424.15	3,071,715.44	18,473.01	50.15	3,475,195.46
602213M	Curb Piece	0.00	0.00	0.00	0.00	4,483,756.38	3,306.34	15.14	4,557,881.40
602054M	Manhole, 4' Diameter	0.00	0.00	0.00	0.00	5,952,168.34	5,559.15	149.76	6,115,337.68
602013M	Inlet, Type Double B	0.00	0.00	0.00	0.00	6,161,911.92	5,480.79	228.87	6,347,956.60
602012M	Inlet, Type B	0.00	0.00	0.00	0.00	55,457,207.29	49,327.07	2,059.79	57,131,609.41
601122P	15" Reinforced Concrete Pipe	0.00	0.00	0.00	0.00	9,529,387.98	202,093.10	192,754.12	73,527,121.46
401099M	HMA - Base Course	7,462,709.49	293.68	113.09	7,503,935.91	11,872,704.81	71,401.35	193.84	13,432,223.99
401078M	HMA - Intermediate Course	129,095,182.40	5,080.24	1,956.38	129,808,345.89	205,382,374.04	1,235,150.66	3,353.20	232,360,030.59
401072M	HMA - Intermediate Course	4,264,405.42	167.82	64.63	4,287,963.38	6,784,402.75	40,800.77	110.77	7,675,556.57
401048M	HMA - Surface Course	77,763,300.43	3,054.51	1,178.47	78,192,772.06	162,259,595.05	960,476.36	2,642.70	183,248,834.28
401036M	Prime Coat, Cut-Back Asphalt	440,277.73	0.06	0.06	440,298.91	605,177.96	3,383.50	9.77	679,261.01
401030M	Tack Coat	376,629.62	5.46	5.71	378,515.93	38,071,566.89	213,041.08	614.88	42,736,043.16
304012P	Concrete Base Course, 12" Thick	0.00	0.00	0.00	0.00	1,927,944.49	1,268.61	196.94	2,015,637.94
304009P	Concrete Base Course, 10" Thick	0.00	0.00	0.00	0.00	26,840,011.49	17,661.06	2,741.77	28,060,841.85
302042P	Dense-Graded Aggregate Base Course, 8" Thick	0.00	0.00	0.00	0.00	1,524,168.29	1,141.78	3,433.42	2,612,506.81
302036P	Dense-Graded Aggregate Base Course, 6" Thick	0.00	0.00	0.00	0.00	319,051.65	239.01	718.71	546,871.76

Equipment

Year	Description	Fuel Type	Power Rating	Hours	Air Conditioning	Direct CO2 (g)	Direct CH4 (g)	Direct N2O (g)	Direct PMBC (g)	Direct CO2 Equiv. from HFCs(g)	Direct CO2 Equiv. (g)
2009	Cement & Mortar Mixers	Diesel	75	60	No	907,215.26	5.29	11.37	138.94	0.00	910,851.52
2007	Cranes	Diesel	750	35	No	5,346,971.98	27.79	74.51	519.20	0.00	5,370,652.64
2004	Pavers	Diesel	600	300	No	36,764,258.82	197.67	506.76	4,448.14	0.00	36,925,505.92
2005	Paving Equipment	Diesel	100	500	No	14,639,239.83	167.78	181.69	3,728.67	0.00	14,699,087.53
2008	Excavators	Diesel	100	100	No	3,224,500.08	20.09	40.02	1,188.66	0.00	3,237,329.22
2007	Crawler Tractors	Diesel	1000	100	No	29,235,726.42	187.70	402.98	3,465.92	0.00	29,364,592.40

Year	Description	Fuel Type	Power Rating	Hours	Upstream CO2 (g)	Upstream CH4 (g)	Upstream N2O (g)	Upstream PMBC (g)	Upstream CO2 Equiv. (g)	Fuel Use	Fuel Unit
2009	Cement & Mortar Mixers	Diesel	75	60	306,336.22	6,587.37	4.37	10.21	446,027.05	206.29	gallons
2007	Cranes	Diesel	750	35	776,356.04	16,694.56	11.09	25.87	1,130,378.21	1,215.80	gallons
2004	Pavers	Diesel	600	300	5,333,246.88	114,684.75	76.15	177.69	7,765,233.65	6,087.08	gallons
2005	Paving Equipment	Diesel	100	500	2,125,767.20	45,711.94	30.35	70.82	3,095,127.48	2,426.24	gallons
2008	Excavators	Diesel	100	100	537,129.15	5,097.67	12.78	25.57	648,142.78	534.45	gallons
2007	Crawler Tractors	Diesel	1000	100	4,241,050.11	91,198.43	60.56	141.30	6,174,989.80	4,840.51	gallons

SECTION 3: RECYCLING CREDIT

NJDOT Contract Num 003048072 Contract ID 10421

Recycled Asphalt Pavement (RAP):		lb
Reclaimed Concrete Material (RCM):	7,500	lb
Foundry Sand:		lb
Coal Bottom Ash:		lb
Glass Cullet/CRCG:		lb
Ground Bituminous Shingle Material:		lb
Remediated Petroleum Contaminated Soil Aggregate:		lb
Blast Furnace Slag:		lb
Coal Fly Ash:	50	lb
Ground Granulated Blast Furnace Slag:		lb
Other Industrial Waste Products:		lb

RECYCLED MATERIALS CREDIT

CO2	=	38,429.22	(g)
CH4	=	26.24	(g)
N2O	=	26.35	(g)
Total CO2 Equivalen	=	47,148.43	(g)

Staging

Item	Year	Fuel Type	Distance (miles)	Number of Trips	Number of Vehicles	Direct CO2 (g)	Direct CH4 (g)	Direct N2O (g)	Direct CO2 Equiv. from HFCs(g)	Direct CO2 Equiv. (g)	Upstream CO2 (g)	Upstream CH4 (g)	Upstream N2O (g)	Upstream CO2 Equiv. (g)	Fuel Use (gal)
Light Commercial Truck	2002	Reformulated Gasoline	18	70	2	1,375,809.11	243.23	183.85	191,938.88	1,629,849.93	275,329.31	1,984.09	54.81	333,986.07	159.72
Combination Short-haul Truck	2006	Reformulated Gasoline	25	60	3	8,824,548.09	2,486.86	264.00	287,908.32	9,246,519.61	1,765,993.64	12,726.19	351.55	2,142,224.79	1,024.49
Single Unit Long-haul Truck	1999	Diesel Fuel	15	36	2	1,140,533.02	3.24	3.25	191,938.88	1,333,546.24	231,708.09	1,564.21	4.02	265,803.78	113.84
Single Unit Short-haul Truck	2004	Diesel Fuel	35	30	2	2,341,944.91	6.31	6.93	191,938.88	2,536,163.03	475,783.80	3,211.92	8.26	545,795.06	233.76
Lighting: 2812.03 kilowatt hours	N/A	N/A	N/A	N/A	N/A	1,383,518.76	34.31	25.87		1,392,259.11					

Lighting

Type	Number	Years	Power Rating	Direct CO2 (g)	Direct CH4 (g)	Direct N2O (g)	Direct CO2 Equiv. (g)
12" Traffic Light - LED	10	3	N/A	1,298,880.0000	32.2080	24.2880	1,307,085.6480

TABULATION OF BIDS

CALL ORDER : 421 CONTRACT ID : 10421 COUNTIES : WARREN
LETTING DATE : 02/01/11 10:00AM DISTRICT : C1
CONTRACT TIME : 09/12/11 COMPLETION DATE
CONTRACT DESCRIPTION : PROJECT(S) : NHS-0040(171)
ROUTE U.S. 22 RESURFACING AND COUNTY ROUTE 519 INTERSECTION
IMPROVEMENTS
FROM PHILLIPSBURG MALL ENTRANCE TO VICINITY OF GREENWICH
STREET, CONTRACT NO 003048072,
FEDERAL PROJECT NO.NHS-0040(171)
TOWNSHIPS OF GREENWICH AND POHATCONG, WARREN COUNTY.

SET-ASIDE :

VENDOR RANKING :

RANK	VENDOR NO./NAME			TOTAL BID	% OVER LOW BID
1	I5980	INTERCOUNTY PAVING ASSOC LLC	$	2,032,323.00	100.0000%
2	T4306	TILCON NEW YORK INC	$	2,286,000.00	112.4821%
3	C7444	CRISDEL GROUP, INC	$	2,336,441.00	114.9641%
4	S5784	SMITH-SONDY ASPHALT CONSTRUCTION CO	$	2,546,511.80	125.3005%
5	L2301	LEHIGH VALLEY SITE CONTRACTORS INC	$	3,324,226.40	163.5678%
	E5929	ENGLISH PAVING CO INC		IRREGULAR	

LINE NO / ITEM CODE / ALT ITEM DESCRIPTION	QUANTITY		(1) I5980 INTERCOUNTY PAVING ASSOC LLC UNIT PRICE	AMOUNT	(2) T4306 TILCON NEW YORK INC UNIT PRICE	AMOUNT	(3) C7444 CRISDEL GROUP, INC UNIT PRICE	AMOUNT
SECTION 0001 ROADWAY								
0001 151003M PERFORMANCE BOND AND PAYMENT BOND		LUMP	12653.00000	12653.00	2500.00000	2500.00	11685.00000	11685.00
0004 153003P PROGRESS SCHEDULE		LUMP	9000.00000	9000.00	2500.00000	2500.00	3825.00000	3825.00
0005 153006P PROGRESS SCHEDULE UPDATE	3.000	U	650.00000	1950.00	500.00000	1500.00	663.00000	1989.00
0006 154003P MOBILIZATION		LUMP	120926.25000	120926.25	200000.00000	200000.00	248321.65000	248321.65
0010 157003M CONSTRUCTION LAYOUT		LUMP	6000.00000	6000.00	22479.20000	22479.20	28305.00000	28305.00
0011 157006M MONUMENT	4.000	U	800.00000	3200.00	500.00000	2000.00	717.10000	2868.40
0012 158003M CAUTION FENCE	108.000	LF	4.00000	432.00	5.00000	540.00	4.60000	496.80
0013 158009M HEAVY DUTY SILT FENCE, ORANGE	200.000	LF	2.00000	400.00	5.00000	1000.00	5.35000	1070.00
0014 158012M HEAVY DUTY SILT FENCE, BLACK	1569.000	LF	3.50000	5491.50	2.00000	3138.00	5.30000	8315.70

TABULATION OF BIDS

CALL ORDER : 421
LETTING DATE : 02/01/11 10:00AM

CONTRACT ID : 10421
DISTRICT : C1

COUNTIES : WARREN

SET-ASIDE :

LINE NO / ITEM CODE / ALT ITEM DESCRIPTION	QUANTITY	(1) I5980 INTERCOUNTY PAVING ASSOC LLC UNIT PRICE	AMOUNT	(2) T4306 TILCON NEW YORK INC UNIT PRICE	AMOUNT	(3) C7444 CRISDEL GROUP, INC UNIT PRICE	AMOUNT
0015 158015M HAYBALE	25.000 U	5.00000	125.00	5.00000	125.00	20.00000	500.00
0016 158030M INLET FILTER TYPE 2, 2' X 4'	62.000 U	95.00000	5890.00	25.00000	1550.00	120.80000	7489.60
0017 158033M INLET FILTER TYPE 2, 4' X 4'	11.000 U	105.00000	1155.00	25.00000	275.00	198.55000	2184.05
0018 158063P CONCRETE WASHOUT SYSTEM	LUMP	1500.00000	1500.00	1000.00000	1000.00	1836.00000	1836.00
0019 158072M OIL ONLY EMERGENCY SPILL KIT, TYPE 1	2.000 U	1.00000	2.00	450.00000	900.00	816.00000	1632.00
0020 158084M EROSION CONTROL SEDIMENT REMOVAL	70.000 CY	1.00000	70.00	5.00000	350.00	58.30000	4081.00
0021 159003M BREAKAWAY BARRICADE	100.000 U	1.00000	100.00	1.00000	100.00	0.01000	1.00
0022 159006M DRUM	300.000 U	0.01000	3.00	1.00000	300.00	0.01000	3.00
0023 159009M TRAFFIC CONE	150.000 U	15.00000	2250.00	20.00000	3000.00	0.01000	1.50
0024 159012M CONSTRUCTION SIGNS	1380.000 SF	1.00000	1380.00	5.00000	6900.00	16.40000	22632.00
0025 159018M CONSTRUCTION IDENTIFICATION SIGN, 6' X 12'	2.000 U	1000.00000	2000.00	900.00000	1800.00	2020.70000	4041.40
0026 159027M FLASHING ARROW BOARD, 4' X 8'	4.000 U	250.00000	1000.00	500.00000	2000.00	1.05000	4.20
0027 159030M PORTABLE VARIABLE MESSAGE SIGN	5.000 U	2000.00000	10000.00	1000.00000	5000.00	3671.90000	18359.50
0028 159108M TRAFFIC CONTROL TRUCK WITH MOUNTED CRASH CUSHION	2.000 U	50000.00000	100000.00	6000.00000	12000.00	13709.05000	27418.10
0029 159126M TEMPORARY TRAFFIC STRIPES, 4"	16870.000 LF	0.25000	4217.50	0.36000	6073.20	0.25000	4217.50
0030 159132M TEMPORARY PAVEMENT MARKINGS	1000.000 SF	1.05000	1050.00	1.00000	1000.00	1.00000	1000.00
0031 159135M TEMPORARY PAVEMENT MARKERS	350.000 U	1.55000	542.50	1.50000	525.00	2.05000	717.50
0032 159138M HMA PATCH	40.000 T	1.00000	40.00	150.00000	6000.00	85.20000	3408.00
0033 159141M TRAFFIC DIRECTOR, FLAGGER	500.000 HOUR	75.00000	37500.00	65.00000	32500.00	1.00000	500.00

TABULATION OF BIDS

CALL ORDER : 421
LETTING DATE : 02/01/11 10:00AM
CONTRACT ID : 10421
DISTRICT : C1
COUNTIES : WARREN

SET-ASIDE :

LINE NO / ITEM CODE / ALT ITEM DESCRIPTION	QUANTITY		(1) I5980 INTERCOUNTY PAVING ASSOC LLC UNIT PRICE	AMOUNT	(2) T4306 TILCON NEW YORK INC UNIT PRICE	AMOUNT	(3) C7444 CRISDEL GROUP, INC UNIT PRICE	AMOUNT
0034 159144M EMERGENCY TOWING SERVICE	5.000	U	1.00000	5.00	75.00000	375.00	255.00000	1275.00
0035 160003M FUEL PRICE ADJUSTMENT		LUMP	2300.00000	2300.00	2300.00000	2300.00	2300.00000	2300.00
0036 160006M ASPHALT PRICE ADJUSTMENT		LUMP	11700.00000	11700.00	11700.00000	11700.00	11700.00000	11700.00
0037 161003P FINAL CLEANUP		LUMP	5500.00000	5500.00	5000.00000	5000.00	4859.65000	4859.65
0038 162003M CONDITION SURVEY	1.000	U	1300.00000	1300.00	2000.00000	2000.00	2364.10000	2364.10
0039 201003P CLEARING SITE		LUMP	5250.00000	5250.00	5000.00000	5000.00	18582.80000	18582.80
0040 202006M EXCAVATION, TEST PIT	10.000	CY	1.00000	10.00	100.00000	1000.00	581.85000	5818.50
0041 202009P EXCAVATION, UNCLASSIFIED	234.000	CY	22.00000	5148.00	100.00000	23400.00	49.60000	11606.40
0042 202021P REMOVAL OF PAVEMENT	1328.000	SY	4.00000	5312.00	50.00000	66400.00	39.15000	51991.20
0043 203041P GEOTEXTILE, ROADWAY STABILIZATION	670.000	SY	1.50000	1005.00	4.00000	2680.00	1.90000	1273.00
0044 302036P DENSE-GRADED AGGREGATE BASE COURSE, 6" THICK	187.000	SY	7.50000	1402.50	25.00000	4675.00	9.70000	1813.90
0045 302042P DENSE-GRADED AGGREGATE BASE COURSE, 8" THICK	670.000	SY	15.00000	10050.00	15.00000	10050.00	19.85000	13299.50
0046 304009P CONCRETE BASE COURSE, 10" THICK	284.000	SY	1.00000	284.00	100.00000	28400.00	71.40000	20277.60
0047 304012P CONCRETE BASE COURSE, 12" THICK	17.000	SY	1.00000	17.00	115.00000	1955.00	81.60000	1387.20
0048 401009P HMA MILLING, 3" OR LESS GRADE CONTROLLE	37726.000	SY	1.50000	56589.00	3.00000	113178.00	2.95000	111291.70
0049 401012P HMA MILLING, MORE THAN 3" TO 6" GRADE CONTROLLED	3018.000	SY	2.00000	6036.00	3.00000	9054.00	4.65000	14033.70
0050 401021M HOT MIX ASPHALT PAVEMENT REPAIR	50.000	SY	1.00000	50.00	110.00000	5500.00	74.35000	3717.50
0051 401027M POLYMERIZED JOINT ADHESIVE	26500.000	LF	0.35000	9275.00	0.01000	265.00	0.35000	9275.00

TABULATION OF BIDS

CALL ORDER : 421
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0052 401030M TACK COAT	12700.000 GAL	0.01000	127.00	1.00000	12700.00	0.01000	127.00
0053 401036M PRIME COAT	220.000 GAL	0.01000	2.20	1.00000	220.00	0.01000	2.20
0054 401042M HOT MIX ASPHALT 9.5 M 64 SURFACE COURSE	110.000 T	51.50000	5665.00	100.00000	11000.00	94.60000	10406.00
0055 401048M HOT MIX ASPHALT 9.5 M 76 SURFACE COURSE	4000.000 T	70.75000	283000.00	80.00000	320000.00	75.55000	302200.00
0056 401072M HOT MIX ASPHALT 12.5 M 64 INTERMEDIATE COURSE	220.000 T	52.75000	11605.00	100.00000	22000.00	94.60000	20812.00
0057 401078M HOT MIX ASPHALT 12.5 M 76 INTERMEDIATE COURSE	6660.000 T	70.00000	466200.00	80.00000	532800.00	73.50000	489510.00
0058 401099M HOT MIX ASPHALT 25 M 64 BASE COURSE	385.000 T	64.59000	24867.15	100.00000	38500.00	96.35000	37094.75
0059 401108M CORE SAMPLES, HOT MIX ASPHALT	50.000 U	50.00000	2500.00	50.00000	2500.00	86.65000	4332.50
0060 453006M FULL DEPTH CONCRETE PAVEMENT REPAIR, HM	100.000 SY	1.00000	100.00	175.00000	17500.00	311.00000	31100.00
0061 456003M SEALING EXISTING JOINTS IN CONCRETE PAVEMENT	8100.000 LF	0.01000	81.00	1.50000	12150.00	1.55000	12555.00
0062 601122P 15" REINFORCED CONCRETE PIPE	213.000 LF	260.00000	55380.00	150.00000	31950.00	176.60000	37615.80
0064 602012M INLET, TYPE B	9.000 U	2500.00000	22500.00	2900.00000	26100.00	4426.40000	39837.60
0065 602013M INLET, TYPE DOUBLE B	1.000 U	6800.00000	6800.00	4100.00000	4100.00	6947.95000	6947.95
0066 602054M MANHOLE, 4' DIAMETER	1.000 U	2400.00000	2400.00	2500.00000	2500.00	4353.60000	4353.60
0067 602099M RESET EXISTING CASTING	43.000 U	900.00000	38700.00	250.00000	10750.00	751.60000	32318.80
0068 602108M SET INLET TYPE E, CASTING	2.000 U	1550.00000	3100.00	1400.00000	2800.00	1260.95000	2521.90
0069 602213M CURB PIECE	24.000 U	250.00000	6000.00	450.00000	10800.00	333.30000	7999.20
0070 606039P HOT MIX ASPHALT DRIVEWAY, 6" THICK	475.000 SY	58.00000	27550.00	50.00000	23750.00	62.15000	29521.25

TABULATION OF BIDS

CALL ORDER : 421 CONTRACT ID : 10421 COUNTIES : WARREN
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0071 606075P CONCRETE ISLAND, 4" THICK	93.000 SY	74.00000	6882.00	87.00000	8091.00	88.75000	8253.75
0072 607018P 9" X 16" CONCRETE VERTICAL CURB	923.000 LF	29.15000	26905.45	34.50000	31843.50	16.30000	15044.90
0073 607069P 9" X VARIABLE HEIGHT CONCRETE VERTICAL CURB	2800.000 LF	30.25000	84700.00	36.00000	100800.00	18.35000	51380.00
0074 608004P NONVEGETATIVE SURFACE, POROUS HOT MIX ASPHALT, 4" THICK	673.000 SY	26.25000	17666.25	26.00000	17498.00	25.50000	17161.50
0075 609003M BEAM GUIDE RAIL	825.000 LF	18.91000	15600.75	19.45000	16046.25	18.35000	15138.75
0076 609021M RUB RAIL	650.000 LF	6.80000	4420.00	6.50000	4225.00	6.65000	4322.50
0077 609024M FLARED GUIDE RAIL TERMINAL	1.000 U	2300.00000	2300.00	2325.00000	2325.00	2295.00000	2295.00
0078 609027M TANGENT GUIDE RAIL TERMINAL	1.000 U	2300.00000	2300.00	2400.00000	2400.00	2295.00000	2295.00
0079 609039M BEAM GUIDE RAIL ANCHORAGE	2.000 U	630.00000	1260.00	454.00000	908.00	612.00000	1224.00
0080 609075M REMOVAL OF BEAM GUIDE RAIL	896.000 LF	1.00000	896.00	2.60000	2329.60	1.00000	896.00
0081 610003M TRAFFIC STRIPES, LONG LIFE, EPOXY RESIN 4"	13300.000 LF	0.32000	4256.00	0.30000	3990.00	0.30000	3990.00
0082 610007M TRAFFIC STRIPES, LONG LIFE, EPOXY RESIN 8"	3800.000 LF	0.58000	2204.00	0.55000	2090.00	0.55000	2090.00
0083 610009M TRAFFIC MARKINGS, THERMOPLASTIC	3600.000 SF	2.60000	9360.00	2.50000	9000.00	2.55000	9180.00
0084 610012M RPM, MONO-DIRECTIONAL, WHITE LENS	315.000 U	25.20000	7938.00	24.00000	7560.00	24.50000	7717.50
0085 610018M RPM, MONO-DIRECTIONAL, AMBER LENS	95.000 U	25.20000	2394.00	24.00000	2280.00	24.50000	2327.50
0086 610021M RPM, BI-DIRECTIONAL, AMBER LENS	10.000 U	25.20000	252.00	24.00000	240.00	24.50000	245.00
0087 612003P REGULATORY AND WARNING SIGN	406.000 SF	56.25000	22837.50	27.00000	10962.00	30.60000	12423.60
0088 612006P GUIDE SIGN, TYPE GA, STEEL "U" POST SUPPORTS	23.000 SF	42.00000	966.00	52.50000	1207.50	40.80000	938.40

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0089 621003P CONCRETE HANDICAP RAMP		LUMP	91418.00000	91418.00	50000.00000	50000.00	58806.40000	58806.40
0090 651255M RESET WATER VALVE BOX	2.000	U	50.00000	100.00	50.00000	100.00	51.00000	102.00
0091 701012P 1 1/2" RIGID METALLIC CONDUIT	135.000	LF	33.62000	4538.70	32.00000	4320.00	22.95000	3098.25
0092 701120M JUNCTION BOX FRAME AND COVER	5.000	U	588.43000	2942.15	560.00000	2800.00	770.10000	3850.50
0093 701123M FOUNDATION, TYPE SFT	1.000	U	2350.00000	2350.00	2240.00000	2240.00	780.30000	780.30
0094 701138M FOUNDATION, TYPE STF	2.000	U	4500.00000	9000.00	4260.00000	8520.00	3243.60000	6487.20
0095 701192P GROUND WIRE, NO. 8 AWG	1737.000	LF	3.15000	5471.55	3.00000	5211.00	2.70000	4689.90
0096 702012M TRAFFIC SIGNAL STANDARD, ALUMINUM	1.000	U	2000.00000	2000.00	1900.00000	1900.00	1861.50000	1861.50
0097 702015M TRAFFIC SIGNAL STANDARD, STEEL	2.000	U	6000.00000	12000.00	5630.00000	11260.00	6726.90000	13453.80
0098 702021M TRAFFIC SIGNAL MAST ARM, ALUMINUM	1.000	U	2000.00000	2000.00	1790.00000	1790.00	1407.60000	1407.60
0099 702024M TRAFFIC SIGNAL MAST ARM, STEEL	2.000	U	4500.00000	9000.00	4215.00000	8430.00	4222.80000	8445.60
0100 702045M IMAGE DETECTOR	7.000	U	5800.00000	40600.00	5470.00000	38290.00	6344.40000	44410.80
0103 802021M TREE REMOVAL, OVER 6" TO 12" DIAMETER	1.000	U	525.00000	525.00	500.00000	500.00	765.00000	765.00
0104 804006P TOPSOILING, 4" THICK	285.000	SY	1.75000	498.75	1.65000	470.25	5.00000	1425.00
0105 804009P TOPSOILING, 6" THICK	154.000	SY	2.36000	363.44	2.25000	346.50	5.10000	785.40
0106 804015P BORROW TOPSOIL	58.000	CY	26.25000	1522.50	25.00000	1450.00	35.70000	2070.60
0107 805003M TURF REPAIR STRIP	4800.000	LF	1.80000	8640.00	1.75000	8400.00	0.35000	1680.00
0108 806006P FERTILIZING AND SEEDING, TYPE A-3	285.000	SY	0.55000	156.75	0.50000	142.50	2.35000	669.75
0109 809003M STRAW MULCHING	285.000	SY	0.55000	156.75	0.50000	142.50	2.35000	669.75
0110 809015M SHREDDED HARDWOOD BARK MULCHING	154.000	SY	4.20000	646.80	4.00000	616.00	8.70000	1339.80

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0111 811039M EVERGREEN TREE, 6-7' HIGH, B&B	1.000 U	185.00000	185.00	175.00000	175.00	147.90000	147.90
0112 811063M DECIDUOUS SHRUB, 18-24" HIGH, #3 CONTAINER	21.000 U	47.25000	992.25	45.00000	945.00	37.75000	792.75
0113 811069M EVERGREEN SHRUB, 36-42" HIGH, B&B	1.000 U	68.30000	68.30	65.00000	65.00	107.10000	107.10
0114 811078M EVERGREEN SHRUB, 18-24" HIGH, #3 CONTAINER	31.000 U	47.00000	1457.00	45.00000	1395.00	37.75000	1170.25
0115 811099M GROUND COVER OR VINE, #1 CONTAINER	30.000 U	15.75000	472.50	15.00000	450.00	31.60000	948.00
0116 811114M PERENNIAL, #SP5 CONTAINER	52.000 U	15.75000	819.00	15.00000	780.00	30.60000	1591.20
0117 811138M PLANT ESTABLISHMENT PERIOD	LUMP	1300.00000	1300.00	1250.00000	1250.00	4080.00000	4080.00
0118 811160M STONE LANDSCAPE WALL	40.000 SF	96.00000	3840.00	50.00000	2000.00	333.70000	13348.00
SECTION TOTALS		$	1,822,890.99	$	2,069,892.00	$	2,098,932.95
SECTION 0002 BRIDGE							
0119 513006P RETAINING WALL, CAST-IN-PLACE, LOCATION NO. ___ 1 (SOLDIER PILE)	354.000 SF	460.00000	162840.00	400.00000	141600.00	348.70000	123439.80
SECTION TOTALS		$	162,840.00	$	141,600.00	$	123,439.80
SECTION 0003 NON PARTICIPATING							
0002 152003P OWNER'S AND CONTRACTOR'S PROTECTIVE LIABILITY INSURANCE	LUMP	4100.00000	4100.00	200.00000	200.00	3975.00000	3975.00
0003 152009P POLLUTION LIABILITY INSURANCE	LUMP	0.01000	0.01	500.00000	500.00	17936.00000	17936.00
0063 601670M CLEANING EXISTING PIPE, 12" TO 24" DIAMETER	6765.000 LF	1.00000	6765.00	3.75000	25368.75	3.70000	25030.50
0101 801006M SELECTIVE THINNING	615.000 SY	5.25000	3228.75	5.00000	3075.00	6.90000	4243.50

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0102 801012M SELECTIVE CLEARING	333.000 SY	5.25000	1748.25	7.25000	2414.25	10.20000	3396.60
SECTION TOTALS		$	15,842.01	$	31,558.00	$	54,581.60
SECTION 0004 CONSTRUCTION ENGINEERING							
0007 155006M FIELD OFFICE TYPE B SET UP	1.000 U	15000.00000	15000.00	20000.00000	20000.00	28549.15000	28549.15
0008 155024M FIELD OFFICE TYPE B MAINTENANCE	9.000 MO	1500.00000	13500.00	2300.00000	20700.00	3187.50000	28687.50
0009 155039M TELEPHONE SERVICE	LUMP	2250.00000	2250.00	2250.00000	2250.00	2250.00000	2250.00
SECTION TOTALS		$	30,750.00	$	42,950.00	$	59,486.65
CONTRACT TOTALS		$	2,032,323.00	$	2,286,000.00	$	2,336,441.00

I CERTIFY THAT THE ABOVE IS AN EXACT TRANSCRIPT OF THE ORIGINAL BID PROPOSAL, EXCEPT THAT ERRORS, IF ANY, IN EXTENSION AND ADDITIONS HAVE BEEN CORRECTED.

SIGNED,

APPENDIX I: RAIL CASE STUDIES

Case study data were obtained from New Jersey Transit (NJT).[95] An older atlas of NJT commuter rail lines (New Jersey Transit 1993) was obtained and provides the basis of our analysis of the Morristown line, the Montclair line, the Princeton line, the Bergen County line, and the Pascack Valley line. In addition bid-sheets were obtained from New Jersey Transit for three rail stations including Lindenwold station, the Pennsauken Transit Center, and Ridgewood station. The modeling assumptions are fully presented in the section of the report entitled Data and Assumptions for a Life-Cycle Greenhouse Gas Analysis of Rail Transit Capital Projects.

These case studies are aimed at demonstrating the applicability of using readily available transit data to evaluate the life-cycle greenhouse gas (GHG) emissions from construction projects. We document the information that is available for various commuter rail lines in New Jersey and evaluate its usefulness. GHG emissions from the construction of track, overhead catenary structures, tunnels, bridges, passenger stations, parking facilities, and rolling stock are included in our analysis.

New Jersey Transit Commuter Lines

At the suggestion of a contact at New Jersey Transit, data for NJT commuter lines were taken from (New Jersey Transit 1993) that presents commuter lines as schematic diagrams called *map pages*. The diagrams show single, double, triple, and quadruple track, electrified and non-electrified portions, tunnels, bridges, and passenger stations. They are drawn to scale. Pedestrian tunnels and overpasses are shown, as are cross streets, overpasses, and water features. Mile markers and distance from the origin are shown for most features. Crossovers are shown but not included because they are clearly not to scale and are not quantifiable. Power supply substations are shown but not included because they are accounted for as part of the catenary systems.

Table 42 shows the quantified components for these five NJT commuter rail lines, while the figures that follow show the relative contribution of each major component. Because this is commuter rail we assume that rail size is 115 lbs/yd and that concrete ties are used. As with DRTD light rail we assume that the material inputs from catenary systems are multiplied by the number of tracks for the portions of track that are doubled, tripled, or quadrupled, as are tunnel miles and bridge miles. We assume that whenever rail crosses over a street, undivided highway, small water feature, or a pedestrian tunnel that a bridge of 0.01 miles (52.8 feet) is constructed. The length of bridges over divided highways is doubled. Larger water features are assessed by an approximation of their apparent size on the map provided by NJT. We make a large assumption by assuming that bridges are drawn to scale, however distances measured by mile marker positions and feature locations suggest that the diagrams are drawn to scale. Consistent with our methodology, all stations are assumed to be of the platform type. We recognize that

[95] This component of the work was also a contribution to TCRP H41.

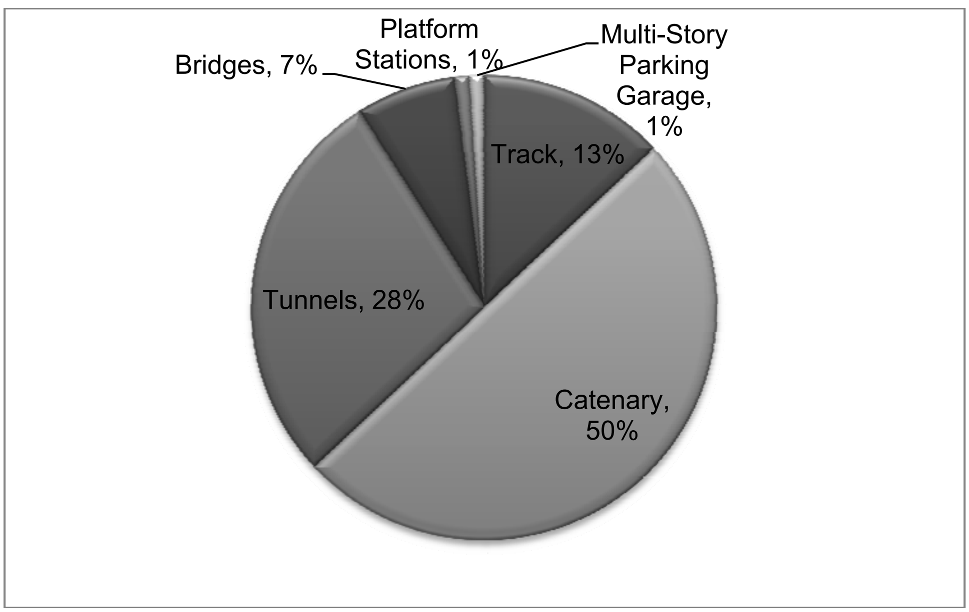
many stations have structures, but information on these was unavailable. Parking facility capacity is estimated from the NJT 2010 Parking Guide (New Jersey Transit 2010). This document establishes the number of parking spaces at each station but does not apportion them between surface parking lots and structured parking garages. We established garage and surface lot parking from various sources. No information about rolling stock was available from our sources. Track spurs and private facilities are not included in our analysis.

Table 42. GHG Emissions from Five New Jersey Transit Commuter Rail Lines.

Morristown Line - Commuter Rail		CO_2 Tonnes	CH_4 Tonnes	N_2O Tonnes	GWP Tonnes
Type of Rail	Commuter				
Track miles	121.8	146,929.0	137.484	21.774	156,566.2
Electrified track miles	94.92	589,311.0	744.961	4.806	606,445.0
Tunnel miles	7	336,097.1	225.723	11.330	344,349.6
Bridge miles	1.2	86,132.4	80.058	3.508	88,901.2
Platforms	25	10,539.0	9.655	0.789	10,986.2
Parking lot spaces	6,055	1,134.5	2.709	0.018	1,197.0
Parking garage spaces	906	9,791.7	8.837	0.756	10,211.7
Total		1,179,934.6	1,209.427	42.982	1,218,657.0
Princeton Line - Commuter Rail		CO_2 Tonnes	CH_4 Tonnes	N_2O Tonnes	GWP Tonnes
Type of Rail	Commuter				
Track miles	3.75	4,523.7	4.233	0.670	4,820.4
Electrified track miles	3.75	23,281.9	29.431	0.190	23,958.8
Tunnel miles	0	0.0	0.000	0.000	0.0
Bridge miles	0.01	717.8	0.667	0.029	740.8
Platforms	2	843.1	0.772	0.063	878.9
Parking lot spaces	285	53.4	0.128	0.001	56.3
Parking garage spaces	0	0.0	0.000	0.000	0.0
Total		29,419.8	35.231	0.953	30,455.3
Pascack Valley Line		CO_2 Tonnes	CH_4 Tonnes	N_2O Tonnes	GWP Tonnes
Type of Rail	Commuter				
Track miles	24.15	29,132.5	27.260	4.317	31,043.3
Electrified track miles	0	0.0	0.000	0.000	0.0
Tunnel miles	0	0.0	0.000	0.000	0.0
Bridge miles	0.06	4,306.6	4.003	0.175	4,445.1
Platforms	16	6,744.9	6.179	0.505	7,031.2
Parking lot spaces	2,042	382.6	0.914	0.006	403.7
Parking garage spaces	0	0.0	0.000	0.000	0.0
Total		40,566.6	38.355	5.004	42,923.2
Montclair Line - Commuter Rail		CO_2 Tonnes	CH_4 Tonnes	N_2O Tonnes	GWP Tonnes
Type of Rail	Commuter				
Track miles	7.81	9,421.3	8.816	1.396	10,039.3
Electrified track miles	7.81	48,488.4	61.295	0.395	49,898.2
Tunnel miles	0	0.0	0.000	0.000	0.0
Bridge miles	0.20	14,355.4	13.343	0.585	14,816.9
Platforms	4	1,686.2	1.545	0.126	1,757.8

Parking lot spaces	5192	972.8	2.323	0.015	1,026.4
Parking garage spaces	1535	16,589.7	14.973	1.281	17,301.3
Total		91,513.8	102.295	3.799	94,839.8
Bergen County Line - Commuter Rail		CO_2 Tonnes	CH_4 Tonnes	N_2O Tonnes	GWP Tonnes
Type of Rail	Commuter				
Track miles	34	41,014.7	38.378	6.078	43,704.8
Electrified track miles	0	0.0	0.000	0.000	0.0
Tunnel miles	0	0.0	0.000	0.000	0.0
Bridge miles	0.16	11,484.3	10.674	0.468	11,853.5
Platforms	7	2,950.9	2.703	0.221	3,076.1
Parking lot spaces	1110	208.0	0.497	0.003	219.4
Parking garage spaces	136	1,469.8	1.327	0.114	1,532.9
Total		57,127.7	53.579	6.884	60,386.8

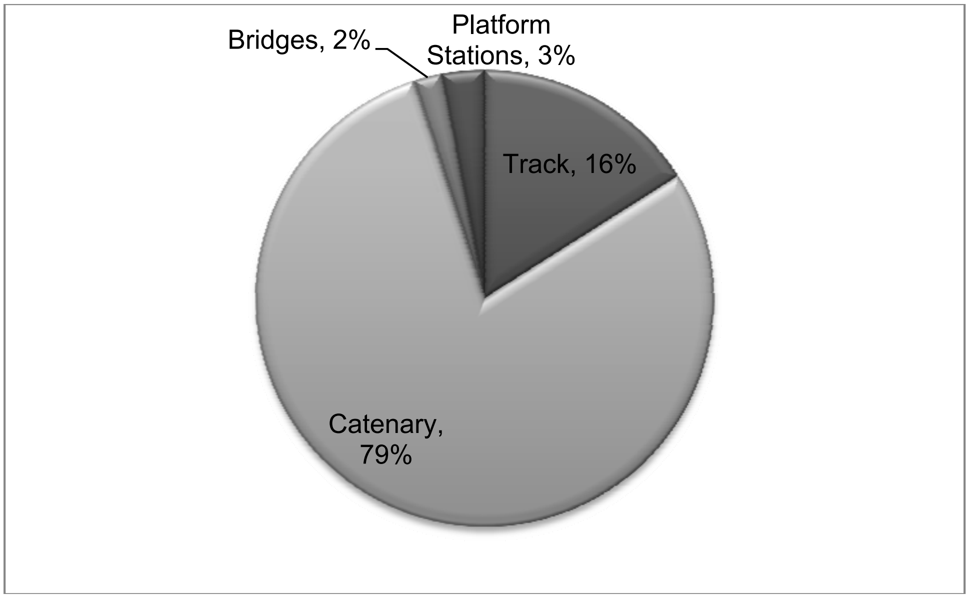
Figure 6. Subsystem Contribution to Total GHG Emissions (GWP) – Morristown Line.



The Morristown line runs from Penn Station in New York City to Hackettstown, NJ. It has a total length of 57 miles and consists of 121.8 miles of track of which 94.92 miles are electrified. This line has seven miles of tunnel and 1.20 miles of bridges. There are 25 stations assumed to be platform type and 6,961 parking spaces. Of this total, 6,055 parking spaces are located in surface parking lots and 906 are located in garage parking facilities. The catenary system accounts for 50% of GWP even though parts of the Morristown line are not electrified. The tunnel is roughly 1.75 miles in length but accommodates four tracks. We estimate embedded GWP from this tunnel at 28% of GWP for the Morristown line. Track accounts for 13% of GWP. Bridges account for 7%

and platform stations and parking garages account for 1% each. Surface lot parking accounts for less than 1% of GWP.

Figure 7. Subsystem Contribution to Total GHG Emissions (GWP) – Princeton Line.



The Princeton line is 3.75 miles of electrified single track. It runs between Princeton Junction, a major stop on the Northeast Corridor line and Princeton Station. We count Princeton Station and the platform that receives Princeton line passengers at Princeton Junction. These facilities are not inconsistent with the platforms described in Chester (2008) for commuter rail. We assume that all use of parking facilities by Princeton line passengers is at Princeton Station because the Princeton line is used to gain access to Northeast Corridor and AMTRAK trains at Princeton Junction. The catenary system accounts for 79% of GHG emissions and track accounts for 16%. A single bridge accounts for 2% and Princeton Station accounts for 3% of GWP. All 285 parking spaces at Princeton Station are surface lot parking which account for less than 1% of GWP.

The Pascack Valley line runs from Pascack Junction through Nanuet, its last stop, to Woodbine yard. It consists of 23.4 miles of non-electrified single track. It includes an estimated 0.06 miles of bridges, which account for 10% of GWP. There are 16 platform stations and 2,042 parking spaces all of which are surface lot parking. Track is the largest source of GHG emissions, accounting for 72% of GWP from the materials used in the Pascack line. Platforms account for another 16% of GWP. Surface parking lots account for 1% of GWP.

Figure 8. Subsystem Contribution to Total GHG Emissions (GWP) – Pascack Valley Line.

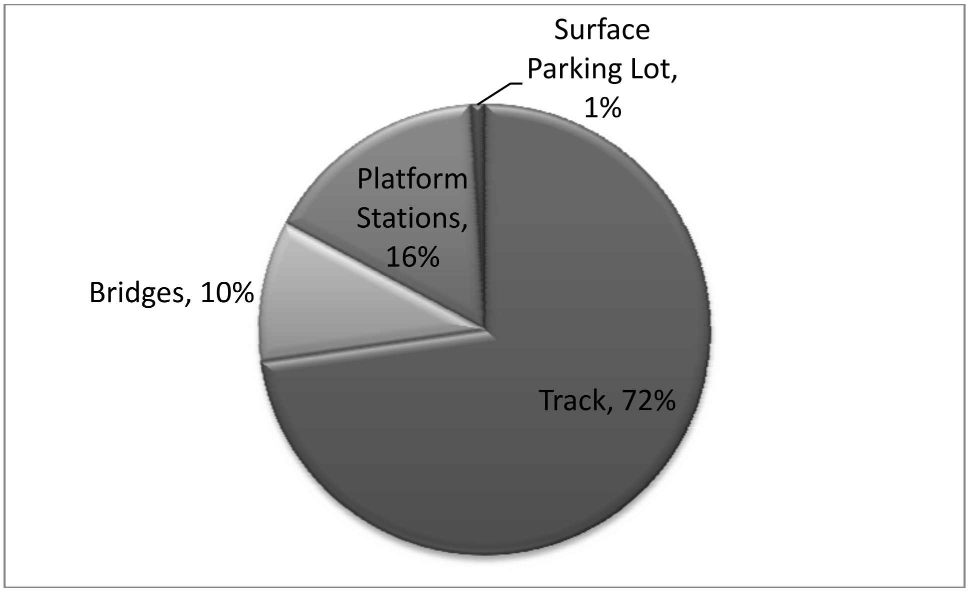
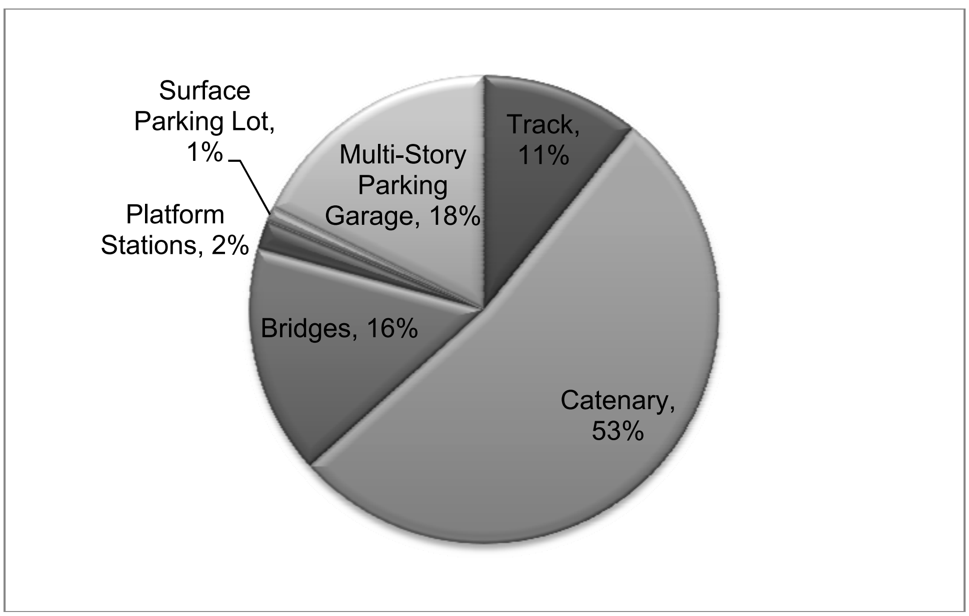
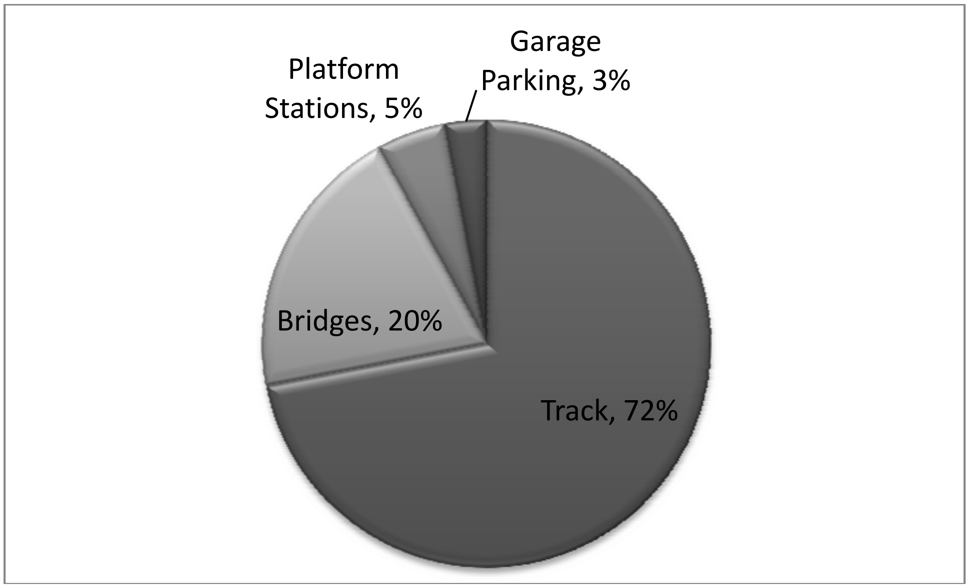


Figure 9. Subsystem Contribution to Total GHG Emissions (GWP) – Montclair Line.



The Montclair line connects with the Morristown line near the Roseville substation. It has a total length of 4.12 miles from the connection with the Morristown line to Montclair station and includes three intermediate station stops. The track is double for 3.69 miles and single for 0.43 miles on either end of the line. The track is electrified along its entire length. We assume 7.81 track miles. Ten small road and small water feature crossings account for 0.20 bridge miles. There are four commuter rail platforms and 6,727 parking spaces. Of these, 5,192 parking spaces are located in surface parking lots and 1,535 are located in garage parking facilities. The catenary system accounts for 53% of GWP from materials. Garage parking accounts for 18% of GWP, bridges account for 16% of GWP and track accounts for 11%. Platform stations account for 2% and surface parking lots account for 1% of GWP.

Figure 10. Subsystem Contribution to Total GHG Emissions (GWP) – Bergen County Line.



The Bergen County line leaves the Main Line at Bergen Junction and rejoins it at Ridgewood Junction. The track is doubled along its entire 17 mile length. The track is not electrified and there are no tunnels. We estimate 0.16 bridge miles, including a drawbridge over the Hackensack River drawn with an apparent length of 0.03 miles (158.6 feet) on the diagram. There are seven stations assumed to be platforms and 1,246 parking spaces. Surface parking lots account for 1,110 parking spaces and the remaining 136 parking spaces are located in garage parking facilities. Track accounts for 72% of GWP from material inputs and bridges account for 20%. Passenger stations account for 5% of GWP and garage parking accounts for 3%. Surface parking lots account for less than 1% of GWP.

Table 43 shows our estimates for the ranges of total GHG emissions per mile for four NJT commuter rail systems. Two of the lines, Princeton and Montclair, are fully electrified. Two others, Pascack Valley and Bergen County are not electrified. The Morristown line, which is partially electrified is not shown. The range of the non-electrified lines is quite small. The range of the electrified lines is larger due to the relative abundance of garage parking on the Montclair line. Our analysis shows that catenary systems account for most GHG emissions on a material basis where they are present. On non-electrified track the track itself is generally the largest source of GHG emissions. Tunnels and bridges, although they do not generally account for large portions of track represent relatively massive material inputs over short distances. Percent emissions from passenger stations are minor when track is electrified. All commuter rail stations are assumed to be of the platform type. These account for between one and two percent of GWP of electrified rail systems. On non-electrified track commuter rail station embedded GHG emissions are overshadowed to the extent that there are bridges and tunnels on the system. Parking spaces did not account for more than one percent of GHG emissions where garage parking was not present. This is largely due to the larger GHG emissions from garage parking per parking space in comparison with surface parking lots. The GWP of GHG increases 57 fold when a parking garage space is substituted for a surface lot parking space.

Table 43. Ranges of Estimated GWP for Electrified and Non-Electrified NJT Commuter Rail Systems.

	GWP (tonnes per mile)
Electrified Rail	
Princeton Line	8,121.40
Montclair Line	12,143.39
Non-electrified Rail	
Bergen County Line	1,776.08
Pascack Valley Line	1,777.36

New Jersey Transit Bid-sheets

We evaluated whether it was feasible to estimate emissions using a bottom-up approach, based on the components specified in contract bid-sheets. We received three contract bid-sheets for station construction/renovation that were provided by NJT. Detailed data on the material inputs would allow us to estimate the life-cycle emissions associated with each. These need to be provided based on material weight or volume with known densities. Measures used in construction contracts commonly awarded by the New Jersey Department of Transportation are generally quantifiable. They may be stated as volumes, such as cubic feet of concrete, reinforced concrete, aggregate or asphalt. They may also be stated as weight, such as pounds of steel, or aluminum. Areas may be used to a known depth, such as square yards of pavement, or metal plating. Linear distance may be used for which the material for which weight or volume has been worked out for a known distance, as we have done with ballast. Pipe, guard rails, and fencing are examples of the latter. After reviewing the three contract bid-sheets it was clear that a bottom-up approach would not work for any of them. Two of the contracts (Pennsauken Transit Center and Lindenwold Station) do not present any quantifiable material inputs. The third contract (Ridgewood Station) specifies most material inputs as lump sums. This is problematic because the material inputs are not quantified.

The contract bid-sheet items that are unquantifiable include items that are exclusively equipment activity inputs. These include such things as site clearing, disposal, drainage, saw-cutting, drilling, grading, excavation, embankment building, and landscaping. To quantify these inputs we could use EPA's NONROAD application with an inventory of the equipment used including fuel type, power rating for each equipment piece, and ideally vintage year. In addition we would need to know either fuel consumption or duration of operation, or as an alternative, a quantified expression of the work performed with each piece of equipment, such as cubic yards of material excavated, linear feet of a hole drilled to a known diameter, or square yards of pavement broken up. This latter type of information can be theoretically interpreted in a rough sense based on production rates per hour, which are often found on equipment specifications. The Lindenwold contract specifies linear feet of drilled shafts of two and three-foot diameters. These could be interpreted if we knew the power rating, fuel type, and production rate of the drill or drills used.

Many of the material inputs are not quantifiable. Lump sums are specified for sub-base courses, sidewalks, curbs, ballast, cast-in-place and precast concrete, concrete wearing surfaces, glass pavers, structural steel, handrails, timber, tiles, sheet metal, doors of a variety of materials, trims of various kinds, and so on. The Lindenwold contract specifies square yards of broken stone surface course, but not the depth. The specification of square feet of non-slip membrane coating is quantifiable but we have not identified the material. The under platform fence and chain link fencing, expressed as linear feet, could be easily quantified if we knew the height. Assuming a default mixture cast-in-place concrete expressed as cubic yards is easily quantifiable, as are brick masonry walls and concrete block expressed in square feet. Retractable platform edges and timber bumper strips expressed in linear feet are not quantifiable.

Our conclusion is that that most of the material inputs in these station contracts are not fully quantifiable. To successfully accomplish the type of inventory we attempted with data readily available from New Jersey Transit it would be necessary to work from the engineering plans and schematic diagrams.

Conclusions

We have examined data obtained from two sources in an attempt to establish what sorts of information might be readily available conduct GHG inventories of rail construction projects. It is impossible to discuss what we have done as a full GHG inventory because we have not been able to present equipment activity data, except for averages for drilling in tunnel construction. An ideal approach is to first quantify the material inputs and then assess the embedded energy and process emissions for each material. These emissions are largely upstream in nature; the fugitive process emissions are the only direct emissions. These can be readily calculated for all major material components. One key input that is missing is that data is not available on construction equipment activity. Specifically, equipment use data would need to be collected either based on fuel consumption or on the total number of hours of equipment operation. Other necessary equipment parameters are fuel type, power rating, and some approximation of average load. To accomplish such a study from the bottom up these data are indispensible. Equipment emissions factors are readily available from NONROAD if these data were available.

Based on our experience with these data it is clear that most analyses of GHG emissions from rail system construction will be based on averages, similar to what we have done. The data from New Jersey Transit include, at best, totals of track miles that are either at grade, below grade, or above grade, as well as the proportion of track that is electrified and supported by bridges or tunnels. The material inputs of stations of a handful of types are assumed based on totals from other rail systems. We are able to estimate track based on a bottom up approach, but no other rail system component. Our attempt to estimate the material inputs of rail passenger stations was not successful. Significant changes will be necessary in the ways that transit agencies present data before valid construction-related greenhouse gas inventories are possible.

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