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Environmental Management System for Transportation Maintenance Operations

FINAL REPORT

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Submitted by

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16. Abstract

The New Jersey's Global Warming Response Act, enacted in 2007, mandates reductions in greenhouse gas (GHG) emissions to 1990 levels by 2020, approximately a 20 percent reduction, followed by a further reduction of emissions to 80% below 2006 levels by 2050. The legislation required several State agencies, including the Department of Transportation (NJDOT) to assess the GHG emissions related to their operations, and develop methods to meet and exceed the 2020 target reductions. To achieve this goal, NJDOT focused on assessing and monitoring the GHG emissions of both its Capital Program and Operations. The purpose of this research project is to support this effort by focusing on effective monitoring of GHG emissions produced by Operations Maintenance activities and identifying solutions for their reduction. The project evaluates emissions generated by vehicles, equipment, and materials used in maintenance operations projects by applying the life-cycle analysis approach. The literature review focuses on identifying the sources of data and methods for evaluating carbon potential of materials mostly used in highway maintenance projects, such as asphalt, concrete, and steel. The review is further expanded to identify potential methods and strategies that will help reduce the GHG emissions of highway maintenance projects, focusing primarily on construction processes and aggregate industry, especially asphalt and bitumen. The emissions generate by vehicles and equipment are also analyzed, along with the strategies for reducing the related carbon emissions through introduction of more fuel-efficient or hybrid engines and alternative fuels. Based on the methods developed in this study and the collected data, a decision support software tool is developed to guide NJDOT in monitoring and assessing alternatives for reduction of GHG emissions related to Operations Maintenance. Both the analysis framework and the decision support tool will provide means for quantifying the effects of different strategies for reducing GHG emission, and will ultimately be useful tools in developing Department-wide GHG emission reduction strategies.

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BACKGROUND

New Jersey has been at the forefront of the efforts to reverse the climate change and other negative environmental effects of greenhouse gas (GHG) emissions. New Jersey has taken a leadership role in the Regional Greenhouse Gas Initiative (RGGI), the first mandatory market based program to cap the GHG emissions levels at the 2009 rate through 2014 and then reduce the rate by 10 percent in 2018. In 2007, the New Jersey legislature went a step further and enacted the Global Warming Response Act (GWRA), calling for more significant reductions of greenhouse gas (GHG) emissions. The law requires the state agencies to reduce the GHG emissions to 1990 levels by 2020, and achieve a further reduction of 80 percent below 2006 levels by 2050. The law mandates that all State agencies take steps in assessing the baseline emission levels, and to evaluate and implement the methods for achieving and exceeding the mandated 2020 targets.

Pursuant to the GWRA mandate, the New Jersey Department of Environmental Protection (NJDEP) published in 2009 a Recommendation Report[1] that establishes New Jersey's current GHG inventory and outlines strategies and methods for GHG emission reductions by sector. According to the report, transportation and energy are the largest contributors to New Jersey GHG emissions. Transportation alone accounts for approximately 35% of gross emissions in the state. The report identified the New Jersey Energy Master Plan (EMP), the New Jersey Low Emission Vehicle (LEV) Program, and the Regional Greenhouse Gas Initiative (RGGI) program as the core measures for meeting its statewide 2020 GHG limits. Consequently, the recently developed New Jersey Energy Master Plan (EMP) identifies the need for a 20% reduction of energy by government facilities through the pursuit of cost-effective alternative fuels and increasing the supply of reliable alternative energy. Currently, alternative fuels account for less than one percent of New Jersey's total energy consumption (Energy Information Administration, 2009), so there seems to be great potential for reducing carbon emissions by increasing the share of alternative fuels. Figure 1 shows GHG emissions by sector for the state of New Jersey.

The 2009 report identifies several strategies for reducing GHG emissions attributed to transportation, including specific initiatives, such as reducing reliance on cars and minimizing the increase in the overall vehicle-miles traveled on the state's roadways,

[1] Meeting New Jersey's 2020 Greenhouse Gas Limit: New Jersey's Global Warming Response Act Recommendations Report, New Jersey Department of Environmental Protection, December 2009. Accessed on 2/11/2012 at http://www.nj.gov/globalwarming/home/gwra_report.html

increasing the use of fuel-efficient vehicles and equipment, promoting the use of alternative fuels, and developing a regional low carbon fuel standards (LCFS). It also outlines the planning strategies, including establishment of a carbon footprint standard for transportation projects, effective implementation of the State Development and Redevelopment Plan (SDRP), and incorporating growth management and GHG reduction goals into the regional plans and programs developed by NJDOT, NJDEP, and all three of New Jersey's Metropolitan Organizations (MPO).

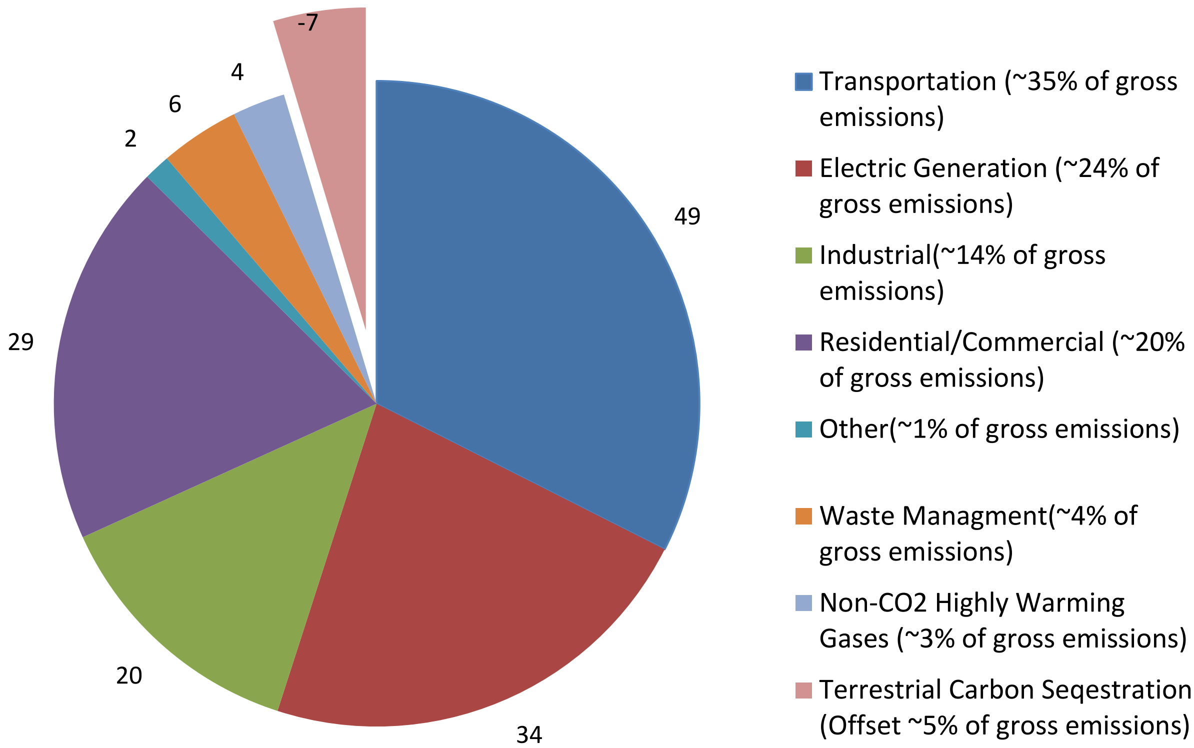

Figure 1. GHG Emissions by Sector; New Jersey, 2004 Millions of Metric Tons CO2eq[2]

In order for NJDOT to accomplish the goals set forth by the GWRA, it is critical to assess and monitor the department's carbon footprint, and then identify and pursue effective strategies for reducing the GHG emissions. In 2009 the NJDOT Bureau of Research held a statewide Sustainable Transportation Forum to highlight the need for a better understanding of the department's carbon footprint and initiate a discussion about the strategies that can help meet the emission reduction goals. Nearly 100 transportation managers attended the forum and discussed the environmental impacts of transportation, current research on carbon emissions, the importance of land use

[2] *New Jersey GHG Inventory and Reference Case Projections 1990-2020 November 2008,* *http://www.nj.gov/globalwarming/home/documents/pdf/njgwra_final_report_dec2009.pdf*

planning in an effective environmental protection, and received updates on ecological research and air quality issues that affect transportation. The audience was also surveyed on future required actions and strategies for minimizing these negative impacts. The participants identified the following strategies: use smarter design standards (58%), recycle or reduce energy consumption (28%), and promote communications/training of state employees (14%) on environmental issues. Also, the majority identified a need for NJDOT to upgrade roadway materials and maintenance work to support sustainable transportation. Figure 2 presents the projected GHG emissions for the state of New Jersey for business as usual (BAU) against the statewide limit for 2020.

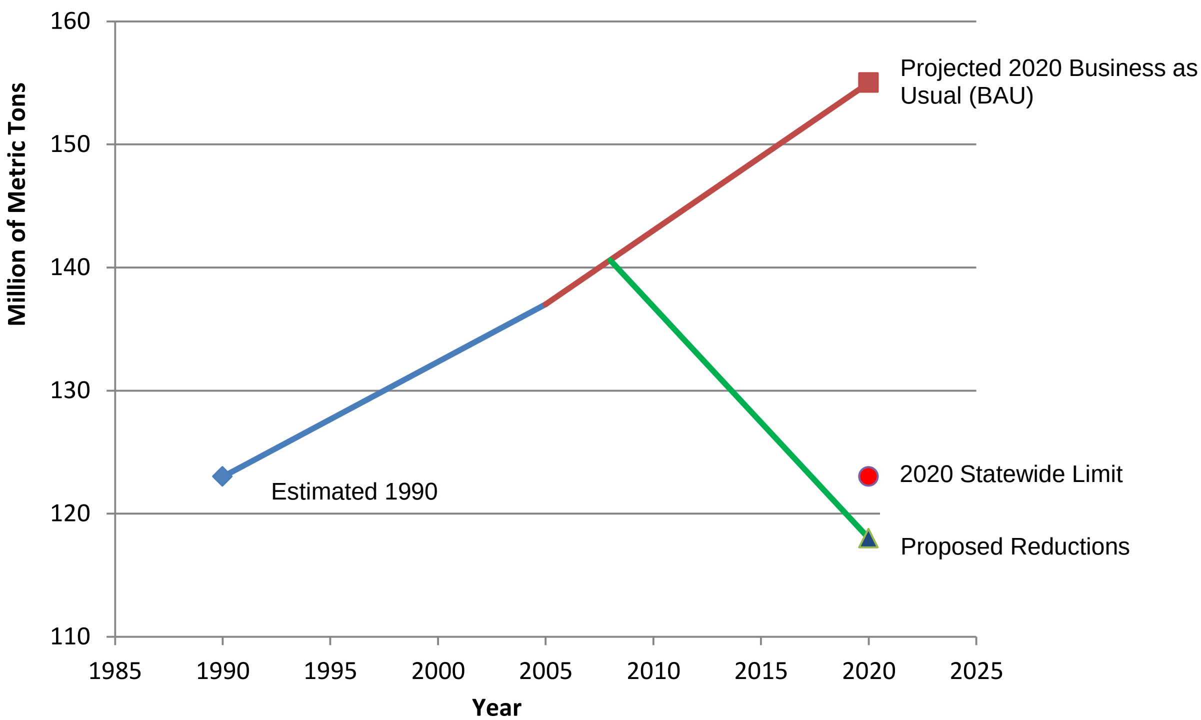

Figure 2. New Jersey Greenhouse Gas Emissions (Estimated 1990, Projected 2020 Business as usual (BAU); 2020 LIMIT, and Proposed Reductions)[3]

[3] (Based on data in "New Jersey Greenhouse Gas Inventory and Reference Case Projections 1990-2020", November 2008. This document is posted on the State's Global Warming Web page at http://www.nj.gov/globalwarming/)

Quantifying the GHG emissions on a department-wide level is clearly the first step in assessing the baseline and then goals for GHG emission reduction. Within NJDOT, Capital Programs, Operations, and Maintenance are the sectors with major contributions to GHG emissions. In the past, NJDOT was not actively collecting data to support quantification of emissions related to any of these three sectors; so the main difficulty in assessing the GHG emission inventory is lack of readily available relevant data, as well as procedures for data collection and methods for analyzing the data.

An Environmental Management System (EMS) is the accepted tool used by state DOTs nationwide to monitor the environmental compliance of their capital improvement, operations, and maintenance functions. These systems are versatile, since they are linked to existing data and are frequently built as programs to increase compliance assurance. Other uses of these systems include prevention of environmental risks and liability violations, track consent orders, and maintaining special projects. They can be used to track policy statements, define roles and responsibilities of units, identify environmental requirements, assess methodologies, prevent and control procedures, follow competency standards, and document control procedures (Venner, et al., 2007).

OBJECTIVES

This research project focuses on GHG emissions produced by the Maintenance Operations sector of NJDOT. The overall goal of this research is to develop methods and tools for an effective assessment of carbon emissions produced by NJDOT Maintenance Operations activities, and evaluation of alternatives for reducing these emissions. The first step in accomplishing this goal is reviewing the current practices related to maintenance projects. This includes specifications of utilized materials, equipment, and vehicles, and identifying their contribution to GHG emissions. Once these contributions are quantified, it is possible to identify methods and strategies for reducing GHG emissions. The specific research objectives are the following:

1. **Assess the impact of Maintenance Operations activities on climate change:** Review the current Maintenance Operations activities, and develop a methodology for quantifying related GHG emissions.

2. **Identify alternatives for reducing GHG emissions related to Maintenance Operations:** Identify actions and strategies for reducing GHG emissions. The strategies should focus on implementation of alternative materials and sustainable construction processes, use of alternative fuels, fuel efficient vehicles, and equipment.

3. **Develop a GHG emission modeling tool**: Based on the results of the review of current practice and alternatives for reducing GHG emissions, develop a software tool that will assist engineers and planners in quantifying GHG emissions and guide them in selecting the most effective strategies for reducing these emissions.

RESEARCH APPROACH

To achieve the study's objectives, a research approach is formulated. The approach consists of six steps, as illustrated in Figure 3. The first two objectives - assessing the impact of maintenance operations activities on climate change, and identifying alternatives for reducing GHG emissions related to them requires an extensive literature survey. A variety of sources including journal papers, research articles, reports, inventories, databases, and web resources are identified and studied for their relevance to providing information about GHG emissions due to transportation maintenance operations. A summary of the literature survey with an overview of the most relevant resources is presented separately in the following section.

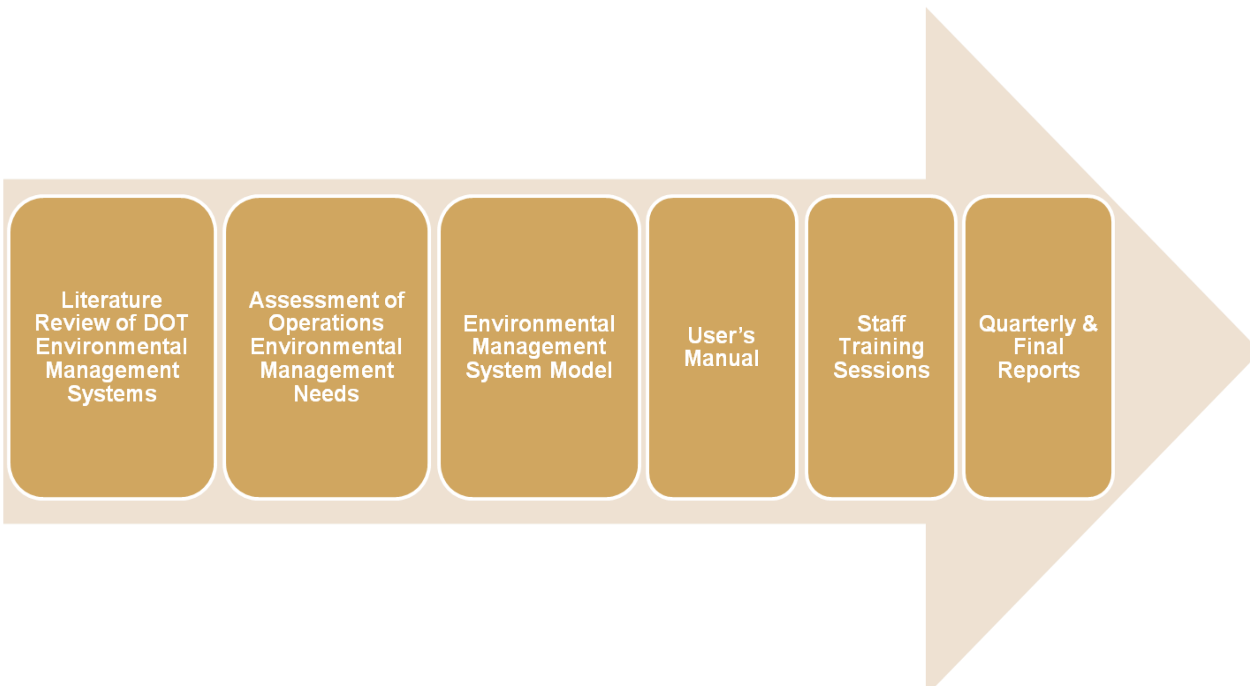

Figure 3. Research approach

The literature survey yielded two important sources of information: 1. The transportation maintenance activities that are responsible for GHG emissions, and 2. Carbon emission databases to quantify GHG emissions. The 2007 NJDOT specifications list and bid sheets were principle sources of information in identifying maintenance activities contributing towards GHG emissions. The 2007 NJDOT specifications list served as one of the background data tables for the selection of various processes, materials, and activities for any maintenance project under consideration. Once the activities are identified, the next step is to quantify GHG emissions. Several carbon emission databases were referred to for this purpose. Among the databases that are publically available, databases published by the National Renewable Energy Laboratory (NREL), University of Bath, UK (Inventory of Carbon and Energy Database), and EPA (Emission Factors for Greenhouse Gas Inventories) were found to be most relevant to this research and served as principle sources of information for CO_2, N_2O, NH_4, and CO_2 equations' calculations.

A methodology for the calculation of GHG emissions for each material, process, and activity was developed using information from references mentioned above. All the activities listed in the 2007 NJDOT specifications list and bid sheets were grouped under three main categories: materials, equipment, and vehicles. A separate strategy was adopted for GHG emissions calculation for each of these categories. This served as the design logic for the environmental management system model. Details of these strategies, methodology, and logic are presented in a separate section following the literature review section.

Finally after the model is developed, a user manual was developed to help understand the functioning of the model and to aid in its use. In addition to this user manual, NJDOT staff training sessions are planned to train end users to independently run this model. Progress of this research was reported in quarterly and supplementary reports throughout the planning, design, and execution phase.

SUMMARY OF THE LITERATURE REVIEW

The primary objective of the literature review is to gather relevant information about the state of practice in quantifying GHG emissions, with a specific focus on transportation and construction sectors. To be able to quantify the GHG emissions generated by transportation maintenance projects, one must have reliable information on carbon content of materials applied in pertinent projects, processes of applying or installing the materials, and emissions generated by the machinery and vehicles used in these processes. Thus, the focus of the literature review is on methods for estimating GHG emissions associated with materials and activities related to the infrastructure maintenance projects, as well as vehicles and equipment used in these projects. The types of materials and equipment used in maintenance projects at NJDOT are described in detail in the NJDOT Standard Specifications for Road and Bridge Construction (2007 Edition)[4]. This document is used as the main reference for identifying the materials and equipment used in the transportation maintenance projects.

Besides the research reports, papers, and articles published in national and international publications, the review included a number of greenhouse gas emission models and calculation tools. These include:

- US EPA Diesel Emissions Quantifier;
- US DOT Clearinghouse for Environment and Climate Change;
- Greenroads 2010 Manual;
- NCHRP Greenhouse Gas Calculator for State Departments of Transportation (GreenDOT) Model;
- National Energy Modeling System (NEMS);
- Energy MARKAL-MACRO;
- MiniCAM;
- Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET); and
- Transitional Alternative Fuels and Vehicles (TAFV).

A detailed review of the resources that were found to be the most useful for this project is provided next.

[4] http://www.state.nj.us/transportation/eng/specs/2007/Division.shtml (accessed February 12, 2012)

Estimation of the GHG Emissions of Materials and Industrial Processes

Estimation of the GHG emissions for various activities and processes for transportation maintenance operations required gathering a wide array of information from multiple sources. Some of the prominent resources included an inventory of GHG emissions databases, current modeling approaches to convert this raw emissions data into specific values generated during maintenance operations, the standardization of this model so that it can be applied to a group of processes or materials together, and other useful techniques that will help estimate best possible numbers for GHG emissions. This section explains, one by one, important references that formed the core of the emission database and modeling methodology in this research.

Inventory of Carbon & Energy (ICE) Version 1.6a[5]

In this report, the authors developed a database which benchmarked and summarized the embodied energy and carbon for over 200 building materials. Embodied energy is the total primary energy consumed during the life time of a product, ideally the boundaries would be set from the extraction of raw materials (including fuels) to the end of the products lifetime (including energy from manufacturing, transport, energy to manufacture capital equipment, heating & lighting of factory, etc.), this boundary condition is known as Cradle to Grave. It has become common practice to specify the embodied energy as Cradle to Gate, which includes all energy (in primary form) until the product leaves the factory gate. The final boundary condition is Cradle to Site, which includes all energy consumed until the product has reached the point of use (i.e. building site) (Hammond and Jones, 2008). Selection of ICE database for base GHG emissions corresponds well with the rest of reviewed literature, which also indicates that life cycle analysis is an appropriate method for estimating GHG emissions of materials and activities. An excerpt from the database is presented in Table 1.

[5] Authors: Hammond, G.P. and C.I. Jones. Published by the University of Bath, UK, 2008. Available at www.bath.ac.uk/mech-eng/sert/embodied/

TABLE 1: An Excerpt from the Inventory of Carbon & Energy (ICE) Database

Materials	Embodied Energy & Carbon Coefficients			Comments
	EE - MJ/kg	EC - kgCO2/kg	EC - kgCO2e/kg	EE = Embodied Energy, EC = Embodied Carbon, CO2e = carbon dioxide equivalent
Aggregate				
General (Gravel or Crushed Rock)	0.083	0.0048	0.0052	Estimated from measured UK industrial fuel consumption data
Asphalt				
4% (bitumen) binder content (by mass)	2.86	0.059	0.066	1.68 MJ/kg Feedstock Energy (Included). Modeled from the bitumen binder content. The fuel consumption of asphalt mixing operations was taken from the Mineral Products Association (MPA). It represents typical UK industrial data. Feedstock energy is from the bitumen content.
5% binder content	3.39	0.064	0.071	2.10 MJ/kg Feedstock Energy (Included). Comments from 4% mix also apply.
6% binder content	3.93	0.068	0.076	2.52 MJ/kg Feedstock Energy (Included). Comments from 4% mix also apply.
7% binder content	4.46	0.072	0.081	2.94 MJ/kg Feedstock Energy (Included). Comments from 4% mix also apply.
8% binder content	5.00	0.076	0.086	3.36 MJ/kg Feedstock Energy (Included). Comments from 4% mix also apply.
Bitumen				
General	51	0.38 - 0.43	0.43 - 0.55	42 MJ/kg Feedstock Energy (Included). Feedstock assumed to be typical energy content of Bitumen. Carbon dioxide emissions are particularly difficult to estimate, range given.

Greenhouse Gas Mitigation Measures for Transportation Construction, Maintenance, and Operations Activities[6]

The purpose of the study was to provide practical information to help transportation practitioners better understand available greenhouse gas analysis techniques.
The purpose of this research was threefold:

1. Identify available methods to accurately estimate GHG emissions resulting from transportation activities, projects, and programs;
2. Evaluate these methods in terms of their strengths and limitations, and applicability for different types of transportation analysis; and

[6] Author: Gallivan, F. (ICF International). Published by the American Association of State Transportation and Highway Officials (AASHTO), 2010. Available at http://onlinepubs.trb.org/onlinepubs/nchrp/docs/NCHRP25-25(58)_FR.pdf

3. Identify gaps in existing tools, and develop recommendations for new methods or improvements to existing methods to fill these gaps.

In NCHRP Project 25-25/Task 58 a spreadsheet-based calculator tool was developed, the Greenhouse Gas Calculator for State Departments of Transportation (GreenDOT). This tool allows one to estimate CO_2 emissions from construction, maintenance, and operations activities, including emissions from electricity used in roadways, emissions from on-road vehicle fleets, emissions from off-road equipment, and emissions related to embodied carbon in materials used in roadway construction.

In addition, the research confirmed that very few DOTs have estimated the impact of mitigation strategies on CO_2 emissions. While DOTs are increasingly exploring mitigation strategies, most have not conducted an evaluation of these strategies. Other interested parties including the U.S. Environmental Protection Agency (EPA), the Federal Highway Administration (FHWA), and private contractors have also produced very few quantitative evaluations of CO_2 reduction strategies that are relevant to DOTs' operations, maintenance, and construction activities. The study concluded that additional research is needed to help DOTs estimate the ability of strategies to reduce activity levels of on-road vehicles and off-road equipment.

Proceedings of the Asphalt's Carbon Footprint Conference[7]

The purpose of the conference, which took place in March 2009 in London, was to monitor greenhouse emissions and move towards greater sustainability. In this seminar, various ways to calculate carbon footprints were analyzed, particularly for within the asphalt. This seminar was geared mainly towards engineers and technicians in the highway and airfield pavement industry who are involved in designing, specifying, producing and laying asphalt. The purpose of the seminar was to provide them with information and knowledge that would enable them to minimize the adverse effects of their industry on the environment.

The references provided in the proceeding's papers are very useful for calculating GHG emissions of NJDOT pavement resurfacing projects as they mainly utilize asphalt and bituminous materials. According to 2007 NJDOT specifications, hot asphalt is used for base, surface, and intermediate courses. These are also used for micro-surfacing and pavement courses, and bitumen is used for patch course and surfacing. Asphalt is the major contributor to carbon emissions, thus it is possible to achieve reductions in GHG emissions by using several techniques addressing this type of material, such as using

[7] Society of Chemical Industry, 2009. Available at: http://www.soci.org/News/construction-asphalt-papers

warm mix asphalt instead of hot mix, preventing moisture ingress, and lowering the mixing and storage temperature of bitumen.

In his conference presentation, Dr. Miles Watkins suggested that recent studies showed that the aggregate industry recorded around 4.94 kg of CO_2 per ton of production in 2007, marking a steady decline over the past several years. This was achieved through the use of good quality heat and power sources and efficient and economic practices. Asphalt production is a hot process and consumes a great amount of energy. Various techniques like reduction of moisture content, use of variable speed drives, and development of bio-derived fuels have been used to improve the process. The presentation by Murray Reid pointed out that highways in the UK have been sustainably maintained by using locally available materials, minimizing and recycling the use of products, and maximizing the use of cold technologies instead of hot ones. Strategies like cold recycling of existing pavements, use of incinerator bottom ash for cold recycled foam bitumen base, and recycling thin surfacing at 25% are implemented for well-maintained highways. In the analysis of the carbon footprint of bitumen, Ian Lancaster provided data on the total carbon emissions from cradle to grave along with the processes to reduce the footprint by prevention of moisture ingress and lower mixing and storage temperatures. Finally, S. Cook discussed the potential of reducing GHG emissions of moving vehicles utilizing the following raw materials in tires: exposed natural rubber, vegetable oils, natural fibers and starch. Fuel economy is the key factor in the reduction of lifecycle energy consumption. Use of ENR-25 has improved the micro-dispersion of silica resulting in improved wet grip and rolling resistance in tires, which reduces the carbon footprint of tires.

Miscellaneous Building Materials (Epoxy Resin – Technical Datasheet)[8]

This reference consists of the description, features and properties of liquid ER2074 – epoxy resins. It also includes the mixing properties of resin packs and bulk mixing and additional information about curing, cleaning, storage, health and safety. Epoxy resins are created by transforming liquid polyether into infusible solids through a special curing process. In most cases, resins are the result of a chemical reaction between epichlorohydrin and bisphenol-A. Overall, the production of epoxy resin is part of the chemical industry that generates over $15 billion annually. Epoxy resins have many different uses. For example, epoxy resins have been used successfully in grouts, mortars, adhesives and coatings. High performance epoxy coatings have been used worldwide for bridge decks, industrial flooring and other concrete coating applications and epoxy paints for industrial flooring and a wide variety of other concrete and

[8] Author: Electrolube, 2005. Published by Electrolube, a division of H. K. Wentworth. Available online at: http://images.mercateo.com/pdf/Schuricht/ER2074_DATA_DE.pdf

industrial maintenance coating. Industrial tooling applications use epoxy resins to make laminates, castings, fixtures, and molds. In the electronics industry, epoxy resins can be used to make insulators, transformers, generators, and switchgear[9].

Reclaimed Asphalt Pavement (RAP)[10]

This reference provides information about the impact of temperature variation of asphalt mix on GHG emissions, primarily focusing on application properties of Reclaimed Asphalt Pavement (RAP). In this document the authors demonstrate the viability of semi-warm and cold temperature asphalt as the alternatives to hot mix asphalt. They show that if warm mix asphalt was used instead of hot mix asphalt, the temperature, as well as energy consumption, would be significantly reduced. This would in turn reduce the carbon footprint of paving/resurfacing projects. Usually, the engineered mixture of aggregate, sand, gravel and asphalt cement (bitumen) is produced at an asphalt plant. The ratio is about 95 percent aggregate to 5 percent asphalt cement. Asphalt cement is the binder - the glue that holds the pavement together. At the plant, the aggregates are heated, driving off moisture. About 500 million tons of asphalt pavement material is produced each year in the U.S. using these methods. The warm mix technologies are compaction aids that improve the workability of the mix. By using warm mix or cold mix asphalt instead of hot mix, the temperature is reduced to about 215 °F (reduction of 50 – 100 °F). Since asphalt is the major GHG emissions contributor in the Aggregate sector, emitting 20% of the overall Aggregate-related carbon, cold mix technology makes a significant contribution to sustainable and carbon-efficient roads by minimizing the energy consumption and vapor emissions associated with paving and resurfacing the roads.

Models for Estimation of Transportation-Related Greenhouse Gas Emissions

This summary provides an overview of the characteristics and the relevance to this study of six frequently used models to calculate emissions related to transportation infrastructure construction and operations. With some modifications or post-processing, these models can be used for calculating GHG emissions from transportation projects. They include:

1. Greenhouse Gas Calculator for State Departments of Transportation (GreenDOT) Model, developed as part of a NCHRP research project;

[9] Source: http://www.intota.com/expertconsultant.asp?bioID=708161&perID=721855

[10] Author: Breneman, E. J. Published by EJB Paving & Materials Co., 2010. Available online at: http://www.ejbreneman.com/EJB-Paving-and-Materials/Warm-Mix-Asphalt-And-Rap-Turning-Black-To-Green/

2. National Energy Modeling System (NEMS), maintained by the Energy Information Administration (EIA), U.S. Department of Energy;

3. Energy MARKAL-MACRO, maintained by Brookhaven National Laboratory and U.S. Department of Energy;

4. MiniCAM, maintained by Pacific Northwest National Laboratory;

5. Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET), maintained by Argonne National Laboratory; and

6. Transitional Alternative Fuels and Vehicles (TAFV), maintained by Oak Ridge National Laboratory (ORNL) and the University of Maine.

The use of these models by the state Departments of Transportation often requires integration of data from many sources. Many of the data sources used to develop these models reside at the federal agencies that created and/or currently maintain the models.

NCHRP GreenDOT MODEL

NCHRP GreenDOT model is a spreadsheet-based tool that allows users to calculate carbon dioxide (CO_2) emissions from the operations, construction, and maintenance activities of state Departments of Transportation. The model was developed by ICF International as part of the NCHRP Project 25-25/Task 58. The model is designed to calculate emissions on different levels, ranging from a single project to the entire annual operations of a department, as well as projects or operations stretching over a period ranging from one day to several years. The are two frequent uses of the tool:

1. Calculation of annual agency-wide emissions,

2. Calculation of emissions related to a specific project, covering a specific period of performance.

Using this tool, transportation agencies can take into account their greenhouse gas emissions as part of their day-to-day activities as well as provide information to the public and other stakeholders in examining the effects of transportation projects over a longer term.

The GreenDOT model deals with several aspects of operations of a State DOT, including: electricity, materials, on-road vehicles, non-road equipment and machinery. Calculations are facilitated in a series of worksheet modules, with each module calculating the CO_2 emission for different aspects of operations. At the end, all emissions are totaled, providing an overall estimate of CO_2 emissions on a departmental level.

Limitations. Although it is very comprehensive, the GreenDOT model does not accept input based on the specifications of an individual State DOT. The inputs must be provided for each material, including its conventional components. For example, for finished material such as a concrete panel, one must input data for virgin aggregate, cement, steel, and water. It would be more convenient to be able to select from various specifications that make up a typical project or a typical project-item (as required by NJDOT) and calculate the corresponding GHG emissions.

National Energy Modeling System (NEMS MODEL)

The NEMS model is used for the Clean Energy Futures (CEF) study. The primary goals of the CEF study are toproduce credible estimates of the potential for energy efficiency and clean energy technologies to address the multiple energy and environmental challenges of the 21st century, describe technology and policy pathways demonstrating this potential, compare the results of this analysis with other key studies.

The objective of the NEMS is to project the energy, economic, environmental, and security impacts that various alternative energy policies and assumptions about energy markets would have on the United States (USDOE EIA 2003a). The Energy Information Administration (EIA) developed this model to forecast national and regional energy supply and demand through 2025. The model allows a wide variety of parameters to be altered to determine their impact on the overall fuel use. Examples include changes in equipment efficiencies, costs, fuel supplies and economic growth.

The NEMS estimated energy and carbon savings based on the performance analysis of heaters and heat pumps. Carbon savings for fuel cells and natural gas heat pumps were based on detailed energy balance calculations for these technologies. As a result, the model shows that the use of fuel cells or natural gas heat pumps and natural gas water heaters, instead of the use of oil/gasoline heat pumps during maintenance operations, would reduce greenhouse gases.

The transportation demand module (TRAN) of the model projects the fuel consumption of the transportation sector by mode, including the use of renewable and alternative fuels, subject to delivered prices of energy and macroeconomic variables, including disposable personal income, gross domestic product, level of imports and exports, industrial output, new car and light truck sales, and population.

Limitations. The NEMS model is designed for an analysis on a census region and census division level. Therefore, extrapolation and interpolation are needed to develop estimates on a state level. Local- or county-level forecasts are not applicable in the model. In addition, the size of the entire NEMS model is very large and detailed, requiring over 10 to 15 megabytes (MB) of storage just for the "restart file," which contains the starting values for the model each year. A "standalone" model run, which consists of running only one module and keeping the others at reference case levels, would require 100 MB of storage space. Although NEMS can be installed on an individual personal computer (PC), the storage requirements are substantial.

MARKAL-MACRO Model

The MARKAL-MACRO Model at DOE is an integration of two models: MARKAL and MACRO. MARKAL is the "bottom-up" technological model of energy and the environment, which includes depletable and renewable natural resources, processing of energy resources, and end-use technologies to meet the projected energy service demands in all sectors.

The model forecasts emissions sources and levels for carbon emissions and any user-specified pollutants and wastes. The value of carbon rights (marginal cost of emissions) is one of the important outputs of the model. Outputs are solved in five-year intervals through 2050. As far as modes, the model covers passenger cars, light trucks, heavy trucks, buses, airplanes, shipping, maintenance operations, passenger rail, and freight rail.

Environmental Impact. MARKAL calculates the total emissions of different pollutants by considering the average emissions coefficients of each technology and total fossil fuels consumption. It is therefore possible to estimate the environmental impact of each optimized scenario, and to assess the environmental compatibility of the model choices. If the analyzed scenarios are not environmentally constrained, it is possible to evaluate air quality improvement due to a better use of resources.

Limitations. The MARKAL-MACRO model has been very effective in forecasting carbon emissions, but there are some limitations to the model. While it can provide an alternative and complimentary approach in longer-term analysis (e.g., projection of renewable fuel penetration and reduction of CO2 emissions), the model does not cover as much detail in all sectors as the NEMS model. The MARKAL-MACRO Model uses a simple approach to forecast energy service demands based on economic indicators such as housing stocks, commercial floor space, industrial production index, and VMT. Modeling at the individual equipment level would be difficult and would require off-line analysis combined with aggregate implementation in MARKAL-MACRO. Individual sector modeling is relatively aggregate and may also require similar off-line analysis.

MiniCAM MODEL

The MiniCAM Model, maintained by the Pacific Northwest National Laboratory (PNNL), forecasts CO_2 and other GHG emissions, and it estimates the impacts on GHG atmospheric concentrations, climate, and the environment. Although the model is a top-down agriculture-energy-economy model, it contains bottom-up assumptions about end-use energy efficiency. MiniCAM Model projections are made through 2100 and in 15-year increments.

MiniCAM is comprised of three separate models: the Edmonds-Reilly-Barns Model (ERB), the Agriculture Land Use Model (AGLU), and the Model for the Assessment of GHG Induced Climate Change (MAGICC). ERB represents the energy/economy/emissions system, including supply and demand of energy, the energy balance, GHG emissions, and long-term trends in economic output. The AGLU simulates global land-use change as it influences the production of composite crops, animal products, and forest products, and tracks GHG emissions associated with land use. The transportation system coverage includes automobiles, light trucks, buses, rail, air, and motorcycles for passenger modes; and trucks, rail, air, ship, pipeline, and motorcycles for freight modes. Seven major energy sources are modeled: oil, gas, coal, biomass, resource-constrained renewables, nuclear, and solar. The MiniCAM is a long-term, partial-equilibrium model of the energy, agriculture, and climate system. The model can produce an end-to-end analysis of energy supply and demand, emissions of greenhouse gases and local air pollutants, as well as mitigation costs. It contains an emissions model that considers energy as well as changes in land use, as well as the full range of greenhouse gases. The MiniCAM is used for modeling over the long term, and can model a wide range of technologies, fuels, and energy carriers to supply end-use energy demands.

Limitations. The main limitation of this model is that the modeling of individual equipment and technology use and purchasing policies requires off-line analysis, whose results would then need to be aggregated and “plugged into” the MiniCAM. The model’s functionality is focused on the national level and does not extend to the regional or state level. Due to the combination of three models within MiniCAM, the complexity of running the model may require specialized knowledge of the operations.

GREET MODEL

Sponsored by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE), Argonne has developed a full life-cycle model called GREET (Greenhouse gases, Regulated Emissions, and Energy use in Transportation).

It allows researchers and analysts to evaluate various vehicle and fuel combinations on a full fuel-cycle/vehicle-cycle basis. The GREET model is designed to serve as an analytical tool for use by researchers and practitioners in estimating fuel-cycle energy use and emissions associated with alternative transportation fuels and advanced vehicle technologies. This tool provides full fuel-cycle emissions analysis from wells to wheels, which represents emissions from all phases of production, distribution, and use of transportation fuels. GREET is an excellent model to determine individual vehicle emissions and would be valuable in assisting evaluation of new transportation fuels and advanced vehicle technologies. GREET Model calculates consumption of total energy (from both non-renewable and renewable sources), fossil fuels (petroleum, natural gas, and coal together), petroleum, coal and natural gas. EPA has incorporated GREET into their air MOVES Model.

Limitations. GREET is relevant only to light-duty vehicles; however, this does not preclude it from being used for other vehicle types in the future. GREET does not include a vehicle choice model to forecast what people might purchase based on consumer preferences, but GREET output (total fuel-cycle emissions factors) can be used with future vehicle technology projections to get a more complete picture of their environmental impacts.

TAFV MODEL

The Transitional Alternative Fuels and Vehicle (TAFV) Model represents economic decisions among auto manufacturers, vehicle purchasers, and fuel suppliers, including distribution to end-users. The model simulates decisions during a transition from current fuels to alternative fuels and traditional vehicles to advanced technology vehicles. Limited availability of alternative fuels, including refueling infrastructure, and availability of alternative fuel vehicle technologies are interdependent. TAFV tracks GHG emissions from fuel production and vehicles using GREET-based emissions factors. TAFV contains a model that predicts choice of alternative fuel and alternative vehicle technologies for light-duty motor vehicles. The nested multinomial logit mathematical framework is used to estimate vehicle choice among technologies and fuel type combinations based on consumer preferences and vehicle attributes. Vehicle choice is dependent on prices, fuel availability, and the diversity of vehicle offerings (all endogenous) as well as luggage space, refueling time, vehicle performance, and cargo space (all exogenous parameters). Alternative fuel vehicles have three costs to vehicle manufacturers: capital costs, variable costs, and costs associated with diverse vehicle offerings. The model has a limited application in this study as it is focusing on only on the light-duty vehicles.

Fuel Catalyst to Reduce GHG Emissions

Based on a suggestion by NJDOT, the team looked at a fuel catalyst developed by Quantum Fire, Inc., and some other industries. Fuel catalyst is an additive that when mixed with fuel in any vehicles, enables complete combustion of the fuel. This improves the number of miles/gallon the vehicle will produce leading to lesser fuel consumption. After careful consideration and preliminary investigation, the team decided that real-time/experimental data would be required to calculate exact savings on GHG emissions related to the use of fuel catalysts. Several factors are likely to contribute to these calculations. First, complete combustion will cause more carbon-dioxide generation, so that needs to be taken into account. It is presumed that this extra carbon-dioxide will be compensated by the increased miles per gallon and also reduction in some of the other GHG emissions that would have been produced due to in-complete combustion in the absence of fuel catalyst. All in all, a conclusion cannot be made without some real data related to usage of usage of fuel catalyst. Fuel catalyst is only one of several innovative things that can be incorporated into the model to make it a comprehensive tool to access all future scenarios to evaluate GHG emission reduction strategies.

Conclusions of the Literature Survey

The review of the state of practice largely confirms that very few DOTs have estimated the impact of mitigation strategies on CO_2 and/or other GHG emissions. While DOTs are increasingly exploring mitigation strategies, most have not conducted a detailed evaluation of current GHG emission inventories. Other stakeholders, including the U.S. Environmental Protection Agency (EPA), the Federal Highway Administration (FHWA), and private contractors, have also produced very few quantitative evaluations of CO_2 reduction strategies that are relevant to DOTs' operations, maintenance, and construction activities. It is clear that additional research is needed to help DOTs estimate the effectiveness of alternative strategies for reducing GHG emissions, such as the use of alternative materials, processes, vehicles and non-road equipment and machinery.

Reducing GHG emissions is very important for making any project greener. This can be achieved by various means: using of new/alternative materials that are more recyclable or have a smaller lifecycle footprint, establishing in-situ recycling and reuse of materials and equipment, modifying the composition of different mixes of materials, and changing minor and major processes. A simple example is to retexture pavement surfaces to avoid having to replace them, which would reduce the carbon footprint of asphalt pavements. Especially relevant to this study are methods for quantifying different reduction alternatives and selecting those that are most effective on a department-wide scale.

Databases used in the study include:

- National Renewable Energy Laboratory (NREL) Database: NREL has published a database for life cycle GHG emissions for several products in the US,
- Inventory of Carbon and Energy (ICE) database,
- NCHRP Project 25-25(58) – GreenDOT Model,
- Processes, Equipment, and Materials: Based on the 2007 NJDOT Specifications and definitions of the Bid Sheet items.

ASSESSMENT OF OPERATIONS ENVIRONMENTAL MANAGEMENT NEEDS

Prior to designing the model, it was important to access the desired and necessary outputs of the model. To address this, feedback was obtained from the NJDOT Maintenance Operations about fundamental requirements for the environmental management system. The feedback provided valuable information varying from basic requirements such as the data contained in the existing management systems should be utilized to the greatest possible extent as an input for the evaluation, to the consideration of improved vehicle performance (in terms of fuel consumption and emissions) resulting from the use of fuel additives or engine retrofit, as well as the ability to evaluate individual projects, maintenance programs, and annual maintenance operations. All the requirements are met in the developed evaluation model.

Supplementary to the information obtained through the literature survey, the assessment of needs provided the input and guidelines for the following aspects of the model:

1. Assess the impacts of the Maintenance Operations activities on Greenhouse Gas emissions.
2. Identify contributing factors: processes, materials, equipment used by Maintenance Operations.
3. Quantify GHG emissions using the Life Cycle Assessment (LCA) framework.
4. Identify applicable strategies for reducing the GHG emissions.

5. Develop a modeling tool that will assist in informed, sustainable Operations Maintenance decision making with respect GHG emissions.

One of the important findings of the assessment of the needs is the fact that different processes and activities need to be handled separately by the model. GHG emissions due to use of materials are calculated based on life cycle assessment framework. Several GHG emissions inventory databases identified earlier in this report provide GHG emission values for various materials used for transportation maintenance activities. Similarly, vehicles and equipment are to be handled separately as the major portion of GHG emissions contributed by them is due to burning of fossil fuels.

Figure 4 shows the contribution of various sectors towards global GHG emissions. It can be clearly observed that transportation is one of the highest impact sectors. Also, a transportation maintenance project need not necessarily fall under the transportation sector. It may contribute towards land use change, it will most likely use energy in electricity, heat, and other forms, it will generate waste, it will contribute to fuel combustion, and it will also take part in contributing towards other sectors in various ways. Figure 5 identifies key processes and activities that contribute towards highway maintenance projects.

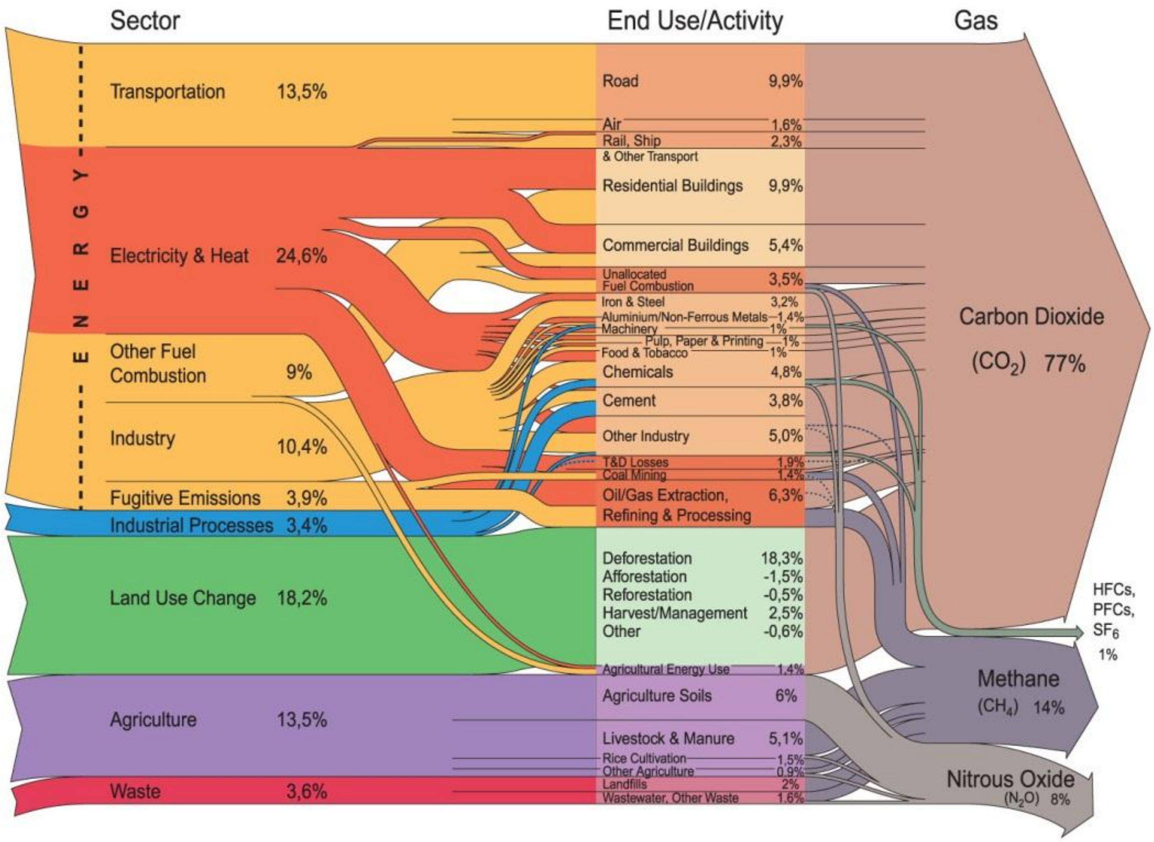

Figure 4. Contribution of different sectors towards world greenhouse gas emissions[11]

[11] Source: World Resource Institute, Climate Analysis Indicator Tool (CAIT), Navigating the Numbers: Greenhouse Gas Data and International Climate Policy. December 2005. Intergovernmental Panel on Climate Change, 1996.

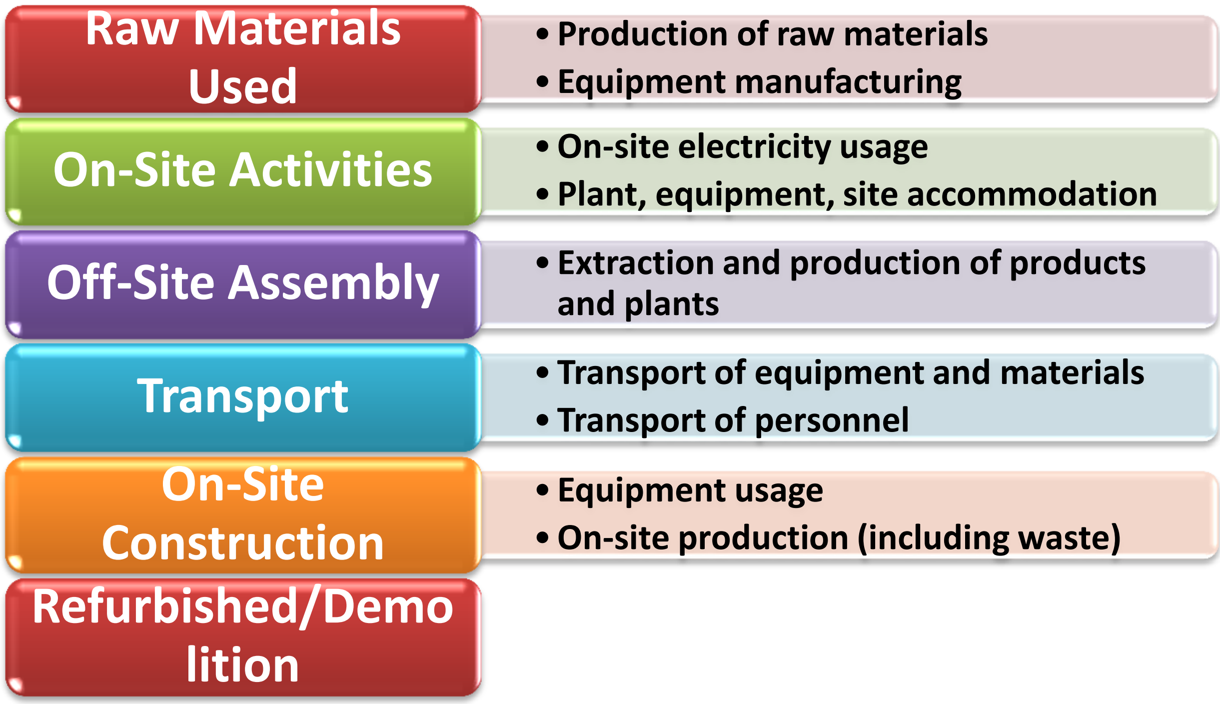

Figure 5. Sources of GHG Emissions in Highway Maintenance Projects

Strategies for Reducing GHG Emissions

In developing strategies for GHG emissions reduction, it is important for DOTs to consider all aspects of transportation projects that are responsible for the production of GHG emissions. Only then would it be possible to identify alternatives and compare their benefits in terms of the relative reduction in GHG emissions. For example, a roadway construction project will produce GHG emissions associated with embodied carbon in the materials used in construction, as well as the equipment used for handling the materials. In addition, extraction, processing, and transportation of the materials will require energy and hence produce CO_2 emissions. It is therefore necessary to break down the primary finished materials into their standard ingredients. In the example of a roadway construction project, several finished materials are responsible for CO_2 emissions, including:

- Concrete Panels – principally composed of cement, aggregate, steel, and water;
- Asphalt – principally composed of bitumen and aggregate;
- Cement Treated Aggregate – principally composed of cement, aggregate, and water;
- Base Aggregate – composed of aggregate only.

There are three ways that DOTs can reduce CO_2 emissions from materials used in roadway construction and repair:

1. Reduce the volume of materials used,
2. Use recycled materials that require less energy to produce than virgin materials ,
3. Alternative preparation practices that reduce energy use, such as warm mix asphalt.

Table 2 below summaries the strategies to reduce GHG emissions that are most relevant to transportation maintenance projects.

TABLE 2: Strategies to reduce greenhouse gas emissions

Use renewable, energy efficient, and recycled materials	▪ Materials that require less energy and have smaller lifecycle footprint. ▪ On-situ recycling and reuse of materials and equipment. ▪ Alternative preparation practices, e.g. Warm-mix asphalt.
Use alternative fuels	Biodiesel, Ethanol, Methanol, CNG.
Use more efficient vehicles and equipment, retro-fit engines	Hybrid, plug-in hybrids, retrofit CNG and biodiesel engines for equipment and heavy machinery.

ENVIRONMENTAL MANAGEMENT SYSTEM MODEL

A conceptual model and a prototype of the customized Environmental Management System was designed and tested by Operations Support supervisors. The following sections detail the logic that was adopted to build the model.

Design Logic:

The literature review provided many emissions models that use different logic and methodologies to deliver CO_2 emissions emerging from various target activities. Based on studies of the various models that were found relevant in the literature review, a unique model is proposed that particularly targets and suits GHG emissions calculations for transportation maintenance projects.

As mentioned earlier, the important sources of information to be used in the model are 2007 NJDOT specifications list, bid sheets, and GHG emissions inventories. It was also observed that materials, vehicles, and equipment contribute towards GHG emissions in different ways. To address this, the model groups similar specifications (items) together (e.g., all specifications using asphalt will be grouped together) and will calculate the GHG emissions for total weight (ton) of the grouped items together based on GHG emission values presented in emission inventory databases. For a finished material (material that requires mixing of various ingredients or raw materials on site before use) such as asphalt, GHG emissions calculations are based on default ratios of raw materials. The user will have the option to change these default mix ratios to suit their needs. Once the GHG emissions values for any particular project are computed, theuser is able to construct and compare different alternative scenarios to reduce the footprint. Presently, the team has worked out details for two main options: 1) change mixing ratios to reduce footprint, and 2) change raw materials (aggregates are replaced completely or partially with recycled material) in favor of more environmentally friendly alternatives. These choices may be expanded to include more alternatives from information collected during the literature survey and possibly new resources. In addition, more alternatives such as: hot mix v/s warm mix asphalt, day time v/s night time laying of materials, etc., are also helpful in reducing GHG emissions associated with a certain project. Finally, the team adopted various techniques and methods to make this model as user friendly as possible. The approach was to make the model progress through different screens. At screen 1 the user will input the information and relevant project data and at the final screen the output of the normal and mitigated/alternative scenario will be presented for comparison. Figure 6 shows the flow diagram of the analysis approach.

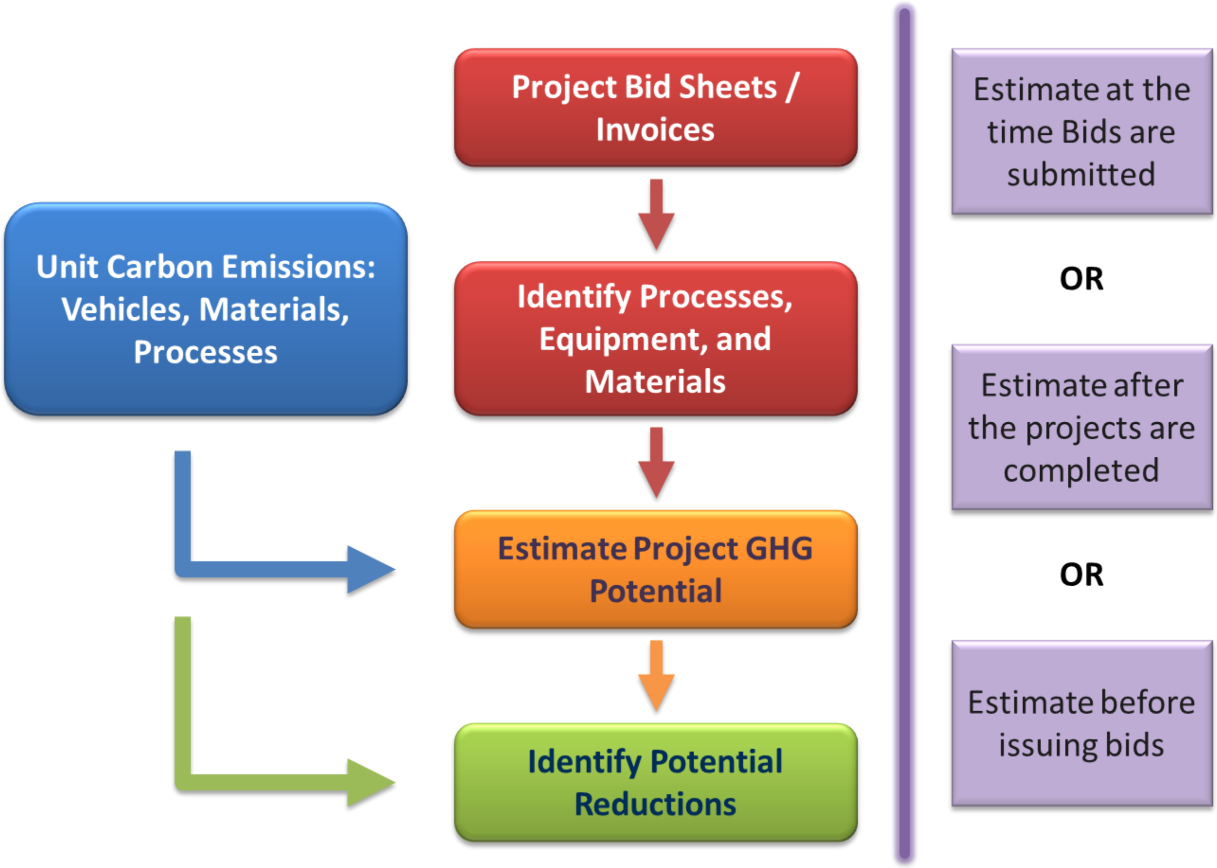

Figure 6. Analysis Approach

Design Considerations:

- Based on NJDOT Specifications and collected data from bid sheets – The project input depends on the ability to select from one of the specifications or the entry of new processes or activities. Together, these specifications and new processes will define each task that the maintenance project will need to execute for completion.

- GHG emission calculations and comparisons with scenarios using different emission reduction strategies – the GHG emission inventory database will provide the conversion of activity to emissions (E.g., ton of material will produce certain ton of CO_{2eq}). A separate calculation strategy was used for materials, equipment, and vehicles.

- Built in Reporting Tool – The software is able to generate reports based on project information and GHG emissions calculations.

- Intuitive User Interface – Special effort has been taken on making the software as user friendly as possible with an intuitive user interface.

The calculations for the items in the 2007 NJDOT specifications list were completed before building thesoftware model, which will access the specifications list database to calculate the GHG emissions for different projects. The calculations for GHG emissions associated with NJDOT 2007 specification items were originally based only on the ICE database described in the summary of the literature survey. National Renewable Energy Laboratory (NREL) and EPA also provide similar databases for embodied carbon based on full product life-cycle assessment. The ICE database was compared with the NREL database and EPA database for most of the commonly used materials, processes, and activities at transportation projects including asphalt, bitumen, steel, concrete, etc. Most numbers were in agreement with each other in both databases. For some materials, original calculations were updated to include NREL/EPA database numbers, which are specifically prepared for the US.

After projects are entered into the database, the user is allowed to select projects for further analysis. Project selection is based on one or more selection criteria: project year, project type, DP number, project name or part of the name, location. One or more projects can be selected for further analysis. The further analysis is done for the whole project selection, not by the individual project.

Some important features of the system are presented below:

- Emissions Estimation Module: Analytical models were integrated and expanded to allow users to estimate the carbon footprint of every project or selection of projects.

- Project Scoring: This module enables users to score and rank projects based on environmental criteria including carbon footprint estimations, overall air quality impacts, environmental preservation, and other information.

- Strategy Evaluation: Users are able to evaluate various aspects of quality of life (stewardship) and economic strategies and their environmental impacts. For example, users can see the impact of including procedures and materials used in reducing the carbon footprint.

- Post-Implementation Analysis: Users are allowed to enter information about observed project impacts following implementation. This feature can be expanded and used to calculate benchmark estimates of various environmental impacts.

- Reporting and Data Sharing: This action allows users to quickly generate effective and informative reports. It also allows the system to share data with other information management and asset management systems, as well as produce data that can be used as inputs for those systems. This offers an effective integration of environmental analysis in the overall asset management system at NJDOT.

Model Methodology:

The methodology adopted to calculate GHG emissions has the following steps.

Step 1: The first thing to do in the system is to enter a project with all its specification items. This can be done by manually entering item by item (select from drop down menu), or by loading an Excel spreadsheet with a specified formatting. An example of the input format is given in appendix D. The item numbers MUST correspond to the item numbers in the 2007 NJDOT specifications list (stored in the database). Otherwise, for those that are not in the database, the user will have to provide additional details (e.g. description, material class, unit of quantity, CO_2 emission per unit, etc.).

Step 2: The second step is entering the data. Execution of this step is different for materials and for equipment and vehicles. Data for materials will specify which materials are used and in what quantity. Furthermore, for finished materials, the user has an option to proceed with the default mix ratio or to modify it. Data for equipment and vehicles includes data about the usage of vehicles and equipment in the project. Vehicles are used to transport equipment, materials, and work crews to and from the project site. Equipment is used at the project site to perform certain construction, repair, rehabilitation, and other roadway infrastructure maintenance activities.

Step 3: Step 3 deals with the calculation of GHG emissions for the data gathered in steps 1 and 2. Calculations will use reference values from GHG emissions databases to calculate ton of GHG emissions for all the materials, equipment, and vehicles used in the project.

Step 4. This step offers the user various alternatives to reduce GHG emissions associated with a single or a selection of projects. Primary alternatives include: use of alternative materials, changing of default mix ratios associated with finished materials, etc.

Step 5: This step is all about presentation. The user is able to generate various reports, data summary sheets, graphs, and charts to compare various scenarios, various alternatives, or even to present data associated with a single or a selection of projects.

Flow of Model Execution to Calculate GHG Emissions for Materials:

The flow of the model execution is illustrated through a series of figures below. Figure 7 explains the process to input project data into the model. The project input form will enable the user to select various materials, processes, and activities, based on the NJDOT specifications list. There is even an option to enter new item with all the relevant information.

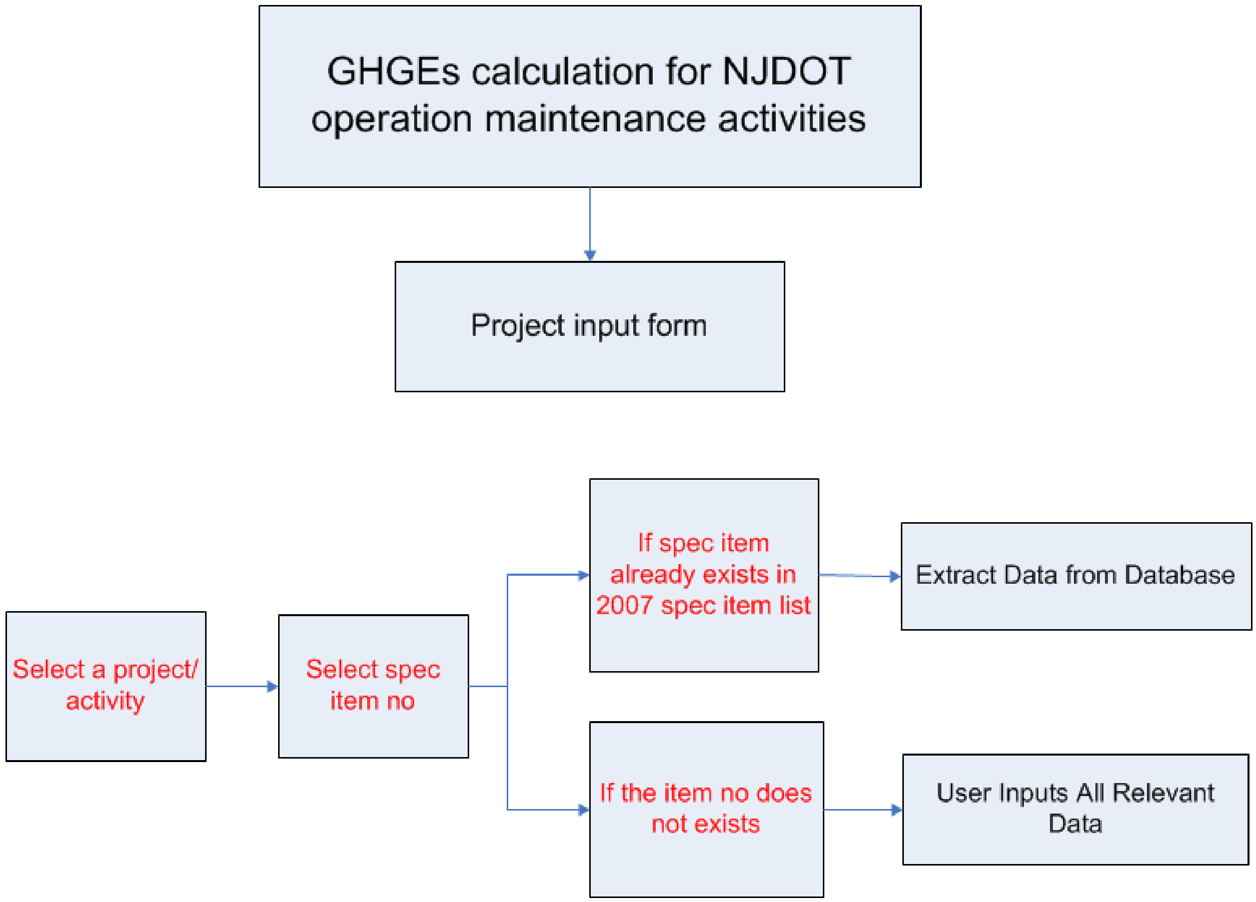

Figure 7. Model input

Concrete panels, base aggregates, asphalt, and cement treated aggregates are grouped together as finished materials. These materials are made of conventional components and need to be mixed and finished on site before they are used. Figure 8 demonstrates the process through which GHG emissions are calculated for the finished materials. One additional step for these finished materials requires the total weight of a single type of finished material be broken down into different weights of raw materials calculated based on default mix ratios or mix ratios edited by the user. Each of the raw material weight is used to calculate respective GHG emission values based on reference values. All GHG emissions for each of the raw materials are then added together to generate total GHG emission values for the selected finished material.

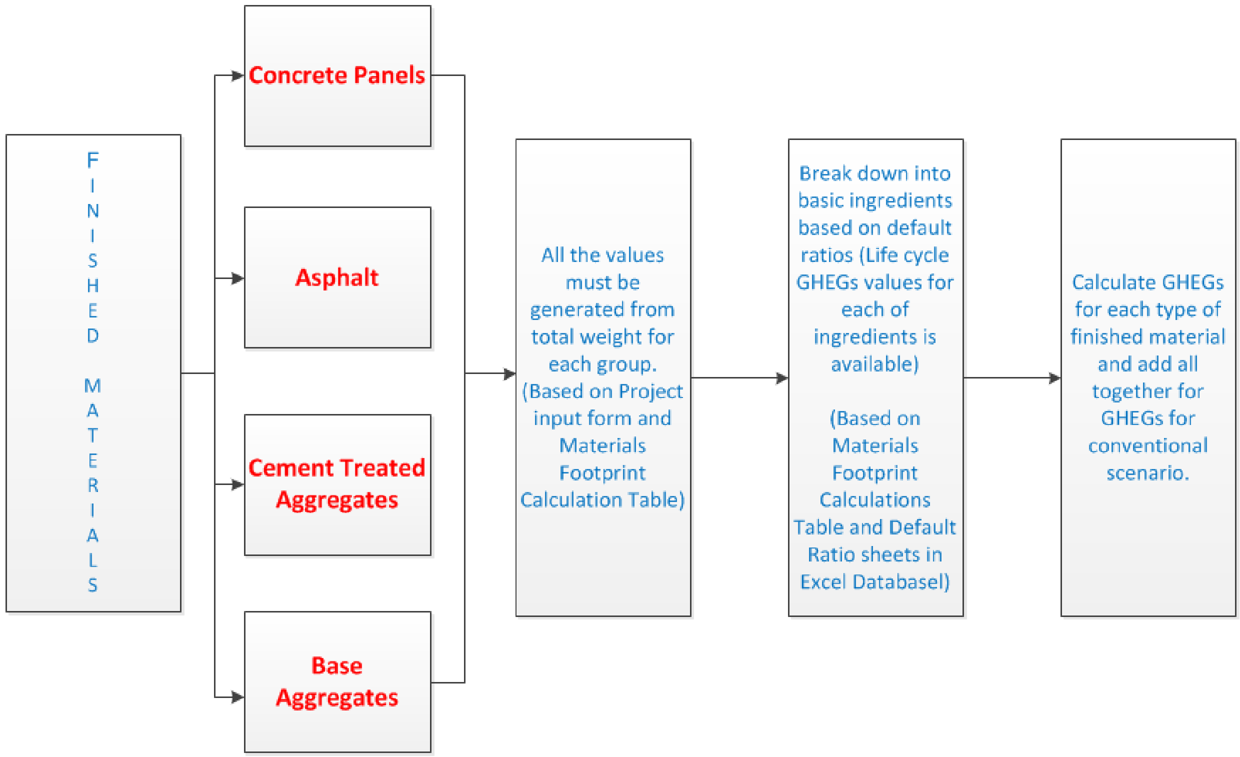

Figure 8. Calculation of GHG emissions for finished materials

Flow of Model Execution to calculate GHG emissions for Vehicles and Equipment:

For the calculation of GHG emissions associated with vehicles and equipment, it is important that the data about the usage of vehicles and equipment in the project has been entered in accordance with step one as described in the model methodology section. Vehicles are used to transport equipment, materials, and work crews to and from the project site. Equipment is used at the project site to perform certain construction, repair, rehabilitation, and other roadway infrastructure maintenance activities.

Several examples of calculations of GHG emissions associated with vehicle use are given in the appendix. Essentially, the CO2 footprint will depend on the type of fuel used, type of engine, and the usage of vehicles (miles traveled) and equipment (hours in use). A typical input associated with a vehicle will require the user to specify vehicle type (light duty truck, van, SUV, heavy duty truck, etc.), engine type (to identify fuel type, gasoline/diesel/electric), and model year.

This is a brief example for a 2009 model light duty truck running on conventional gasoline fuel. The information inputted by the user will prompt the model to pull up the following related information from various dictionaries or tables pre-fed to the model: 2009 model small pickup truck gives 18.63 miles/gallon of gasoline which implies that that truck uses 0.05 gallons of fuel for each mile that it travels. The model also has been pre-fed the information that 1 gallon of conventional gasoline consumed by a small pickup truck will produce 8.81 kg CO_2.

Using all this data:

kg CO_2 equivalent produced per mile run = 8.81*0.05 = 0.47

If a hybrid vehicle was used instead of conventional gasoline vehicle, then the CO_2 equivalent will be contributed partly by the burning of fuel and partly due to electricity produced by the battery used to run the vehicle. Please refer to examples provided in the appendix of this report for more details on calculations of GHG emissions due to the use of different types of vehicles. Calculation of GHG emissions due to the use of various equipment on site is very similar to that of vehicle use.

Alternatives and Analysis:

After projects are entered into the database, user can select one or more projects for further analysis. This selection of projects can be based on one or more selection criteria: project year, project type, DP number, project name or part of the name, location. Users are able to do a variety of analysis and explore many alternatives for the selection of projects. Users can also add new equipment, new vehicle, new vehicle type, new material, change mixing ratios for finished materials and replace conventional materials in a mix by alternative material or recycled material.

Procedure to Add Equipment/Vehicle

- Specify the type of vehicle/equipment. Select from the existing types or type a new one.
- Select Engine Type from a drop-down based on Table of Engine Types. Fuel Type is automatically determined based on selected Engine Type.
- Enter total inventory for the new equipment type, as well as CO_2 emission rate per hour of use OR MPG value of vehicle for years (1990-2020). The CO_2eq is then calculated by the model.

All finished materials' calculations have two alternatives: change mixing ratios, and change ingredients (replace conventional components with renewable or recycled components). The user may select either or both of the alternatives.

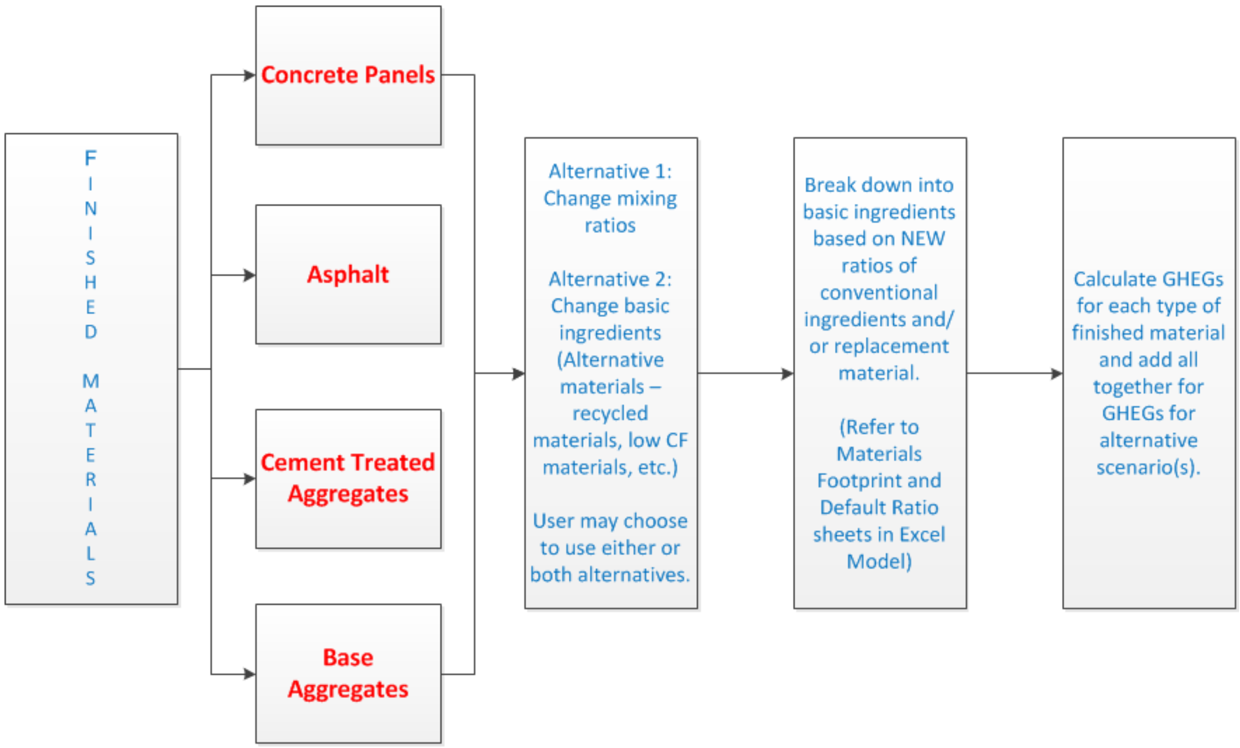

Figure 9. Calculation of GHG emissions for finished materials – choice of alternatives

The GHG emissions calculated using either or both of the alternatives provides quantitative information about the benefits with use of these pre-defined alternatives. Figure 9 shows the alternatives available to the user to reduce GHG emissions. Figure 10 explains the process by which the default mixing ratios related to finished materials (pre-selected based on literature search) may be changed to suit specific requirements. The choice of one or more alternatives can be made for a single project or for a selection of several projects. This enables the user to compare various scenarios and alternatives leading to better decision-making.

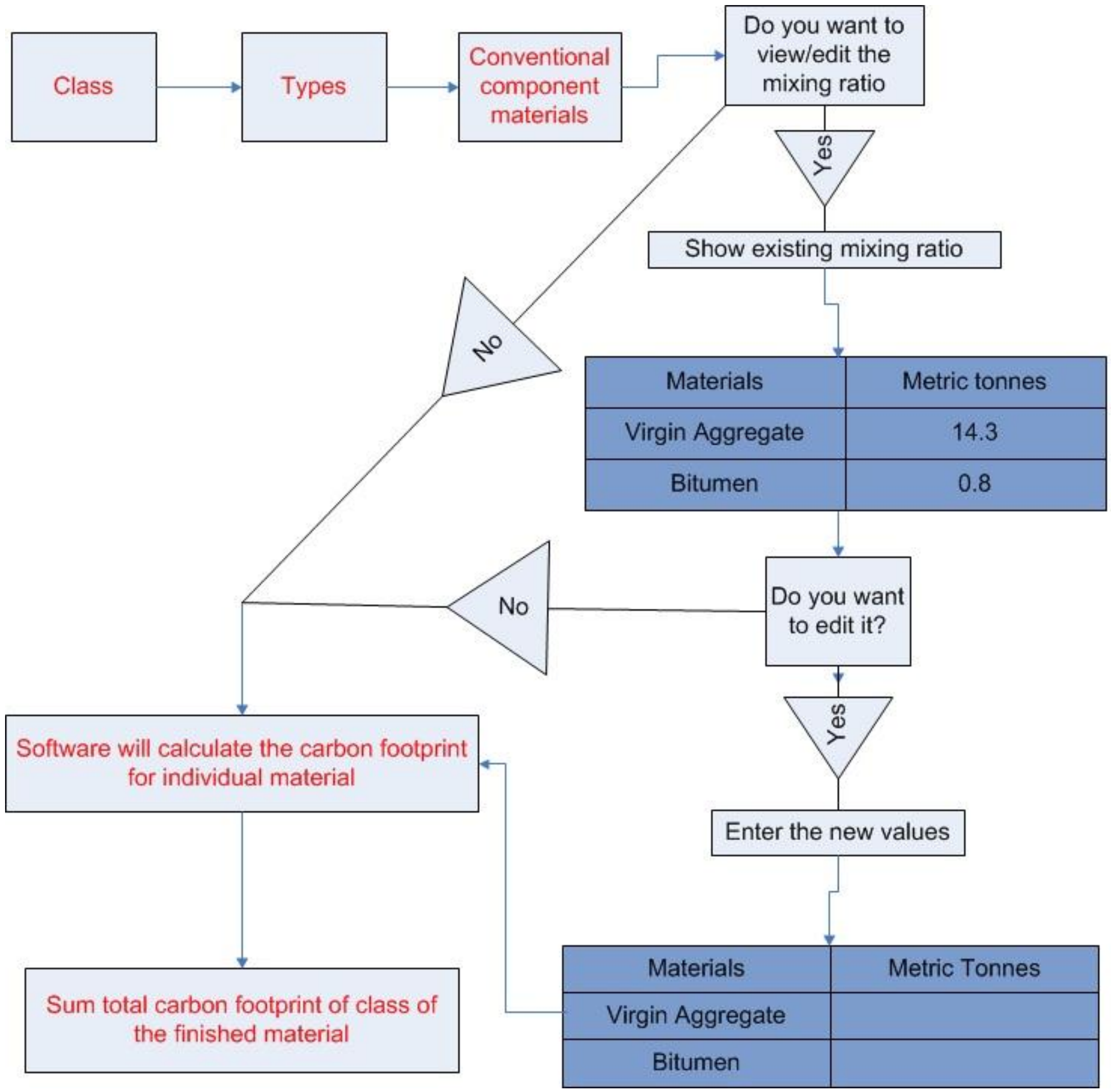

Figure 10. Calculation of GHG emissions for finished materials – option to view/change mixing ratio

PROJECT DELIVERABLES

1. **Software for EMS**

EMS software is user friendly with facility to automate calculations for changes in project parameters. The software system is scheduled to be installed at the three regional offices and tested for communications compatibility and network efficiency. A tutorial will be held for regional supervisors to provide input on designing customized workshops for staff members.

2. User’s Manual

The development of the User’s Manual is underway. Upon completion, the user’s manual will serve as a reference guide on data requirements, analytical tools used in the model, project scoring methods, strategy evaluation, and reporting procedures. This reference will be used during training, along with accompanying Power Point presentations. The manual will be further revised and refined to reflect the redesigned software logic and user interface modifications.

3. Staff Training Sessions

Parallel with the development of the graphical user interface and User’s Manual, training materials are being developed as well. These materials will be used in training sessions with NJDOT staff and will use examples to illustrate the application of the software. Operations Support will participate in a tutorial review of the EMS model. Program activities are expected to include an overview of the system, analytical exercises, and development of practice reports. After the research team holds the supervisory tutorial, staff members will participate in a two-hour training session at the Operations Support location. The regional sessions may be longer, since an additional section will be presented on data transfer procedures.

4. **Data Tables**

GHG Emissions calculations done with the EMS software rely on several data tables, including GHG emissions inventory databases, a modified specifications list with detailed GHG emissions calculations for each specification item, vehicles and equipment tables, fuel emission charts, alternative materials, mixing ratios for finished materials, and many other minor tables. All these data tables will be made available to NJDOT for review and future updates (if necessary).

CONCLUSIONS AND RECOMMENDATIONS

In conclusion, the Environmental Management System project will enhance the ability of NJDOT Operations to be an effective steward of the environment. The proposed monitoring system improves environmental management and departmental performance. It will also provide NJDOT with the ability to offer relevant, useful, well formatted, accurate, and timely information and analysis of the environmental impact of transportation maintenance. Furthermore, NJDOT Operations will be prepared to effectively monitor GHG emissions activities for compliance in the future.

There are three main outcomes of this project:

1. Enable estimation of the current Operations Maintenance GHG emissions.
2. Implement a decision support tool for analyzing potential strategies for reducing GHG emissions.
3. Guidelines (operational and policy) for management decisions to reduce GWP:
    - Modify specs,
    - Modify equipment/vehicle requirements,
    - Modify fuel requirements, etc.

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APPENDICES - EXAMPLES OF GHG EMISSIONS CALCULATIONS AND SUPPORTING MATERIAL

A. Sample calculations - Materials

The total area of the shape(s) in Figure 11 can be calculated as follows:

Area A is a rectangle 100' × 100' = 10,000 square feet

Area B is a triangle 30' × 100'÷2 = 1,500 square feet

Area C is a rectangle 20' × 120' = 2,400 square feet

Area D is a circle $70^2 \div 4 \times 3.14 = (70 \times 70) \div 4 \times 3.14 = 3{,}846.5$ square feet

Planter Area is represented by the two rectangles and two circles with the area of:

$$45' \times 5' \times 2' + ((2.5')^2 \times \pi) \times 2 = 489.3 \text{ square feet}$$

Therefore, the total paved area is:

10,000 + 1,500 + 2400 +3846.5 – 489.3 ≈ 17,257 square feet

To compute the volume, multiply the 6” (0.5 ft) thickness of the proposed pavement by the area previously computed.

Volume = [Area] × [Thickness]

$= (17{,}257 \text{ ft}^2) \times (0.5 \text{ ft}) = 8{,}628.5 \text{ ft}^3 \approx 320$ CY

To calculate the weight of material needed for the pavement project previously computed, one needs to know the compacted density of the paving material. Density is defined as the weight of material per unit of volume and it can be found listed in resources such as the Physics Factbook for typical concrete mixtures. For example:

Density of the pavement = 145 lb/ft^3

Weight = Volume × Density

$\Rightarrow$ Weight = $8{,}628.5 \text{ ft}^3 \times 145$ pcf = 1,251,132.5 lb

Convert to tons = 1,251,132.5 lb ÷ 2,000 lb/ton ≈ 626 tons

B. Sample calculations – Vehicles' GHG Emissions

Example #1		
Vehicle Type	**Light-Duty Truck (Van, Pickup, SUV)**	
Engine Type	**Gasoline Conventional**	
Model Year	**2009**	

Calculation

Fuel	Gasoline	
Plug-in Hybrid?	No	0%
MPG	18.63	mi/gal

	Gasoline		Electricity	
GGE	1.00	gal/gal	33.53	kWh/gal
CO_2e per unit	8.81	kg/gal	0.483	kg/kWh
Units	0.05	gal/mile	-	kWh/mile
CO_2e/mile	0.47	kg CO_2e	-	kg CO_2e

Total CO_2e	**0.47**	**kg CO_2e/mile**

Example #2		
Vehicle Type	**Auto**	
Engine Type	**Diesel-Electric Hybrid (Plug-in)**	
Model Year	**2010**	

Calculation

Fuel	Diesel	
Plug-in Hybrid?	Yes	33%
MPG	61.98	mi/gal

	Diesel		Electricity	
GGE	0.88	gal/gal	33.53	kWh/gal
CO_2e per unit	10.30	kg/gal	0.483	kg/kWh
Units	0.01	gal/mile	0.18	kWh/mile
CO_2e/mile	0.10	kg CO_2e	0.09	kg CO_2e

Total CO_2e	**0.18**	**kg CO_2e/mile**

Example #3	
Vehicle Type	**Auto**
Engine Type	**Gas/Ethanol FFV**
Model Year	**2010**

Calculation

Fuel	Ethanol/Gas	
Plug-in Hybrid?	No	0%
MPG	27.25	mi/gal

	Ethanol/Gas		Electricity	
GGE	1.06	gal/gal	33.53	kWh/gal
CO_2e per unit	8.28	kg/gal	0.483	kg/kWh
Units	0.04	gal/mile	-	kWh/mile
CO_2e/mile	0.32	kg CO_2e	-	kg CO_2e

Total CO_2e	**0.32**	**kg CO_2e/mile**

Example #4	
Vehicle Type	**Auto**
Engine Type	**CNG Engine**
Model Year	**2010**

Calculation

Fuel	CNG	
Plug-in Hybrid?	No	0%
MPG	27.25	mi/gal

	CNG		Electricity	
GGE	0.12667	1000 cu. Ft./gal	33.53	kWh/gal
CO_2e per unit	54.55	kg/1000 cu. Ft.	0.483	kg/kWh
Units	0.0046	1000 cu. Ft./mile	-	kWh/mile
CO_2e/mile	0.25	kg CO_2e	-	kg CO_2e

Total CO_2e	**0.25**	**kg CO_2e/mile**

Example #5	
Vehicle Type	**Auto**

Engine Type	**Electric**
Model Year	**2010**

Calculation

Fuel	Electricity	
Plug-in Hybrid?	No	0%
MPG	85.00	mi/gal

	Electricity		Electricity	
GGE	33.53	kWh/gal	33.53	kWh/gal
CO_2e per unit	0.483	kg/kWh	0.483	kg/kWh
Units	0.39	kWh/mile	-	kWh/mile
CO_2e/mile	0.19	kg CO_2e	-	kg CO_2e

Total CO_2e	**0.19**	**kg CO_2e**

C. Supporting material for GHG Emissions Calculations

Density Estimation - Physics Factbook

Edited by Glenn Elert
Available at: http://hypertextbook.com/facts/index-topics.shtml

The Physics Factbook was referred to for guidance in estimating density of various construction materials. For example, concrete is a very important building material, but its density can vary from one application to another. Several different coarse aggregates such as sand and pebbles are mixed with water and cement and then the mix is hydrated to interlock and bind the crystals together and harden the structure. In construction of highways, various types of concrete are used. Reinforced concrete is strengthened by steel. Pre-stressed concrete is made by casting concrete around steel cables stretched by hydraulic jacks. Compressed concrete is the strongest one. It is mainly used for floors and roofs. In order to calculate the GHG emission of concrete, its carbon equivalent needs to be established, which in turn is directly proportional to weight. When the unit measure of the material quantity used in a project is expressed in terms of volume, the density of material has to be known to determine its weight.

TABLE 3: Concrete Density Table from the Physics Factbook

Bibliographic Entry	Result (w/surrounding text)	Standardized Result
Dorf, Richard. *Engineering Handbook*. New York: CRC Press, 1996.	"The density of normal concrete is 2400 kg/m^3 and the density of lightweight concrete is 1750 kg/m^3	1750–2400 kg/m^3
Brooklyn Public Library Files; 1999	"Typical density of concrete (2.3 g/cm^3)"	2300 kg/m^3
McGraw-Hill Encyclopedia of Science and Technology.	"Volume generally assumed for the density of hardened concrete is 150 lb/ft^3 (2400 kg/m^3)"	2400 kg/m^3

The information provided in the Physics Factbook is found useful in calculating total carbon emission from concrete. Soil aggregate base course, dense graded base course, concrete barrier curb, concrete parapet, deck, panel – these all use concrete as a raw material, but their units of measurement are different (e.g. linear foot, square yard, cubic yard are used interchangeably). In order to measure the emission in CO_2 equivalent, unit conversion is required. This is where density of concrete plays the role. The density gives us the total weight of the concrete in tons which is calculated as:

Volume = [weight] x [density]

Measuring a Pavement Job
An online guidebook published by the National Asphalt Pavement Association (NAPA)
Available at:
http://www.hotmix.org/index.php?option=com_content&task=view&id=144&Itemid=227

This document has been useful in calculating the total quantity of aggregate applied in construction and its equivalent amount of carbon by converting its respective unit to tons and kilograms. It provides several guidelines to calculate the area to be paved. This can be accomplished by dividing the pavement area into simple geometric shapes, and by subtracting and/or adding their areas as appropriate. For example, the diagram in Figure 1 shows a shaded area representing the shape of a surface to be paved. It may seem complicated, but it can be broken down as a combination of rectangles, triangles and circles, whose areas can be easily calculated.

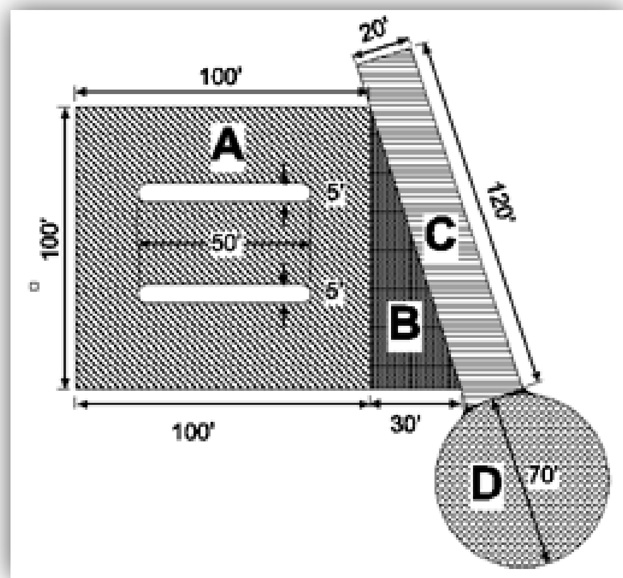

Figure 11. Total area of a surface to be paved divided into geometric shapes

Engineering Unit Conversions
Author: Michael R. Linderburg
Published by Professional Publications, Inc.; Fourth Edition, December 1998

This reference book provides a variety of engineering conversion factors that will be useful in calculating the quantities of materials used in maintenance projects adequate for carbon footprint estimation. For example, the conversion factors are used in this study to obtain the value of equivalent weight of CO_2 in kilograms, which required conversion of units used in specifications.

Conversion Example1: Dense graded Aggregate Concrete Base Course, 4" thick

Lifecycle CO_2 for concrete = 0.023 kg CO_2/ kg

Density of concrete = 1,460 kg/m^3

Weight = [Density] x [Volume]

Volume = [Paved Area] x [Thickness]

Paved area = 18,000 ft^2 = 18,000 ft^2 x 0.093 m^2/ft^2 = 1,674 m^2

Thickness = 4" = 4" x (0.0254 m/inch) = 0.1016 m

$\Rightarrow$ Volume = 1,674 [m^2] x 0.1016 [m] = 170.08 m^3

$\Rightarrow$ Weight of concrete = 1,460 [kg/m^3] x 170 [m^3] = 248,314 kg

GHG EMISSIONS = [Weight of concrete] x [CO_2 content for concrete]

$\Rightarrow$ <u>GHG EMISSIONS = 248,314 [kg] x 0.023 [kg CO_2/kg] = 5,711 kg CO_2</u>

Conversion Example2: Hot mix asphalt (HMA) pavement repair, 6" thick

Lifecycle CO_2 for concrete = 1.48 kg CO_2/ton =

= 1.48 [kg CO_2/ton] x 0.001 [ton/kg] = 0.00148 kg of CO_2/kg

HMA pavement area = 2,500 m^2

HMA density = 145 pcf = 2300 kg/m^3 (from conversion tables)

HMA thickness = 6" = 6" x (0.0254 m/inch) = 0.1524 m

$\Rightarrow$ Volume of HMA = [Area] × [Thickness] = 2,500 m^2 x 0.1524 m = 381 m^3

$\Rightarrow$ Weight of HMA= [Volume] x [Density] = 381 m^3 x 2,300 kg/m^3 = 876,300 kg

GHG EMISSIONS = [Weight of HMA] x [CO_2 content for HMA]

$\Rightarrow$ <u>GHG EMISSIONS = 876,300 [kg] x 0.00148 [kg CO_2/kg] = 1,297 kg CO_2</u>

D. Sample Input File

Line No.	DP Number	Item No.	Alternative	Description	Units	Quantity
1	09403	151003M		PERFORMANCE BOND AND PAYMENT BOND	LS	1.00
2	09403	152003P		OWNER'S AND CONTRACTOR'S PROTECTIVE LIABILITY INSURANCE	LS	1.00
3	09403	154003P		MOBILIZATION	LS	1.00
4	09403	155006M		FIELD OFFICE TYPE B SET UP	U	1.00
5	09403	155024M		FIELD OFFICE TYPE B MAINTENANCE	MO	6.00
6	09403	155039M		TELEPHONE SERVICE	LS	1.00
7	09403	157003M		CONSTRUCTION LAYOUT	LS	1.00
8	09403	158063P		CONCRETE WASHOUT SYSTEM	LS	1.00
9	09403	158072M		OIL ONLY EMERGENCY SPILL KIT, TYPE 1	U	2.00
10	09403	159003M		BREAKAWAY BARRICADE	U	500.00
11	09403	159006M		DRUM	U	100.00
12	09403	159009M		TRAFFIC CONE	U	750.00
13	09403	159012M		CONSTRUCTION SIGNS	SF	5,000.00
14	09403	159015M		CONSTRUCTION IDENTIFICATION SIGN, 4' X 8'	U	6.00
15	09403	159027M		FLASHING ARROW BOARD, 4' X 8'	U	4.00
16	09403	159030M		PORTABLE VARIABLE MESSAGE SIGN	U	6.00
17	09403	159108M		TRAFFIC CONTROL TRUCK WITH MOUNTED CRASH CUSHION	U	6.00
18	09403	159126M		TEMPORARY TRAFFIC STRIPES, 4"	LF	795,564.00
19	09403	159138M		HMA PATCH	T	100.00
20	09403	159141M		TRAFFIC DIRECTOR, FLAGGER	HOUR	640.00
21	09403	159144M		EMERGENCY TOWING SERVICE	U	1.00
22	09403	160003M		FUEL PRICE ADJUSTMENT	LS	1.00
23	09403	160006M		ASPHALT PRICE ADJUSTMENT	LS	1.00
24	09403	201003P		CLEARING SITE	LS	1.00
25	09403	302051P		DENSE-GRADED AGGREGATE BASE COURSE, VARIABLE THICKNESS	CY	100.00
26	09403	401009P		HMA MILLING, 3" OR LESS	SY	349,444.00
27	09403	401021M		HOT MIX ASPHALT	SY	1,646.00

				PAVEMENT REPAIR		
28	09403	401027M		POLYMERIZED JOINT ADHESIVE	LF	192,884.00
29	09403	401030M		TACK COAT	GAL	52,417.00
30	09403	401054M		HOT MIX ASPHALT 12.5 M 64 SURFACE COURSE	T	17,865.00
31	09403	401057M		HOT MIX ASPHALT 12.5 H 64 SURFACE COURSE	T	24,070.00
32	09403	401108M		CORE SAMPLES, HOT MIX ASPHALT	U	155.00
33	09403	404006M		STONE MATRIX ASPHALT 12.5 MM SURFACE COURSE	T	13.00
34	09403	453006M		FULL DEPTH CONCRETE PAVEMENT REPAIR, HMA	SY	1,058.00
35	09403	507020P		ASPHALTIC BRIDGE JOINT SYSTEM	LF	152.00
36	09403	602099M		RESET EXISTING CASTING	U	23.00
37	09403	602105M		SET INLET TYPE B, CASTING	U	22.00
38	09403	602123M		RECONSTRUCTED INLET, TYPE B, USING EXISTING CASTING	U	20.00
39	09403	602153M		RECONSTRUCTED INLET, TYPE B, USING NEW CASTING	U	1.00
40	09403	602210M		BICYCLE SAFE GRATE	U	11.00
41	09403	602213M		CURB PIECE	U	77.00
42	09403	602216M		CLEANING DRAINAGE STRUCTURE	U	12.00
43	09403	606012P		CONCRETE SIDEWALK, 4" THICK	SY	10.00
44	09403	606039P		HOT MIX ASPHALT DRIVEWAY, 6" THICK	SY	5,364.00
45	09403	606042P		HOT MIX ASPHALT DRIVEWAY, VARIABLE THICKNESS	SY	6,977.00
46	09403	606051P		CONCRETE DRIVEWAY, 6" THICK	SY	1,565.00
47	09403	606060P		CONCRETE DRIVEWAY, REINFORCED, 8" THICK	SY	36.00
48	09403	606084P		DETECTABLE WARNING SURFACE	SY	36.00
49	09403	607018P		9" X 16" CONCRETE VERTICAL CURB	LF	4,198.00
50	09403	610003M		TRAFFIC STRIPES, LONG LIFE, EPOXY RESIN 4"	LF	265,188.00
51	09403	610009M		TRAFFIC MARKINGS, THERMOPLASTIC	SF	370.00
52	09403	MMR081M		TRAFFIC MARKINGS, LINES, THERMOPLASTIC	LF	13,411.00

53	09403	610012M		RPM, MONO-DIRECTIONAL, WHITE LENS	U	595.00
54	09403	610018M		RPM, MONO-DIRECTIONAL, AMBER LENS	U	445.00
55	09403	610021M		RPM, BI-DIRECTIONAL, AMBER LENS	U	620.00
56	09403	610024M		REMOVAL OF RPM	U	1,660.00
57	09403	651255M		RESET WATER VALVE BOX	U	41.00
58	09403	653084M		RESET GAS VALVE BOX	U	22.00
59	09403	MME078M		IMAGING DETECTION SYSTEM, 1 CAMERA	U	1.00
60	09403	MME079M		IMAGING DETECTION SYSTEM, 2 CAMERA	U	3.00
61	09403	MME080M		IMAGING DETECTION SYSTEM, 3 CAMERA	U	2.00
62	09403	701012P		1 1/2" RIGID METALLIC CONDUIT	LF	40.00
63	09403	702048M		LOOP DETECTOR	LF	100.00
64	09403	702051P		LOOP DETECTOR CABLE	LF	100.00
65	09403	804006P		TOPSOILING, 4" THICK	SY	5,676.00
66	09403	805003M		TURF REPAIR STRIP	LF	41,631.00
67	09403	806006P		FERTILIZING AND SEEDING, TYPE A-3	SY	5,676.00
68	09403	806018P		FERTILIZING AND SEEDING, TYPE F	SY	568.00
69	09403	809003M		STRAW MULCHING	SY	5,676.00