ABSTRACT

Title of Document: A TOOL FOR QUANTIFYING THE CARBON FOOTPRINT OF CONSTRUCTION PROJECTS IN THE TRANSPORTATION SECTOR

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The U.S. construction industry ranks third in the nation in its production of carbon dioxide emissions. Increasing global pressure towards developing emissions reduction strategies is bound to affect the construction industry. The objective of this thesis was to develop a tool to estimate the carbon footprint of construction projects associated with transportation infrastructure. The tool determines emissions from an inventory of equipment, construction processes, and credits efforts to reduce emissions, while incorporating recent and future greenhouse gas (GHG) policies on quantifying emissions. This tool will enable construction companies to identify sources and reduce emissions, while also allowing state agencies to monitor these companies in accordance with GHG laws. The tool was applied to data associated with the construction of the Intercounty Connector, a new roadway that will connect counties in Maryland. Application of the tool to this case study showed its utility and highlighted the need for reduction strategies.

A TOOL FOR QUANTIFYING THE CARBON FOOTPRINT OF CONSTRUCTION PROJECTS IN THE TRANSPORTATION SECTOR

By

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Dedication

To my parents who have made me who I am…….

Thank you for your love throughout the years.

How else could I become what I've become?

All your plans and hopes and even fears

Now come together in what I have done.

Know that I am grateful for your love.

Your hard work is mirrored now in mine.

On you all my accomplishments must shine.

Underneath my pride, your spirits move.

~ G.F.Handel

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List of Acronyms

Acronym	
ACES	American Clean Energy and Security Act
ARB	Air and Resource Board (under U.S. state of California)
ARRA	American Recovery and Reinvestment Act of 2009
C stock	Carbon stock
CAR	Climate Action Report (developed by U.S. Government)
CCSP	Climate Change Science Program
CCTP	Climate Change Technology Program
CCX	Chicago Climate Exchange
C-density	Carbon density
CEMS	Continuous emission monitoring system
CER	Certified Emissions Reduction
CH_4	Methane
CO	Carbon monoxide
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
COP15	United Nations Conference on Climate Change
CORINAIR	Core Inventory if Air Emissions in Europe
DOE	Department of Energy (under U.S. Government)
DOT	Department of Transportation (under U.S. Government)
ECMT	European Conference of Ministers of Transport
EF	Emission factor
EFDB	Emission factor database (by IPCC)
EIIP	Emissions Inventory Improvement Program (by EPA)
EPA	Environmental Protection Agency (under U.S. Government)
FIADB	Forest Inventory and Analysis Database (by USDA)
GHG	Greenhouse Gas
GWP	Global warming potential
ha	Hectare
hp	Horsepower
ICC	Inter County Connector
IPCC	International Panel on Climate Changes (under UNFCCC)
kg	Kilogram
L	Liters
LSD	Low sulfur diesel (550 ppm)
M2M	Methane to Markets
MC	Medium cure asphalt
MD	State of Maryland

MMT	Million metric tons
MT	Metric tons
N	Nitrogen
N_2O	Nitrous dioxide
NASA	National Aeronautics and Space Administration (under the U.S. Government)
NCDC	National Clean Diesel Campaign by EPA
NO	Nitric oxide
NOx	Nitrogen oxides
O_2	Oxygen
O_3	Ozone
OTAQ	Office of Transportation and Air Quality (under U.S. Government)
PM	Particulate matter
ppm	Parts per million
RC	Rapid cure asphalt
RGGI	Regional Greenhouse Gas Initiative
ROG	Reactive organic gas
SC	Slow cure asphalt
SHA	State Highway Administration (of MD)
SOC	Soil organic carbon
SOx	Sulfur oxides
U.S.	United States of America
ULSD	Ultra low sulfur diesel (15 ppm)
UNFCCC	United Nations Framework Convention on Climate Change
USDA	Unites States Department of Agriculture
VOC	Volatile organic content
WHO	World Health Organization (under United Nations)

Chapter 1. Introduction

The turn of the 21st Century saw the world population rise to approximately 6.7 billion of which the United States accounts for almost five percent [U.S Census Bureau, 2009]. This exponential growth has created an increased demand on energy and other natural resources, resulting in wide-spread impact on the environment. Growing awareness of the impact of greenhouse gas (GHG) emissions produced by humans on climate change has brought critical attention towards developing strategies to identify their sources, and estimate and reduce their magnitude. The objective of this thesis is to develop a tool to determine emissions from major sources in construction projects associated with transportation infrastructure.

While GHGs are vital to life on earth to help regulate surface temperatures and the climate, constant emissions through human activities in the past decades have resulted in excessive concentrations in the atmosphere causing global warming. Global warming is known to have several environmental and health effects. With the intentions of reversing the effects of climate change, global and national agencies have, and continue to develop regulatory policies such as the Kyoto Protocol and the American Reinvestment and Recovery Act to reduce emissions. Chapter 2 presents an overview of GHG, its sources and the general effects of climate change. Current and future polices in relation to GHG reduction are also discussed in this chapter.

The common methods of calculating GHG emissions based on an emission factor and conversion to carbon dioxide equivalents (CO_2e) are presented in Chapter 3. Existing models employed in carbon emissions estimation are also reviewed.

Chapter 4 focuses on emissions in the construction industry in the United States (U.S.), and the impact of specific governmental emissions reduction strategies on the industry. Many of these strategies, like the U.S. Environmental Protection Agency's (EPA) Clean Air Nonroad Diesel Rule, have already been implemented and are establishing standards for the management of construction projects. Therefore, this chapter introduces the motivation behind this research and thesis, since construction agencies will be required to evolve in their methods to meet these strict standards.

Chapter 5 describes in detail the methodologies and assumptions used to develop the carbon footprint estimation tool proposed herein. The carbon estimation tool will determine emissions from operation of an inventory of applicable equipment (type, brand and age), and construction processes (site preparation, materials productions, etc.), while crediting any efforts to reduce GHG emissions through reforestation or equipment retrofit. The tool also incorporates the recent and future GHG policies on quantifying emissions.

The tool was applied to data obtained from the Intercounty Connector project (ICC) by the Maryland State Highway Administration as a case study to evaluate its use and efficiency in Chapter 6.

The developed tool enables construction companies to actively reduce emissions and optimize the construction process and costs. Simultaneously, this tool will allow state agencies to monitor these companies in accordance with recent GHG reduction laws at both state and federal levels. These benefits are described in Chapter 7. A discussion of potential uses of the developed carbon footprint estimation tool beyond transportation infrastructure construction is also provided.

Chapter 2. Background

2.1 Overview of Greenhouse Gas Emissions

Greenhouse effect is a natural phenomenon that is induced when atmospheric gases trap the ultraviolet rays from the sun within the earth's atmosphere. It is therefore essential in maintaining the earth's temperature and climatic conditions. Naturally occurring atmospheric gases such as water vapor, carbon-dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), ozone (O_3) and, anthropogenic-produced gases such as halocarbons, nitric oxide (NO), carbon-monoxide (CO), aerosols, and fluorinated gases are collectively classified as greenhouse gases (GHGs). Additionally, other air pollutants such as sulfur oxides (SO_x), reactive organic gases (ROG) and particulate matter (PM) also indirectly affect greenhouse gas effect [USEPA, 2010c].

CO_2 is produced primarily from the combustion of fossil fuels like petroleum, diesel and biofuels, and biomass such as trees and solid wastes as a result of their high carbon content. It is also formed naturally during biological respiration and artificially during the production of materials like cement, steel, asphalt and chemicals. CO_2 is sequestered through the natural carbon cycle by forests and oceans. CH_4 is emitted from the burning of fuels as well, in addition to being produced from livestock, agricultural practices and decay of organic material [USEPA, 2010c]. NO and NO_2, the primary constituents of NO_x emissions, are formed when nitrogen (N), either in the air or in fuel, combines with oxygen (O_2) at high temperatures. Other pollutants such as PM and CO are formed as a result of incomplete combustion of fuel; whereas, SO_x are formed from the sulfur content in the fuel [USEPA, 2009b]

Although the earth produces GHGs through natural processes such as respiration of plants and animals, volcanic eruptions and regular changes in temperatures, the concentration of these gases in the atmosphere is maintained through natural absorption by forests and oceans. However, since the industrial revolution, anthropogenic activities such as use of fossil fuels, and deforestation for urbanization and agriculture have resulted in an increased deposition of these gases into the atmosphere [IPCC, 2007]. The International Panel on Climate Change (IPCC) has thus established a strong correlation between the anthropogenic deposition of GHGs and global warming resulting in climate change. Due to its large volumetric prevalence, CO_2 is considered a major player in elevating greenhouse effect, and accounts for approximately 86% of all United States (U.S) emissions. CO_2 emissions are increasing at a rate of about 0.3% per year, resulting in almost 36% total increase since the Industrial Revolution [USEPA, 2009a]. The excessive presence of GHGs, further worsened by the constant growth in population, magnifies the greenhouse effect, thereby raising the earth's temperature and bringing about 'global warming'. Global warming is a result of the exacerbation of the earth's greenhouse effect.

Some of the observed effects of climate change include increase in the earth's temperatures, melting of the glacial ice-caps, rise in sea level, and variations in the length of seasons. Recent years (1995 to 2006) have been recorded to be the warmest years since 1850. The warmer temperatures are known to cause changes in regional precipitation, later freezing and earlier break-up of ice on rivers and lakes, lengthening of growing seasons, shifts in plant and animal ranges, and earlier flowering of trees. The sea-level has been predicted to rise between seven and twenty-three inches by 2080, posing increased risk of loss of land and habitats, and danger to human population in coastal areas. Moreover, the changes in climatic conditions have increased the probability and intensity of extreme climatic events such as hurricanes, droughts, wildfires and other natural disasters, resulting in damages to human lives, property and the nation's economy [IPCC, 2007].

Beside the environmental effects, climate change is also known to affect the human health directly from exposures to heat-waves or cold fronts, and the lengthening of transmission seasons of vector borne diseases that thrive in warm temperatures. Decreased air quality has contributed to increased incidences of respiratory diseases and damage to lung tissue [WHO, 2003].

Although each of the GHGs have varying effects on the environment and human health, it is critical that their concentrations in the atmosphere be reduced to curb climate change and therefore, preserve the earth for future generations.

2.2 Greenhouse Gas Policies and Regulations: Global and National

The United Nations Framework Convention on Climate Change (UNFCCC) was developed in 1994 to address the urgent need to reduce GHG emissions and thus curb climate change. 193 nations collectively established the Framework's objective of "…stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system." [ECMT, 2007]. In 1997, the UNFCCC members drew up the Kyoto Protocol, an international binding agreement signed by 37 industrialized countries and ratified by 55 nations, all committing to reduce GHG emissions to 5% of their 1990 levels by 2012. The Framework presents market-based strategies such as emission trading, clean development mechanism and joint implementation to help participants implement the protocol. Although the Framework provides these global options, it strongly encourages that national measures be taken [UNFCCC, 2010].

Under its commitment as a member to the UNFCCC, the U.S. government develops a national emissions inventory, recording sources and sinks of emissions from various sectors of the economy. These inventories are developed in accordance with the guidelines established by the IPCC. Additionally, the State Department also authors the Climate Action Report documenting current climatic conditions, GHG emissions, policies and regulations [U.S. Department of State, 2006].

Within the U.S., the government collaborates with several federal agencies such Environmental Protection Agency (EPA), Department of Energy (DOE), Department of Transportation (DOT), Department of Agriculture (USDA) and National Aeronautics and Space Administration (NASA) in efforts to monitor and reduce emissions. However, most of these efforts are executed under the close guidance of the EPA.

In its efforts to abate emissions, the government has developed initiatives/programs, some of which facilitate technological and informational exchange while others provide financial incentives. One of the notable informational exchange initiatives is the Climate VISION Partnership established between major industrial sectors (e.g., oil and gas, transportation, electricity generation, mining, manufacturing and forestry products) and four U.S agencies (DOE, EPA, USDA, DOT) to reduce GHG emissions in the next decade.

Similarly, the Clean Energy-Environment State Partnership Program and the Climate Leaders program are collaborations between EPA and states, and private companies, respectively, to encourage goals and establish concrete strategies towards emissions reduction. Other initiatives like ENERGYSTAR buildings and Green Power Partnerships deal with reduction of emissions through energy efficiency. The Climate Change Technology Program (CCTP) and the Climate Change Science Program (CCSP) are initiatives that revolve around the development of clean technology and the improvement in the understanding of the science behind climate change [USEPA, 2010c].

2.3 Emissions reductions: The Future

As the awareness of global warming continues to grow, political and public sentiment has been increasing towards employing strategies that promote clean development and, thereby, reduce national emissions. Being the North American country that ranks as top emitter per capita worldwide, the U.S. contributes almost 19.4% of global emissions although they account for only 5% of global population [IPCC, 2007]. This has thus resulted in a watchful eye towards U.S. efforts in reducing its emissions. Moreover, in the recent 2009 United Nations Conference on Climate Change (COP15), the U.S. developed the Copenhagen Change Accord in collaboration with other top emitters in the world (China, Brazil, India and South Africa) to set forth the groundwork for global action against climate change. According to the Accord, U.S. pledged a 17% decrease of its 2005 levels by 2020. Therefore, the U.S. Government is exploring the institution of various federal and state legislations toward wide-spread emissions reduction. These include, but are not restricted to, enforcing a carbon tax and/ or carbon trading systems, and carbon allowances [UNFCC COP15, 2009].

Already under the Obama Administration, the energy provisions of the American Recovery and Reinvestment Act of 2009 (ARRA) promotes emissions reduction through energy efficiency. The $787 billion Act not only provides tax incentives for use of renewable energy and energy-efficient technologies, but also offers grants, contracts and loans for programs in energy-efficiency. Under this act, with approximately $300 million financial assistance, the EPA strengthened the National Clean Diesel Campaign (NCDC) [ARRA, 2009].

Other national efforts to reduce emissions include the set-up of partnerships to implement cap-and-trade programs. Ten U.S. states in the Northeast and Mid-Atlantic regions have set up a regional mandatory cap-and-trade market system called Regional Greenhouse Gas Initiative (RGGI) that aims to reduce emissions from the power sector by 10% by 2018 and sell carbon offsets. Proceeds from this effort are channeled to various clean energy projects [RGGI, 2009]. Several U.S. states have since established local carbon markets that allow individuals and businesses to purchase and sell carbon offsets. The Maryland Terrapass and Chicago Climate Exchange (CCX) are few examples of state based carbon trading programs [MD Terrapass, 2010 & CCX, 2010]. Other market-based emissions reductions programs include the Methane to Markets (M2M) initiative chaired by the EPA. This global program focuses on the recovery and sale of CH_4 as clean energy [USEPA, 2010b].

With several of these global and national policies as a foundation, the world has begun to set the stage to develop stringent programs to combat climate change. This in turn is bound to have an effect on the future functioning of business across the world.

Chapter 3. Greenhouse Gas Emissions Calculations

3.1 Emission Factor (EF)

The quantification of emissions is vital in the management of air quality. Emissions estimates help identify key sources and enable the development of strategic tools to combat poor air quality. Emissions are determined via the use of an appropriate emission factor (EF). An EF is "a representative value that relates the quantity of pollutant released to the atmosphere with an activity associated with the release of that pollutant" [USEPA, 2010c].

EFs are typically long-term averages developed from published technical data, documentation from emission tests or continuous emission monitoring system (CEMS) and personal communication. Since the development of EFs is dependent on the data available, their accuracy is sometimes imperfect. Hence, the use of an EF in quantifying emissions is at best an approximation unless based on long-term empirical data [USEPA, 1997]. Table 3-1 lists well known EF for a variety of fuels used in transportation.

Several EF databases are maintained globally and nationally to facilitate agencies, industries, consultants, and other users in estimating emissions. The IPCC manages an EF database (EFDB) library based on The Core Inventory of Air Emissions in Europe (CORINAIR). The EFDB allows the user to obtain EFs based on IPCC source/sink categories, which include energy, land use change, solvents, industries, etc. [IPCC-NGGIP, 2009].

Table 3-1. Carbon dioxide emission factors of transportation fuels.
Source: EIA,2010

Transportation Fuel	Emission Factors	
	Pounds CO_2 per Unit of Volume	Kilograms CO_2 Per Million BTU
Aviation Gasoline	18.33 per gallon	69.16
Biodiesel		
▪ B100	0 per gallon	0.00
▪ B20	17.89 per gallon	59.44
▪ B10	20.13 per gallon	66.35
▪ B5	21.25 per gallon	69.76
▪ B2	21.92 per gallon	71.8
Diesel Fuel (No.1 and No.2)	22.37 per gallon	73.15
Ethanol/Ethanol Blends		
▪ E100	0 per gallon	0.00
▪ E95	2.93 per gallon	14.71
▪ E10 (Gasohol)	17.59 per gallon	65.94
Methanol/Methanol Fuels		
▪ M85	10.68 per gallon	64.01
Motor Gasoline	19.54 per gallon	70.88
Jet Fuel, Kerosene	21.09 per gallon	70.88
Natural Gas	120.36 per 1000 cubic feet	53.06
Propane	12.67 per gallon	63.07
Residual Fuel (No.5 and No.6 Fuel Oil)	26.00 per gallon	78.8

EPA's AP-42 document is a compilation of EFs for air pollutants used within the U.S. Several website databases such as CHIEF and FIRE access EFs from the AP-42 and related documents. Many U.S. states have also developed similar software models and documents for the purpose of producing state emissions inventories [USEPA, 2010c].

EFs are ranked based on their methods and the expanse of the data used in their development. The EPA AP-42 EF ratings are assigned as in Table 3-2.

Table 3-2. AP-42 ratings of emission factors established by EPA.
Source : USEPA, 2009b

Rating	Quality	Assignment Analysis
A	Excellent	Excellent. Emission factor is developed primarily from A and B rated source test data taken from many randomly chosen facilities in the industry population. The source category population is sufficiently specific to minimize variability.
B	Above Average	Emission factor is developed primarily from A or B rated test data from a moderate number of facilities. Although no specific bias is evident, is not clear if the facilities tested represent a random sample of the industry. As with the A rating, the source category population is sufficiently specific to minimize variability.
C	Average	Emission factor is developed primarily from A, B, and C rated test data from a reasonable number of facilities. Although no specific bias is evident, it is not clear if the facilities tested represent a random sample of the industry. As with the A rating, the source category population is sufficiently specific to minimize variability.
D	Below Average	Emission factor is developed primarily from A, B and C rated test data from a small number of facilities, and there may be reason to suspect that these facilities do not represent a random sample of the industry. There also may be evidence of variability within the source population.
E	Poor	Factor is developed from C and D rated test data from a very few number of facilities, and there may be reason to suspect that the facilities tested do not represent a random sample of the industry. There also may be evidence of variability within the source category population.

U	Unrated	Unrated (only used in the L&E documents). Emission factor is developed from source tests which have not been thoroughly evaluated, research papers, modeling data, or other sources that may lack supporting documentation. The data are not necessarily "poor," but there is not enough information to rate the factors according to the rating protocol. "U" ratings are commonly found in L&E documents and FIRE rather than in AP 42.

3.2 Carbon Density (C-density)

CO_2 is constantly cycled between the atmosphere and forest systems. Trees continually absorb CO_2 from the atmosphere via photosynthesis to grow and store it in the form of carbon in the biomass of the tree (leaves, trunk, roots, etc.). CO_2 is also stored as carbon in soil, which accumulates when organic matter decomposes. Most soil organic carbon (SOC) is stored within the first meter depth from the soil surface. The amount of CO_2 absorbed and therefore the carbon stored, depends on the tree type, age, tree size and climatic conditions of the region. Together, the amount of carbon stored in the biomass and the soil is termed the carbon stock (C-stock) of that ecosystem and is quantified by the carbon density (C-density) of that system. C-density is therefore, defined as the average mass of carbon stored in the biomass of a living system per area of that system. Table 3-3 lists the C-density of the various forests types (where non-soil refers to the carbon stored in tree parts, and soil refers to that stored in the soil) in the northeast region of the U.S. [USEPA, 2009a].

Table 3-3. Carbon density values for various forest types in the northeast region of the U.S. *Source: USEPA, 2009a*

Region	Forest Type	Carbon Density (MT/ha)	
		Non-Soil	Soil
Northeast (CT,DE,MA,MD,ME,NH,NJ,NY,OH,PA,RI,VT,WV)	White/Red/Jack Pine	135.8	78.1
	Spruce/Fir	104.2	98
	Oak/Pine	127.1	66.9
	Oak/Hickory	115	53.1
	Elm/Ash/Cottonwood	96.2	111.7
	Maple/Beech/Birch	129.4	69.6
	Aspen/Birch	72.6	87.4
	Minor Types & Nonstocked	80.1	82.7
	All	118.2	69.7

3.3 Measuring Greenhouse Gases: GWP and Units

3.3.1 Global Warming Potential (GWP)

GHGs are measured qualitatively through the intensity of their effect on the earth's atmosphere. This intensity is determined by the GHG's global warming potential (GWP). GWP is defined as "the ratio of radioactive force absorbed by one unit mass of the greenhouse gas to that of one unit mass of reference gas over a specified time period". CO_2 is the globally accepted reference gas with a GWP of one, and GWP is typically measured for 1, 20, 50, 100 -year time periods [USEPA, 2006 & IPCC, 2007]. Therefore, the GHG CH_4 with a 100-year GWP of 21 has 21 times the effect on the atmosphere as compared to CO_2.

Table 3-4 lists the GWP values of some common GHGs. The GWPs for all species of air pollutants as mandated by the IPCC can be found in Appendix 1.

Table 3-4. GWP Values for some common GHGs. *Source: IPCC, 2007*

Species	Chemical Formula	Lifetime (Years)	Global Warming Potential (Time Horizon)		
			20 years	**100 years**	**500 years**
Carbon Dioxide	CO_2	Variable	1	1	1
Methane	CH_4	12±3	56	21	6.5
Nitrous Oxide	N_2O	120	280	310	170
HFC-23	CHF_3	264	9100	11700	9800
Perfluoromethane	CF_4	50,000	4400	6500	10,000
Sulphur hexafluoride	SF_6	3200	16,300	23,900	34,900

In addition to being a measure of a GHG's effect on the atmosphere, GWPs are used to convert GHGs into carbon-dioxide equivalents (CO_2e). This allows for the use of an easy and standard unit of reporting of the quantities of GHGs being measured. Mass units of GHG are converted to CO_2e by multiplying the amount by its GWP. For example, 50 pounds of CH_4 = 50 pounds x 21= 1,050 pounds CO_2e [IPCC, 2007].

3.3.2 Units of Measurement

The units of measurement are typically recorded in teragrams (Tg) or million metric tons (MMT). Common units of measurement and their conversions are listed in Table 3-5.

Table 3-5. Common units of measurement of GHGs & their conversions.
Source: USEPA, 2005

From		To
1 metric ton of carbon equivalent	=	3.667 metric tons CO_2e
1 metric ton of CO_2e	=	0.2727 metric tons of carbon equivalent
1 teragram	=	1 million metric tons
1 kilogram	=	2.205 pounds
1 pound	=	0.000454 metric ton
1 metric ton	=	1.102 tons

The U.S. Inventory of GHGs typically account CO_2, CH_4, CO, NO_2 and fluorinated gases emitted from various sources while estimating GHGs in Tg CO_2e. However, since these GHGs contribute towards air pollution, several inventories of emission estimates, especially those from vehicles, also include other pollutants such as SOx and PM.

3.4 Overview of Existing Estimation Models of Greenhouse Gases in the U.S.

Several models currently exist that enable the quantification of GHGs, and the subsequent development of emissions inventories. Under the Clean Air Act, the EPA puts forth models that estimate emissions from various sources. The NONROAD2008 model helps in the inventory of emissions from non-road vehicles and diesel equipment; whereas, the recent MOVES2010 model estimates on-road and highway vehicle emissions. GLOBEIS on the other hand estimates the volatile organic content (VOC), CO and soil NOx emissions from biogenic sources [USEPA, 2010c]. The USDA have developed two models, the COLE and CCT, that estimates C-stocks and measure carbon flux for region in the U.S. based on forest inventory data [USDA NRS, 2010].

Additionally, many states and private agencies develop models to estimate emissions. The state of California's Air and Resource Board (ARB) is a pioneer in developing specific strategies and regulations towards emissions reduction. The EMFAC2007 model is one such model that calculates emission rates from all on-road vehicles operating on the state's roads [ARB, 2007]. The OFFROAD2007 model on the other hand estimates the contribution of emissions due to agricultural, construction, lawn and garden equipment, and recreation vehicles [ARB, 2009]. Table 3-6 provides a summary of the existing GHG estimating models.

Table 3-6. Summary of current models in emissions estimation & their uses.

Emissions Type	Model Name	Source	Use
Vehicle	NONROAD2008	EPA	Non-road vehicles and diesel equipment
	MOVES2010	EPA	On-road and highway vehicles
	EMFAC2007	California ARB	On-road vehicles in California
	OFFROAD2007	California ARB	Agricultural, construction, lawn and garden equipment, and recreation vehicles
Biogenic	GLOBEIS	EPA	VOC, CO and soil NOx emissions from biogenic sources
	COLE	USDA	Tool for Forest Carbon Analysis
	CCT	USDA	State-level annualized estimates of carbon stocks on forestland

The majority of these models determines individual source emissions (e.g., passenger cars) and rarely determines comprehensive emissions for a source category (e.g., transportation). Therefore, there exists a need for an all-encompassing emissions estimation model that will enable users to quantify emissions from various sources simultaneously. This, in turn, will encourage and support proactive efforts in GHG emission reduction.

Chapter 4. Emissions in Construction

4.1 Emissions in the Construction Sector

The 873.1 billion U.S. dollar construction industry (2003) in the U.S. ranks first amongst 55 nations globally. The industry is vital in the development of the nation's infrastructure, which includes construction of residential and industrial buildings, roads, bridges and other long-standing structures. Within the U.S., this industry permeates both the transportation and industrial sectors as it involves the use non-road vehicles and equipment, like excavators and cranes, and supports large construction-based industries, like cement and chemicals. The transportation and industry sectors contribute almost 28 % and 33% to U.S. national emissions, respectively. Collectively, emissions from the construction industry amount to nearly 2% (~131 MMT CO_2e) of the total U.S. emissions (Figure 4-1) [USEPA, 2008]. Despite the economic recession, it has been estimated that by 2030, about half of the buildings in America will have been built after 2000, implying that half the volume of urban structures will be constructed within 25 years just to support population growth [Nelson, 2004]. While each individual construction project may not produce large quantities of GHGs compared with operations in other sectors, because there are consistently a large number of on-going construction projects, the aggregate product of these projects is large [Truitt, 2009]. The construction industry is the third largest emitter of carbon dioxide as a function of emission produced per unit of input energy (Figure 4-1) [USEPA, 2008].

In 2006, U.S. fossil fuel emissions constituted 20% of the global fuel emissions. Close to 94% of the U.S. emissions are generated from anthropogenic burning of fossil fuels, approximately half each from stationary sources such as industries, commercial plants and residences, and a third from the transportation sector [USEPA, 2009a]. A majority of emissions result from the use of fuel for operating equipment and vehicles, or production of electricity in the transportation segment of the construction sector [USEPA, 2009d].

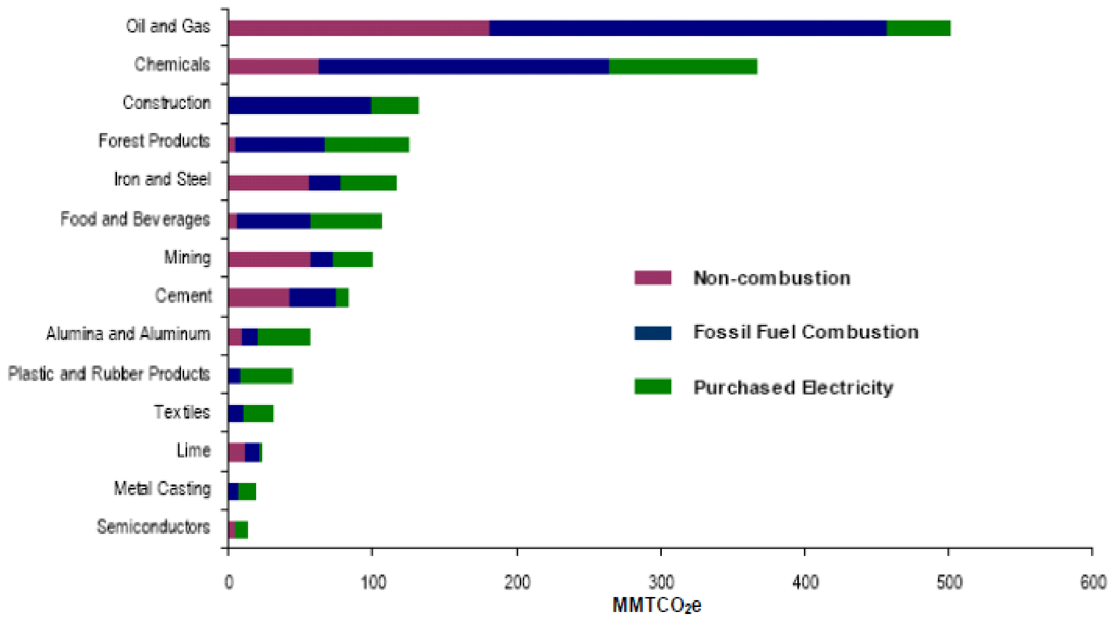

Figure 4-1. Construction industry as the 3rd largest emitter amongst all U.S. industries.
Source: USEPA, 2009d

The transportation sector in the U.S. is divided into transportation vehicles (on– and non-road) and non-transportation vehicles. Transportation vehicles include cars, motorcycles, light and heavy trucks, buses, ships and aircraft, among others; while, non-transportation vehicles include construction, agricultural and commercial equipment, generators and recreational vehicles [USEPA, 2009e]. As seen in Figure 4-2, construction equipment play a significant role in contributing towards the emissions from non-transportation vehicles, resulting in 2% or approximately 59.7 MMT CO_2e of the transportation emissions [OTAQ, 2006].

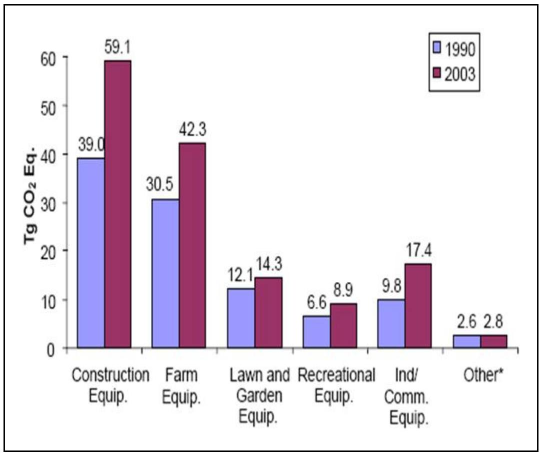

Figure 4-2. Construction equipment as leading emitter among non-transportation sources.
Source: OTAQ, 2006

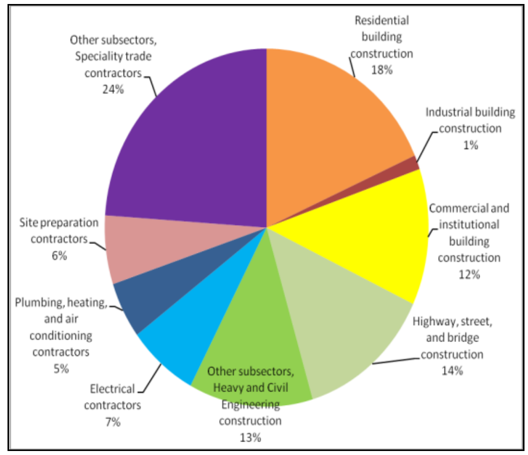

Figure 4-3. Division of emissions from construction industry by sub-sectors.
Source: USEPA, 2009d

The remainder of the 131 MMT CO_2e of the total construction emissions stems from the use of electricity and off-gassing from industrial processes in the construction industry, including cement and materials productions, and use of chemicals and steel. These processes are particularly important while considering emissions due to the construction of buildings, and heavy and civil engineering subsectors of the industry (Figure 4-3) [USEPA, 2009d].

In addition, the construction industry reduces emission sinks as building of structures often call for deforestation of standing forests which are important sources of sequestration of atmospheric carbon.

4.2 Emissions Reduction Polices in Construction

To help abate emissions, the Office of Transportation and Air Quality (OTAQ) has established programs that have already produced wide-scale reductions. Some of these programs directly impact or regulate the construction industry. The most evident of these is the National Clean Diesel Campaign (NCDC) that promotes immediate improvement in air quality from diesel engines through various regulatory and voluntary strategies. The voluntary Diesel Retrofit Technology Verification Program provides agencies a list of retrofit technologies approved by the EPA. The technologies typically enable reductions of emissions between 20 and 90%. However, it is the NCDC regulatory programs that have had the most impact. The Clean Air Nonroad Diesel Rule establishes a set of standards mandated by the EPA towards reductions of emissions from diesel engines by almost 90%. In addition, EPA has also established a tier-system, and enforces the use of low sulfur diesel in heavy-duty engines.

The EPA's tier system regulates emissions from diesel engines based on the equipment age and horsepower (Appendix B). The system has four levels: tier 1, 2, 3 and 4. Conceptually, a tier 1 level vehicle would be older and produce greater emissions as compared to a tier 4 level vehicle. Although not strictly mandated, EPA strongly encourages construction projects to utilize higher tiered equipment so as to reduce construction emissions. This would imply that either the construction equipment fleet should be relatively new or the older equipment must be retrofit with reduction technologies. Also, according to these standards, manufacturers would be required to meet the most recent set of emissions standards put forth by the EPA. The low sulfur diesel produces a 99% reduction of the sulfur content in the fuel, reducing from current levels of 3300 parts per million (ppm) to 15 ppm.

The most updated tier system took effect in 2008; whereas, the diesel fuel rule will be executed starting 2010 [USEPA, 2009c].

4.3 Project Motivation

Currently, construction emissions are only calculated to develop state and national inventories. Also, traditional approaches for construction planning do not consider emissions as a decision factor. Studies have shown that almost 53% of survey respondents do not employ any form of emissions reduction strategies (Figure 4-4) [USEPA, 2008]. This is mainly because the development and installation of lower emitting vehicle technology is time-consuming, expensive, and sometimes creates unfavorable trade-offs between cost, productivity and emissions. Similarly, green efforts or environmental restoration involves permitting processes that are tedious and expensive. Therefore, the present sentiment in the construction industry towards emissions reduction is for the most part negative or neutral [USEPA, 2009d]. However, future implementation of carbon reduction programs (e.g. cap, tax, or imposition of stricter standards) will define how contractors bid on jobs and implement their construction plans so as to meet these standards while remaining profitable.

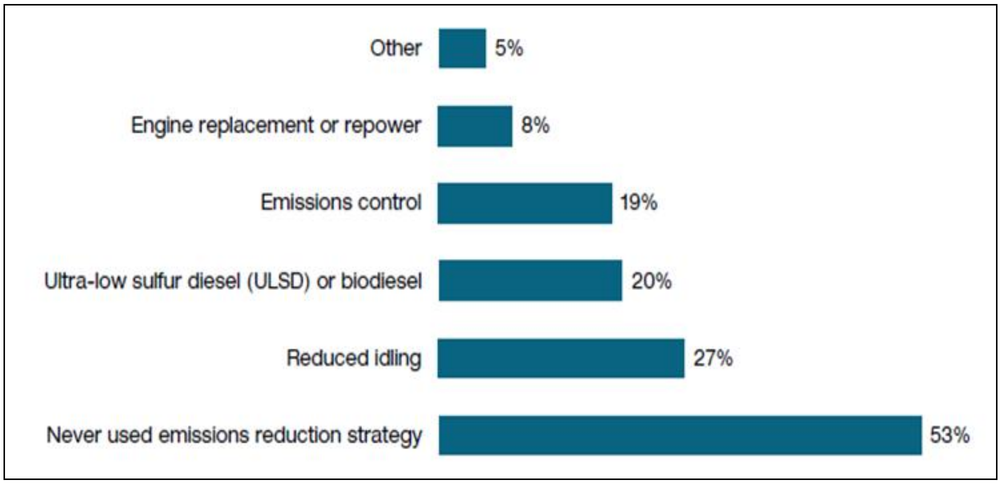

Figure 4-4. Industry survey of Construction Firms that use Emissions Reduction Strategies. *Source: USEPA, 2008*

The proposed carbon footprint estimation model was developed to facilitate these companies to identify sources and quantify emissions from their projects, and therefore, aid their efforts for emissions reduction. The details of the proposed model development, its uses, and benefits will be discussed in the following chapters.

Chapter 5. Carbon Footprint Estimation Model for Construction Projects

5.1 Description of Model

The state-of-the-art and state-of-the-practice in relevant carbon footprint computation used nationally and around the globe were reviewed. Various estimation models (Table 3-6), the IPCC Guidelines, and EPA best-practice methodologies were evaluated for their potential to aid in GHG emissions estimation for activities on individual construction projects. Although there currently exist models that estimate construction-related emissions from equipment, land-use change or carbon stocks of forests, there does not exist a tool that estimates the net emissions from all major activities undertaken during a construction project. The carbon footprint model was therefore, developed to address the need for a calculator to estimate emissions from all the major processes observed during the course of a construction project, from site preparation to landscaping.

The proposed model aims to measure production of emissions from the operation of an inventory of applicable equipment, quantify the loss in carbon sinks from deforestation and soil movement, and also include the amount of sequestration of CO_2 achieved from reforestation efforts. Moreover, the model integrates key GHG reduction policies that impact construction, like the EPA Tier System and the NCDC.

The estimation model and its interface were constructed on Microsoft Office so as to produce a tool that is both simple to use and user-friendly. The selection of this model platform will not require the user to purchase specialized software for the utilization of this carbon footprint tool. The model-interface was created with drop-down menus and integrated instructions such that it would require minimum effort by the user to input the required data. The output of the tool is showcased in a way that clearly defines the amount of GHG (in MT CO_2e) and other related air pollutants associated with each process, and the total net emission of the project to aid the user in the decision-making process to achieve their goals of emissions reduction.

5.2 Components of Estimation Model

The components of the carbon footprint estimation model were developed based on the four major processes in construction projects, namely site preparation, operation of construction equipment, materials production and environmental impact mitigation (Figure 5-1).

The site preparation component quantifies the amount of CO_2 absorbed by forests and the organic soil layer that is lost during deforestation from clearing and grubbing processes, and movement of existing forest soil. The equipment component estimates emissions produced during the operation of all equipment on site for the duration of the project; whereas, the materials production component computes emissions from on-site production of cement, concrete asphalt and off-gassing from the use of chemical solvents, like surface coatings and fertilizers. The environmental impact mitigation component determines the amount of CO_2 absorbed through the re-plantation of trees that would help abate the emissions otherwise produced during construction.

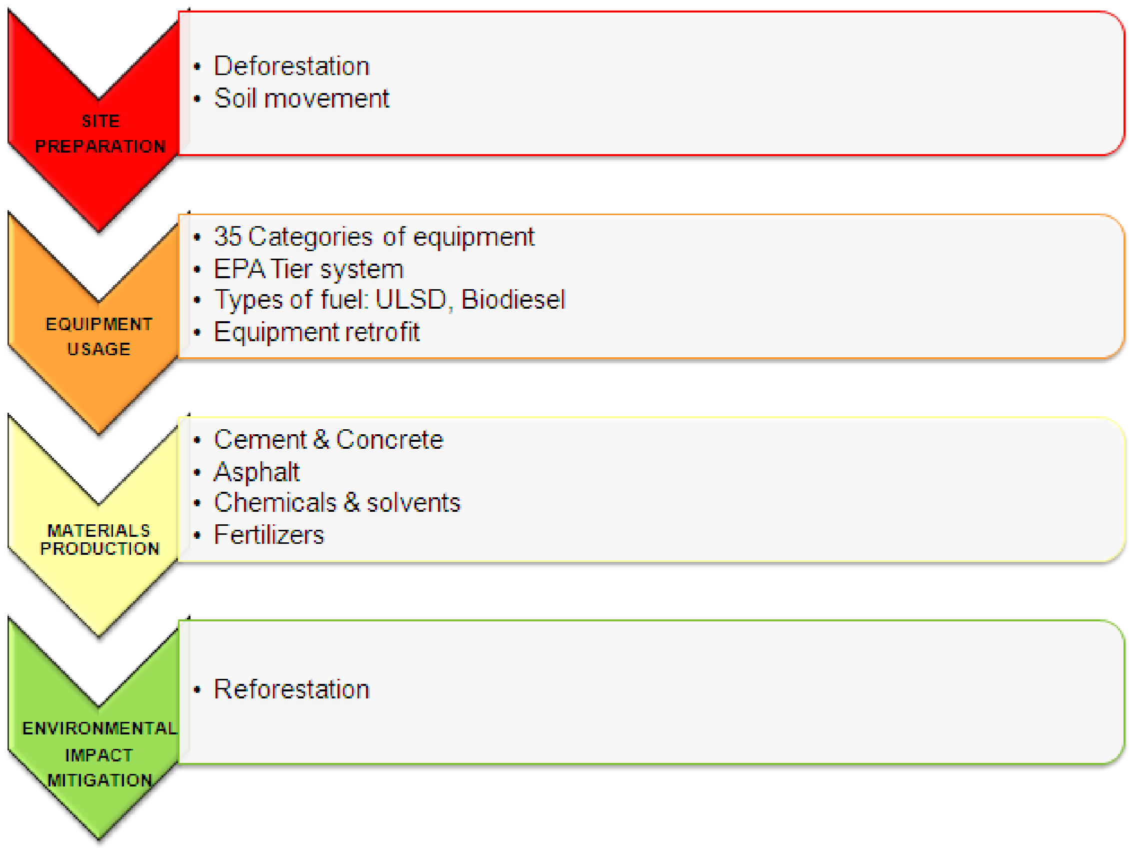

Figure 5-1. Flowchart illustrating the various components of the developed carbon footprint estimation model.

5.3. Methodology of Emissions Estimation of Model Components

Each component in the model performs calculations based on a set of data input by the user using a database of EFs specifically created for each component and a mathematical relationship, converting input data and appropriate EF to amount of CO_2e produced/sequestered by that activity. Subsections 5.3.1-5.3.4 list the input data, EF database used, assumptions and equations used to estimate emissions for each component of the carbon footprint estimation model.

To develop the carbon footprint model, the highest levels of EFs per component i.e. AP-42 Type A or B (see Chap 3, Section 3.1) were either obtained and adapted from various sources, or estimated directly through stoichiometric relationships of the processes that the components capture. Moreover, all equations and methodologies used to estimate emissions are in accordance with the most recent IPCC guidelines [IPCC, 2006]. The IPCC guidelines categorize methodologies into various tiers: Tier 1 being the lowest and Tier 3 being the highest. IPCC defines good practice decision trees to facilitate the selection of the optimal method of determining emissions based on the amount of data available for the emissions calculations. An example decision tree describing good practice methodology for calculating emissions from cement production is reproduced in Figure 5-2.

Basic equations obtained from extensive study of literature in the area, were tailored accordingly to incorporate details of each construction process based on studies of the best practice guidelines for emissions estimation, policy trends and statistical analysis. The tailored equations used in the proposed model were developed to meet either the IPCC Tier 2 or Tier 3 criteria. Hence, the proposed tool provides a detailed quantitative and qualitative estimation of net emissions from a construction project.

The site-preparation component mainly focuses on accounting for the CO_2 that would normally be sequestered by growing trees or forests and in the primary layer of the soil (humus or organic layer) that is lost when a construction site is cleared.

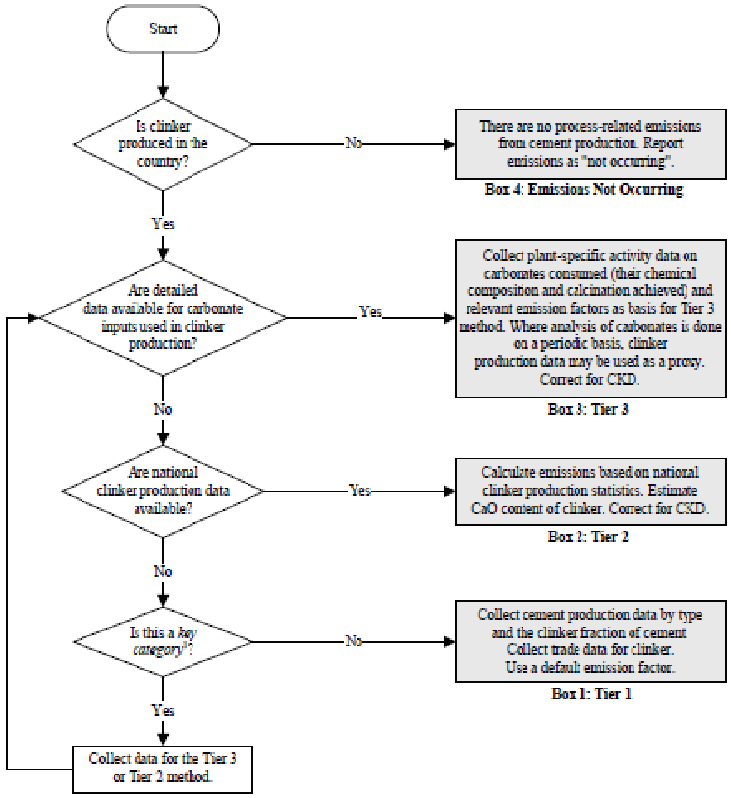

Figure 5-2. An example IPCC decision tree describing best practice methodology & their respective Tier levels. *Source: IPCC-NGGIP, 2000*

5.3.1 Site-Preparation: Deforestation & Soil Movement

Input Data

Since the amount of carbon sequestered in forest trees is dependent on the region within the U.S. and the type of forests in each region, the site-preparation component of the model classifies the vegetation on the construction-site prior to construction in the same manner. Users must specify the location of their construction site within the U.S. and also the forests types within their construction site. In addition, the user must manually enter extent of the area of each type of forestland that the construction project would clear. A screenshot of the mock user-interface illustrating these categories of input data as required from the user is shown in Figure 5-3. For example, if the construction site is located in the state of Maryland and the construction project would require the deforestation of 1,000 hectares (ha) of Jack Pine trees, the user would choose from the model's drop-down menu: 'Northeast' under Regions, then 'White/Red/Jack Pine' under Forest Types and enter 1,000 ha under Forest Area. Similarly as shown in the figure, for a construction site in Florida with 500 ha of Cypress trees and 700 ha of Elm trees, the user would pick 'Southeast' region, 'Oak/Gum/Cypress' and 'Elm/Ash/Cottonwood' forest types, and enter '500 ha' and '700 ha' forest area, respectively.

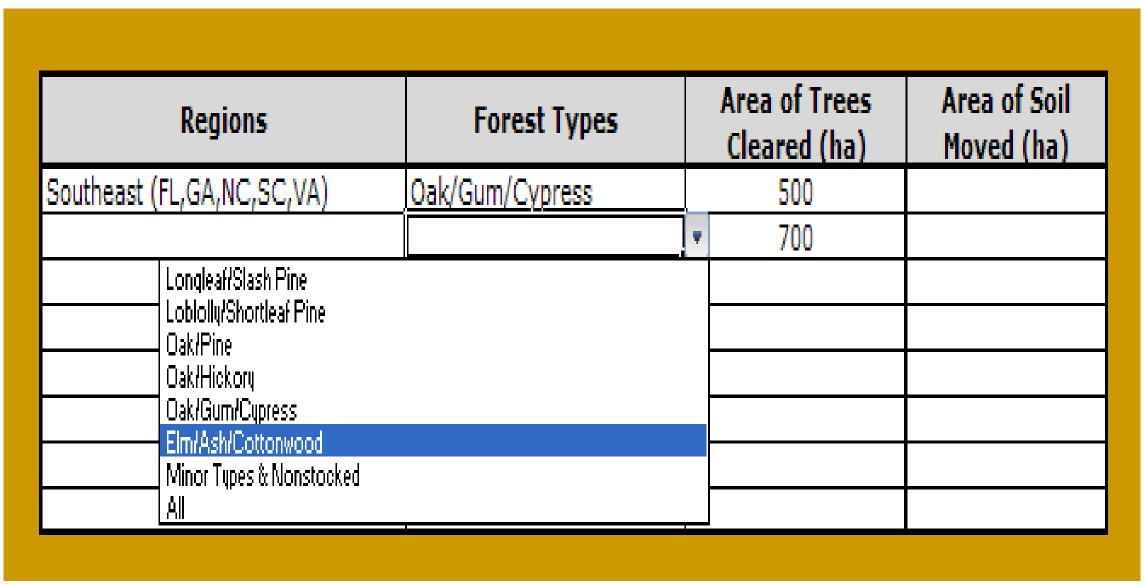

Figure 5-3. Screenshot of mock user-interface for site-preparation component

Database

The database for the site-preparation component of the carbon footprint estimation model was built based on data obtained directly from the latest Inventory of U.S. Greenhouse

Gas Sources and Sinks: 1990-2007. According to the region and forest types, the Inventory lists C-density values by various carbon pools in forest ecosystems, namely above-ground biomass, below-ground biomass, dead wood, litter and soil organic carbon. The categories in the database and the C-density values reflect USDA's most recent inventory by state as in the Forest Inventory and Analysis Database (FIADB) and is in accordance with the IPCC guidelines.

This component's database lists the C-density (MT/ha) of major forest types in each region of the U.S. The classification of regions and the forest types per region in this component are consistent with those in the Inventory. Thus, the database categorizes the 50 U.S. states into 11 regions based on their geographic locations: Northeast (CT,DE,MA,MD,ME,NH,NJ,NY,OH,PA,RI,VT,WV), Northern Lake States (MI,MN,WI), Northern Prairie States (IA,IL,IN,KS,MO,ND,NE,SD), South Central (AL,AR,KY,LA,MS,OK,TN,TX), Southeast (FL,GA,NC,SC,VA), Pacific Northwest-Westside (Western OR & WA), Pacific Northwest-Eastside (Eastern OR & WA), Pacific Southwest (CA), Rocky Mountain-North (ID,MT), and Rocky Mountain-South (AZ,CO,NM,NV,UT,WY) [USEPA, 2009a].

Although the C-density data in the Inventory is listed by carbon pool, the C-density values of the forest types under each region that are used in this component are summarized into just two categories: Non-soil and Soil C-density. The non-soil C-density values were obtained by summing all carbon pools related to tree parts (live and dead), i.e. above-ground biomass, below-ground biomass, dead wood and litter; whereas, the soil C-density is only the soil organic carbon values. Tables 5-1 and 5-2 demonstrate a sample conversion of the

Inventory data into the model site-preparation component's database. Appendix C contains the site- preparation database as used in the model.

Table 5-1. Original data with C-density values for all carbon pools in the northeast region. *Source: USEPA, 2009a*

Region	Forest Type	Carbon Density (MT C/ha)				
		Above-ground Biomass	Below-ground Biomass	Dead Wood	Litter	Soil Organic Carbon
Northeast (CT,DE,MA,MD,ME,NH, NJ,NY,OH,PA,RI,VT,WV)	White/Red/Jack Pine	91.8	19.0	11.2	13.8	78.1
	Spruce/Fir	51.1	10.8	11.7	30.6	98.0
	Oak/Pine	75.7	15.0	9.1	27.3	66.9

Table 5-2. Database constructed for site-preparation component of model from original data with soil & non-soil carbon pools. *Source: USEPA, 2009a*

Region	Forest Type	Carbon Density (MT C/ha)	
		Non-Soil	Soil
Northeast (CT,DE,MA,MD,ME,NH,NJ,NY,OH,PA,RI,VT, WV)	White/Red/Jack Pine	135.8	78.1
	Spruce/Fir	104.2	98.0
	Oak/Pine	127.1	66.9

Assumptions

This component was developed under the assumption that the construction site to be cleared is primarily forestland. Additionally, sites that are mostly grasslands or ground vegetation would be covered under the 'Minor types and nonstocked' forest type category in the database. If the site is an urban land, i.e. has previously built structures, then this component will not be used in the model under the assumption that no sequestration capabilities that previously existed would be lost by subsequent construction in the area. Due to the lack of a comprehensive statistical database of soil carbon, and since the first meter of soil typically accounts for the highest concentration of carbon [Francek, 2009], the sequestration capacity lost due to movement of soil is assumed to be from the loss of the soil organic content within each forest and region. Also, biological activity in the soil produces NOx (primarily N_2O) emissions. However, the N_2O emissions from forest soil as summarized in Table 5-3 are typically small compared to soil organic carbon (as shown previously) [USEPA, 2009b]. Due to this reason, and since during site-preparation, soil is being removed from the site, natural NOx emissions are considered to be negligible and hence, are not accounted for in this component.

Table 5-3. N_2O emissions from forest soils. *Source: USEPA, 2009b*

Forest Ecosystems	Emission Factor	
	Lbs N_20 /acre/yr	**MT N_20/ha/yr**
Tropical forest	3.692	0.0041
Savanna	2.521	0.0028
Temperate forests (coniferous)	1.404	0.0016
Temperate forest (deciduous)	0.563	0.0006
Grassland	1.503	0.0017
Shrubs/woodlands	2.456	0.0028

Equations Used

The following relationship was used to convert C-density to the CO_2 sequestration capacity (MT CO_2e) lost due to site-preparation. This methodology is in accordance with IPCC Tier-2 level good practice emissions estimation.

$$EM_{Site-\mathrm{Pr}ep} = [EM_{Deforest} + EM_{Soil}]$$
$$EM_{Deforest} = \sum(C\sim density \cdot A_{Forest} \cdot CC)$$
$$EM_{Soil} = \sum(C \sim density \cdot A_{Soil} \cdot CC)$$

Notation

$EM_{Site\text{-}Prep}$: Emissions from site-preparation (MT of CO_2)

$EM_{Deforest}$: Emissions from clearing and grubbing/deforestation (MT of CO_2)

EM_{Soil}: Emissions from movement of soil (MT of CO_2)

C~density: Carbon density obtained from component database (MT C/ha)

A_{Forest}: Area of forest cleared by construction; input by user (ha)

A_{Soil}: Area of soil removed for construction; input by user (ha)

CC: Carbon Conversion = Ratio of CO_2 to carbon, 44 units CO_2/1 unit C = 3.67

5.3.2 Equipment Usage

This component calculates emissions produced from the operation of various types of equipment like dozers, loaders, scrapers, dump trucks etc., during the period of construction.

Input Data

This component requires the user to input information about the characteristics of the equipment used within the construction site. Specifically, the user describes his/her inventory of equipment, and chooses from a list of 35 equipment categories. The user then enters the number of pieces and hours of operation for each type of equipment chosen. Other details such as the age, model year and engine horsepower (hp) or instead, if known, the EPA Tier level of each type of equipment, would also need to be fed into the model. If the user has available only the age, horsepower and model year of the equipment, this component will automatically associate the appropriate tier level to that equipment piece. However, if only the tier level is available, the user will enter the tier level and choose an appropriate maximum horsepower within the tier level. Based on this information, the model will automatically associate the appropriate model year for the equipment piece. If the user's equipment inventory contains any pieces that were retrofit with an emission reduction technology, the model allows the user to pick from a list of EPA approved retrofit technologies. In addition, the type of fuel used by the equipment such as ULSD, B5, B20 and

B100 also need to be entered. A screenshot of a mock user-interface illustrating these categories of input data as required from the user is shown in Figure 5-4.

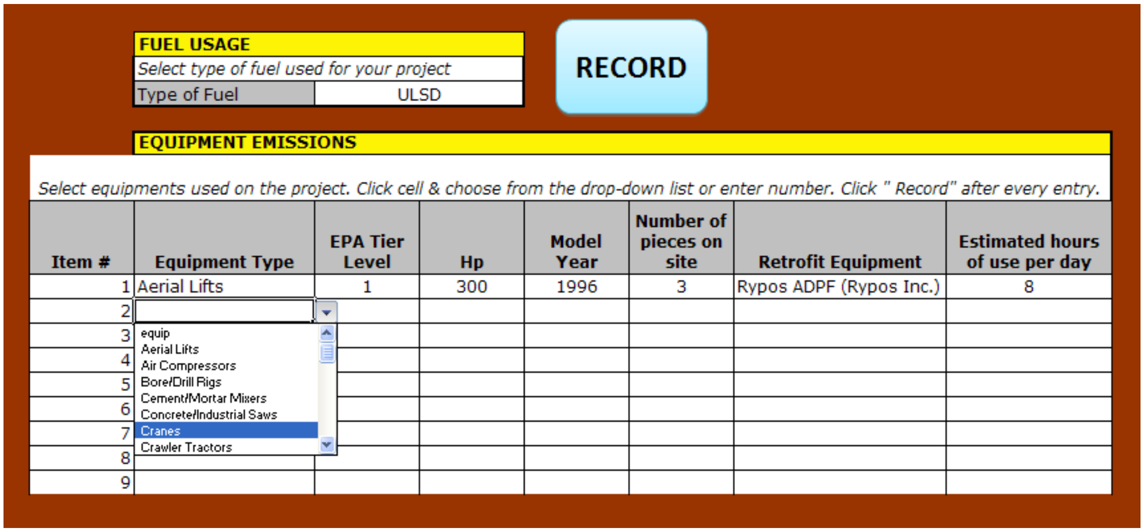

Figure 5-4. Screenshot of mock user-interface for equipment usage component.

Database

The component's database was developed based on the best available data that ordinarily exist for the purpose of this component, accumulated from several sources. The component's database is a compilation of EFs for all GHGs and is categorized yearly (1995-2025) by equipment type, and all available rated power for each equipment type (hp). The equipment categories and their rated powers are consistent with those listed by EPA and in other emissions models used nation-wide [USEPA, 2009e & ARB, 2009].

The EFs for the 35 categories of equipment options in the proposed model is obtained directly from California ARB's OFFROAD2007 Model. The EF data obtained from the OFFROAD2007 model were derived based on average annual fleet make-up of the equipment category for each year through 2020, vehicle population in each equipment category by horsepower rating and load factor. This data, however, was only available for the years 2007 to 2025. Since the average life expectancy of construction equipment is typically 10 to 20 years, the data needed to be extended to accommodate older equipment that may still be in use. Thus, a new database was developed for this component, by extrapolating the OFFROAD2007 data for all equipment categories to the years 1995 through 2025. The extrapolation was conducted based on the average percent difference obtained by calculating the changes in the PM standards mandated by the EPA Tier system over time (Appendix B). These standards are specific to a range of horsepower and model years of any non-road equipment. Therefore, for any given year, the extrapolated database applies a 21% increase in all GHG emissions (ROG, NOx, Sox, CO_2, CO and CH_4) to that equipment that falls within a certain range of rated power only if that range and model year underwent changes in PM standards in the EPA Tier system. The assumptions used to establish this extrapolation rate are explained in the following section. Table 5-4 provides the rated power and model years to which the extrapolation trend was applied in the database for the years 2007 to 2002. A complete summary of the years and rated power the extrapolation trend was applied to is listed in Appendix D. This EF database is in compliance with AP-42 Type-A standards.

In addition to the EF database for equipment, an intermediary database was created so as to allow for flexibility with the information input by the user, while also letting the model obtain and process the information appropriately. Thus, the input-interface lets the user either enter the tier level of equipment type or the age, rated power and model year to determine the appropriate EF from the database.

Table 5-4. Extrapolation trend as applied to model years 2007-2002 & rated power based on analysis of PM standards.

Applicable Rated Power Range	2007-06	2006-05	2005-04	2004-03	2003-02
>11 to 25 hp	same	same	21	same	same
>25-50 hp	same	same	same	21	same
>100-175 hp	21	same	same	same	21
>175-300 hp	same	21	same	same	21
>300-600 hp	same	21	same	same	same
>600-750 hp	same	21	same	same	same
>750-1200 hp	same	21	same	same	same
>1210-9999 hp	same	21	same	same	same

This database allows the model to associate a maximum rated power and a median model year should the user input just the tier level for the equipment type. The maximum rated power was determined directly from the EPA NONROAD model; whereas, the median year was calculated based on the model year range established by EPA for each tier level and every range of rated power. Table F-1 and F-2 in Appendix F outlines the details of this intermediary database. An example of the database for the year 2006 is documented in Appendix G.

Assumptions

The original EF data was obtained from the California ARB's OFFROAD2007 model [ARB, 2009]. Although ambient changes in temperature and pressure from state to state may result in temporal and spatial differences in emission production, it was assumed that these EFs are representative of the emissions due to only the equipment performance, with negligible effects due to environmental conditions. The EPA Tier system and other related emission standards primarily regulate PM and NOx emissions. PM emission standards in particular have been consistently monitored since 1988 [USEPA, 2007c]. Consequently, consistent data for PM emission factors are available via various models. Also, it is assumed that as EPA mandated these standards over time, equipment manufacturers met these standards accordingly. This implies that equipment manufactured in 2004 would have met all the EPA emissions standards established until the year 2004. Therefore, in determining the change in emissions so as to estimate the implied improvement in equipment emissions from 1998 to 2007, chronological analysis of the PM emission factors (acquired from 2009 Diesel Tier standards) was performed.

From the analysis of the differences in PM standards of the EPA tier system as shown in Appendix E, it can be seen that there is approximately 21% average increase in standards, implying a 21% decrease in emissions from pre-tier 1(tier 0) to tier 1, tier 1 to tier 2, and tier 2 to tier 3. Subsequently, emissions for appropriate equipment categories from the year 2007 to 1995 were increased by 21% annually as shown in Table 5-4 and summarized in Appendix D in accordance with EPA tier system standards. Thus, a comprehensive emission factor database was established from years 1995-2025.

It must be noted that this database reflects EFs for diesel fuel only. To accommodate the use of other fuels, a correction factor will be applied during calculation. EPA mandated the use of low sulfur diesel (LSD) in 2006, and the use of ULSD in construction equipment will be mandated as of June 2010 [USEPA, 2007b]. Moreover, some companies may wish to use biodiesel blends such as B5, B20 and B100 in the future. Therefore, correction factors were determined to accommodate all fuel types that may be used by construction equipment.

Again, these correction factors were developed based on the percent PM emissions reduction that the fuel offers with diesel fuel as a base case.

It was assumed that with the ratification of ULSD in all non-road vehicles in 2010, the diesel fuel used to produce biodiesel will be ULSD only, and thus, the PM emissions reductions will be enhanced as such. For example, B5 biodiesel typically offer a 2% reduction in PM emissions from diesel fuel. If ULSD with a 32% (25%+7%) reduction is used in production, a total of 34% reduction will be achieved [USEPA, 2007b]. Appendix H describes in detail how the correction factors were determined. Table 5-5 lists these fuel-based correction factors.

Table 5-5. Fuel-based correction factors used in equipment usage emissions calculation.

Fuel	Reductions in PM from Base Case
Diesel	0 (Base case)
Low Sulfur Diesel (LSD)	25%
Ultra-Low Sulfur Diesel (ULSD)	32%
Biodiesel B5	34%
Biodiesel B20	44%
Biodiesel B100	81%

Equations Used

The operation of construction equipment emits several GHGs (NO_x, CO_2, CH_4, CO) and air pollutants (ROG and SO_x). A basic emissions calculation relationship [EPA, 2009] was adapted to develop the following equation for determining emissions of individual

GHGs and air pollutant emissions from operating equipment during an activity [EPA, 2009]. This relationship corresponds to the IPCC Tier-3 level good practice emissions estimation.

$$EM_{Equip} = EF \cdot A \cdot N \cdot [(1 - CF_{Fuel}) + (1 - CF_{Retrofit})] \cdot P \cdot Unit\,Conversion$$

<u>Notation:</u>

EM_{Equip}: Emissions of GHG or air pollutant from each equipment type

(MT of NO_x/CO_2/CH_4/CO/ROG/SOx per equipment type)

EF: Emission factor from component database (lbs/hour)

A: Operation time per equipment (hours/day); input by user

N: Number of pieces of each equipment type; input by user

CF_{Fuel}: Fuel-based correction factor (%/100)

$CF_{Retrofit}$: Retrofit technology-based correction factor (%/100)

P: Period of stay of per equipment or period of construction (days); input by user

Unit Conversion: 1lb = 0.000454 MT

The air pollutant emissions, i.e. PM, SOx and ROG, are listed separately; whereas, individual GHG emissions, i.e. NO_x, CO, CO_2 and CH_4, were converted to total CO_2e emissions emitted from each equipment type using the following relationship.

$$EM_{TotalEquip} = \Sigma[(EM_{NO_x} \cdot GWP_{NO_x}) + (EM_{CO} \cdot GWP_{CO}) + (EM_{CH_4} \cdot GWP_{CH_4}) + (EM_{CO_2} \cdot GWP_{CO_2})]$$

Notation

$EM_{Total\ Equip}$: Total emissions from each equipment type (MT of CO_2e)

EM_{NOx}: Total NO_x emissions from each equipment type (MT of NO_x)

EM_{CO}: Total CO emissions from each equipment type (MT of CO)

EM_{CH4}: Total CH_4 emissions from each equipment type (MT of CH_4)

EM_{CO2}: Total CO_2 emissions from each equipment type (MT of CO_2)

GWP_{NOx}: Global warming potential of NO_x = 310 [IPCC, 2007]

GWP_{CO}: Global warming potential of CO = 3 [IPCC, 2007]

GW_{CH4}: Global warming potential of CH_4 = 21 [IPCC, 2007]

GW_{CO2}: Global warming potential of CO_2 = 1 [IPCC, 2007]

5.3.3 Materials Production

This component captures emissions from the production or use of major materials used on-site namely cement, asphalt, solvents (i.e. grease and coatings), and fertilizers. The air pollutants and GHGs produced by usage of these materials are calculated primarily from their stoichiometric relationships based on their respective chemical compositions. The component then summarizes the total emission from each material produced to estimate total emissions from all materials production on the construction project as follows.

$$EM_{TotalMat} = EM_{Cement} + EM_{Concrete} + EM_{Asphalt} + EM_{Solvent} + EM_{Fert}$$

5.3.3.1 Cement and Concrete

Production and usage of cement primarily emits CO_2 gas. CO_2 is formed during the calcination process, when calcium carbonate ($CaCO_3$) is heated in a kiln to produce lime (CaO), which is mixed with silica to form raw forms of cement called clinkers. Clinkers are then mixed with water and other materials to form various types of cement like Portland or masonry cement [USEPA, 2009a]. The percentage of clinker used in cement varies by the type of cement. Therefore, the amount of CO_2 emitted is directly proportional to the amount of cement produced and the percentage of clinker used to produce it. CO_2 emitted can be quantified using the stoichiometric relationship of the calcination process to yield an EF which reflects the mass of CO_2 produced per unit of lime (clinker).

Input

To estimate CO_2 emissions from cement, the user would enter the amount and type of cement consumed on-site after specifying the clinker type used in the cement i.e. 65% CaCO or 65% CaCO & 2% MgO blend. The amount of cement consumed on site would include the amount produced on-site (Q_{Prod}) and that amount brought into or imported to the site (Q_{Imp}). A screenshot of the user-interface is shown in Figure 5-5.

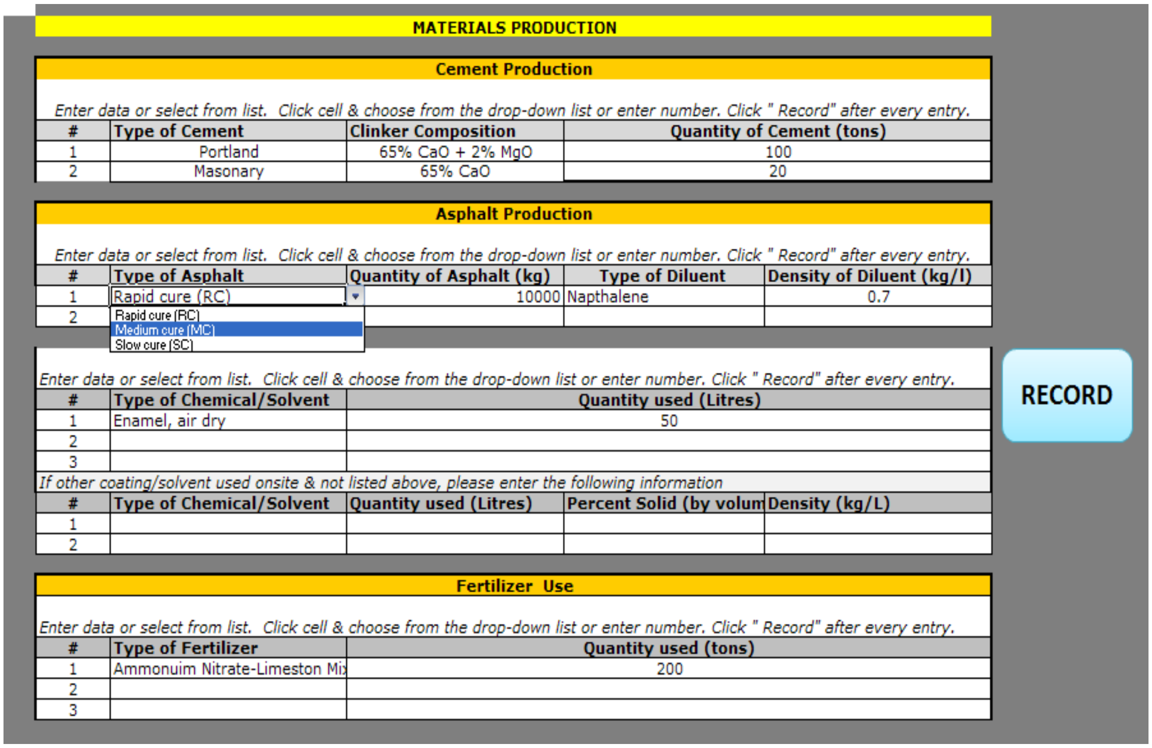

Figure 5-5. Screenshot of mock user-interface for materials production component.

Database

The EF for the clinkers was calculated based on the stoichiometric equations of the calcification process as shown below yielding the amount of CO_2 produced per unit of lime or clinker to make the cement. This is an AP-42 Type-B EF. The EF determination for each blend is summarized in Table 5-6 [USEPA, 2009b].

65% CaCO Clinker Blend:

$$CaCO_3 + Heat \rightarrow CaO(clinker) + CO_2$$

65% CaCO & 2% MgO Clinker Blend:

$$CaCO_3 + MgCO_3 + Heat \rightarrow [CaO + MgO](clinker) + 2CO_2$$

Table 5-6. Calculation of emission factor for cement based on clinker type.

Clinker Blend	EF Calculation
65% CaCO	$EF_{\mathrm{CaO}} = 0.65CaO \cdot \left[\frac{44.01g/moleCO_2}{56.08g/moleCaO}\right]$ = 0.51 tons CO_2/ton clinker
65% CaCO & 2% MgO	$EF_{\mathrm{CaO+MgO}} = 0.65CaO \cdot \left[\frac{44.01g/moleCO_2}{56.08g/moleCaO}\right] + 0.02MgO \cdot \left[\frac{44.01g/moleCO_2}{40.31g/moleMgO}\right]$ = 0.53 tons CO_2/ton clinker

Notation

EF_{CaO}: Emission factor for 65% CaCO (MT CO_2/ton clinker)

$EF_{CaO+MgO}$: Emission factor for 65% CaCO & 2% MgO (MT CO_2/ton clinker)

M_{CO2}: Atomic mass of CO_2 = (12.01+ 2x16) = 44.01g/mole CO_2

M_{CaO}: Atomic mass of CaO = (40.08 + 16) = 56.08g/mole CaO

M_{MgO}: Atomic mass of MgO = (24.31 + 16) = 40.31g/mole MgO

The average fraction of clinker of 96% for Portland cement and 64% for masonry is generally accepted world-wide [IPCC-NGGIP, 2000].

Assumptions

Although in addition to cement manufacturing, limestone ($CaCO_3$) may be used in construction as a raw material to prepare road-beds, it is assumed that emissions are only produced when used to produce cement on construction sites, because CO_2 is only emitted when limestone is heated. Therefore, emission from limestone usage is limited to its consumption as an aggregate in cement production. It has been theorized that the use of concrete (made from cement with the addition of water and gravel), may result in some emissions. Due to lack of literature supporting this theory, this component assumes emissions from production of concrete ($EM_{Concrete}$) on-site may account for 1% of emissions due to cement production.

Equation

The EFs calculated above, and the amount of cement input by the user, were converted to CO_2 emissions using the following relationship developed from the IPCC Tier-1 level good practice emissions methodology.

$$EM_{Cement} = \sum[(Q_{\mathrm{Prod}} - Q_{\mathrm{Imp}}) \cdot EF_{Clinker} \cdot WF_{Cement}]$$
$$EM_{Concrete} = 0.01 \cdot EM_{Cement}$$

<u>Notation</u>

EM_{Cement}: Total emissions from use of cement on-site (MT of CO_2)

Q_{Prod}: Quantity of cement produced on-site (MT); input by user

Q_{Imp}: Quantity of cement brought into site (MT); input by user

$EF_{Clinker}$: Emission factor based on clinker type i.e. $EF_{CaO} = 0.51$, $EF_{CaO+MgO} = 0.53$ (MT CO_2/ton clinker)

WF_{Cement}: Weight fraction of clinker in type of cement (%/100)

$EM_{Concrete}$: Total emissions from use of concrete on-site (MT of CO_2)

5.3.3.2 Asphalt

Asphalt in paving operations is typically used by combining aggregate materials with asphalt binders. The binders constitute of asphalt cement formed of distilled crude oils and liquefied asphalt. Of the major types of asphalt i.e. hotmix, cutback and emulsion, cutback liquefied asphalt are primarily used for the purposes of construction, and tack and seal of roadways. Additionally, the other types of asphalt also produce negligible amounts of emissions. Cutback asphalt contains diluents that are used to thin the asphalt cement. Depending on the viscosity desired, the diluents content can vary between 25% and 45%. After application on surfaces, these diluents evaporate resulting in the hardening of the asphalt. Cutback asphalts are therefore, classified based on the amount of diluents evaporation or curing that occurs into rapid cure (RC) with 95% evaporation, medium cure (MC) with 70%, and slow cure with 25% curing [IPCC, 2006].

The use of asphalt results in VOC emissions that primarily constitute of CH_4 and hazardous air pollutants [USEPA, 2007a].

Input

To estimate emissions from use of asphalt, the user enters the type of asphalt i.e. RC, MC or SC, and the percent diluents by volume, if known. If the diluents percentage is unknown, the user may assume an average of 35%. Additionally, the user would input the density of diluents should other types beside naphthalene and kerosene be used. A screenshot of a mock user-interface is shown in Figure 5-5.

Database

The emissions factors were estimated based on the AP-42 and IPCC methodologies. The amount of VOC emitted is assumed to be directly proportional to the amount of diluents evaporated (1:1 ratio). Thus, an equation was developed based on material balance, to estimate the amount of diluents i.e. VOC emitted, given the type of asphalt and its diluents percentage.

$$Q_{Asphalt} = (V_{Diluent} \cdot D_{Diluent}) + (V_{AspCement} \cdot D_{AspCement})$$
$$V_{Diluent} = Percent_{Diluent} \cdot (V_{Diluent} + V_{AspCement})$$

The above equations were used to obtain a relationship for the amount of diluents (VOC emitted) in the asphalt used.

$$M_{Diluent} = \left\{ \frac{Q_{Asphalt}}{D_{Diluent} + D_{AspCement} \cdot \left(\frac{1 - Percent_{Diluent}}{Percent_{Diluent}} \right)} \right\} \cdot D_{Diluent}$$

<u>Notation</u>

$M_{Diluent}$: Mass of diluents in asphalt = Mass of VOCs (kg)

$Q_{Asphalt}$: Quantity of asphalt used (kg); input by user

$V_{Diluent}$: Volume of diluent in asphalt (L)

$D_{Diluent}$: Density of diluent (kg/L)

$V_{AspCement}$: Volume of asphalt cement in the asphalt (L)

$D_{AspCement}$: Density of asphalt cement (kg/L)

$Percent_{Diluent}$: Percentage of diluents in asphalt, as stated by user or assumed to be 35% (%/100)

Assumptions

Although other forms of asphalt may be used, since cutback asphalt is primarily used in construction, and produces the highest emissions amongst all types, this component only estimates emissions from the use of cutbacks. Due to the prominent use of naphthalene and kerosene (in addition to asphalt cement) as diluents, only these two diluents are accounted for in the component. Also, since VOC emissions from asphalt primarily constitute of CH_4, the emissions calculated in this section are converted to CO_2e by applying the GWP for CH_4 (21) [USEPA, 2009b].

Equation

The equation for $M_{Diluent}$ calculated above is used as the emission factor to convert the amount of asphalt consumed on-site to CO_2 emissions using the following relationship developed from the IPCC Tier-1 level good practice emissions methodology.

$$EM_{Aspahlt} = \left[\left\{ \frac{Q_{Asphalt}}{D_{Diluent} + D_{AspCement} \cdot \left(\frac{1 - Percent_{Diluent}}{Percent_{Diluent}} \right)} \right\} \cdot D_{Diluent} \right] \cdot R_{Evap} \cdot GWP_{CH_4} \cdot UnitConversion$$

Notation

$EM_{Asphalt}$: Emissions from use of asphalt (MT of CO_2e)

R_{Evap}: Rate curing obtained from Table 5-7 (%/100)

$D_{Diluent}$: Density of diluent obtained from Table 5-8 or manually input by user (kg/L)

GWP_{CH4}: Global warming potential of CH_4 = 21 [IPCC, 2007]

Unit Conversion: 1kg = 0.001 MT

$Q_{Asphalt}$, $V_{Diluent}$, $D_{Diluent}$,$V_{AspCement}$, $D_{AspCement}$, $Percent_{Diluent}$: Denoted previously

Table 5-7. Percent evaporation of diluents by cutback asphalt curing type.
Source: USEPA, 2007a

Cutback Asphalt Type	Percent Evaporation (%)
RC	95
MC	70
SC	25

Table 5-8. Density of diluents used in asphalt production emissions calculations. *Source: USEPA, 2007a*

Diluent	Density (kg/L)
Naphthalene	0.7
Kerosene	0.8
Asphalt Cement	1.1
Note: Densities of other types of diluents that are used must be obtained separately.	

5.3.3.3 Coatings & Solvents

Several types of paints and coating are used for protective and decorative purposes of construction structures. These typically include paints, varnishes, stains, etc. Emissions from this category primarily include VOCs.

Input

This component requires user to choose the type of coatings /solvents used on-site and determine the volumes used. He/she then enters the density and solids content of each coating/solvent chosen. If the type of coating/solvent other than those provided by the model is used on-site, the user may manually enter the type, volume, percent solid (by volume) and density data for the coating/solvent. A screenshot of a mock user-interface is shown in Figure 5-5.

Database

As the types of chemicals and their characteristic information may vary from project to project, and with time, typical categories of coatings/solvents as listed in EPA's AP-42 document were used. These categories and their respective information (i.e. percent solid and density data) are listed in Appendix I. The use of these national (U.S.) data in estimating emissions is in accordance with the IPCC good practice guidelines.

Assumptions

Due to the lack of availability of information determining the constituents of the VOCs, emissions from coatings/solvents are not converted to CO_2e. Instead, emissions from this segment are listed separately solely to indicate their existence and quantify them.

Equation

The VOC emissions from coatings/solvent use is determined by performing a mass balance based calculation estimating the amount of solid VOCs present in the material used.

$$EM_{Solvent} = \sum(Q_{Solvent} \cdot Percent_{Solid} \cdot D_{Solvent} \cdot UnitConversion)$$

<u>Notation</u>

$EM_{Solvent}$: Emissions from use of coating/solvent (MT of VOC)

$Q_{Solvent}$: Quantity of coating/solvent used on-site (L); input by user

$Percent_{Solid}$: Percentage of solid in coating/solvent from Appendix I

or input by user (%/100)

$D_{Solvent}$: Density of coating/solvent from Appendix I or input by user (kg/L)

Unit Conversion: 1kg = 0.001 MT

5.3.3.4 Fertilizers

The addition of chemical fertilizers to soil produces NOx emissions into the atmosphere as soil bacteria degrades the nitrogen content through various microbial processes to produce primarily nitrous oxide (N_2O) emissions.

Input

To estimate NO_2 emissions from fertilizer usage, the user would enter the amount and choose from a list, the type of fertilizer used on-site. If the type of fertilizer used on-site in not listed in the model, the user may manually enter the name and nitrogen content (% N/ton fertilizer). A screenshot of a mock user-interface is shown in Figure 5-5.

Database

The EFs were determined based on the nitrogen (N) content in each fertilizer type. A list of common fertilizers and their respective N-content are listed in Appendix J. These are obtained directly from AP-42 Compilation of Air Pollutant [USEPA, 2009b] and were calculated based on the chemical composition of the fertilizer. The EF for fertilizer is the emission coefficient based on research by the USDA, which estimates approximately 1.84 kg of N_2O is produced per 100 kg of nitrogen applied as fertilizer. These EFs have an AP-42 Type-D rating.

Equation

The NOx emissions from the use of commercial fertilizers on-site can be calculated using the following relationship developed from the IPCC Tier-1 good practice emissions methodology. It must be noted that there only exist a Tier 1 methodology for NOx emissions for fertilizers under the IPCC Guidelines.

$$EM_{Fert} = \sum[(Q_{Fert} \cdot N \sim Conent_{Fert}] \cdot EF_{Fert} \cdot N \sim Conversion$$

<u>Notation</u>

EM_{Fert}: Total emissions from use of fertilizers on-site (MT of CO_2)

Q_{Fert}: Quantity of each type of fertilizer used on-site (MT); input by user

$N{\sim}Content_{Fert}$: Nitrogen content by weight in fertilizer type from Appendix J

(%/100 N/ton Fertilizer)

EM_{Fert}: Emissions coefficient = 0.0184 (tons N_2O as N/ton N applied)

N~ Conversion: Ratio of N_2O to N_2O as N = 44/28 = 1.57

5.3.4 Environmental Impact Mitigation

The Environmental Impact Mitigation component primarily calculates the emissions offset by a project through any efforts made towards mitigating environmental impact from the construction project. The component accounts for any efforts by a construction project towards re-plantation of trees (or reforestation) after the building of structures. This component thus calculates the amount of atmospheric CO_2 absorbed by trees re-planted on the construction site.

Input

Since the amount of carbon sequestered in trees is specific to the region, type and age of the trees, this component classifies the vegetation to be re-planted on construction-site post construction. Users must identify the location of their construction site in the U.S. and specify type and age of trees to be planted. Additionally, the user manually enters the spacing used for re-plantation (ha/tree). For example, a 12’x10’ spacing requirement would translate to 120 square feet per tree or 0.00035 ha/tree spacing. If the data for number of trees planted is unknown, but the area of reforestation for each type of tree is available, the tree spacing requirement maybe used to obtain an estimate of the number of trees replanted by means of the relationship below.

$$No.Trees = \frac{Area_{\mathrm{Re}\ forestation}}{Tree - Spacing}$$

<u>Notation</u>

No. Trees: Number of trees replanted by tree type

$Area_{Reforestation}$: Known area of reforestation by tree type (ha)

Tree-Spacing: Spacing per tree used for reforestation e.g., 12'x10' per tree or 0.00035 ha/tree

A screenshot of the user-interface illustrating these categories of input data as required from the user is shown in Figure 5-6.

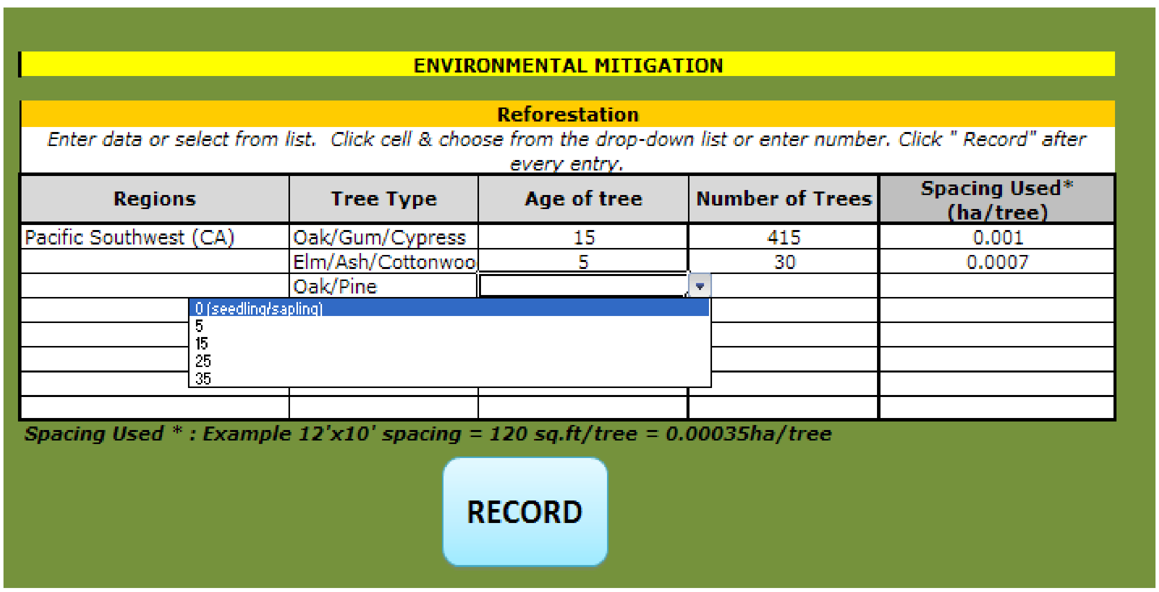

Figure 5-6. Screenshot of mock user-interface for environmental impact mitigation component.

Database

The database for the environmental impact mitigation component of the carbon footprint estimation model was based on the data obtained directly from USDA Forest Services documents. The document compiles look-up tables that record mean C-density values of common forest trees by region. These tables further establish age-growth volume relationships for tree categories and previous land use, based on national data for average level of planting or stand establishments. Moreover, the tables list C-density values by various carbon pools in forest ecosystems, namely: live tree, standing dead tree, understory vegetation, down dead tree, forest floor, and soil organic carbon. The categories in the database and the C-density values reflect USDA's most recent data obtained from various projection and inventory models, and is in accordance with the IPCC guidelines [Smith. J et al, 2006].

This component's database uses the afforestation tables in Smith. J et al. (2006) and lists the C-density (MT/ha) of major forest types in each region of the United States.

The classification of regions and tree types in this component are similar to those in the site-preparation component of this model. The C-density values, again, were summarized into only non-soil (including live tree, standing dead tree, understory, down dead tree, forest floor), and soil organic carbon pools for trees between the ages 0 to 35.

Appendix K contains the environmental mitigation database as used in the model.

Assumptions

This component uses afforestation data from the USDA [Smith. J et al., 2006] based on the assumption that the areas to be re-planted on the construction site are primarily barren and are considered previously non-forest land. In addition, the database consists of only C-density values for trees of ages 0 to 35 years; although, the sequestration capabilities of trees extend well beyond 35 years. This assumes that trees beyond the age of 35 years would not be used for reforestation due to the high costs and logistic difficulties that would be associated with the transport and plantation of very large trees.

Also, it was assumed that the soil used for landscaping and to support reforestation would be equivalent to the organic soil layer of a tree type to ensure compatibility. Moreover, this is supported by the common practice of using organic soil salvaged from the site-preparation process of construction. Therefore, the sequestration capacity of the soil used in the reforestation efforts would be determined using the C-density values of the soil carbon pool of the trees chosen for re-plantation by the user. However, if the soil used is not equivalent to the organic soil of the tree type, an average soil C-density value may be used instead. This value can be estimated by calculating the averages of the soil C-density values for the various tree types and their respective age groups of trees re-planted on the project. The volume of soil re-soiled is converted to area based on the depth of soil replaced (i.e. Area = volume/depth). For example, if 500 cubic meters of soil was used to re-soil a depth of 0.5 meters, the area re-soiled would be 500 cubic meters/0.5 meters = 1000 square meters.

Equations Used

The following relationship was used to convert C-density to the CO_2 sequestration capacity (MT) gained with reforestation of a construction site.

$$EM_{EnvironMit} = [EM_{\mathrm{Re}\,forest} + EM_{\mathrm{Re}\,soil}]$$
$$EM_{\mathrm{Re}\,forest} = \sum(C \sim density \cdot N_{Tree} \cdot Spacing \cdot CC)$$
$$EM_{\mathrm{Re}\,soil} = \sum(C \sim density \cdot A_{\mathrm{Re}\,soil} \cdot CC)$$

Notation

$EM_{EnvironMit}$: Sequestration capacity gained through environmental mitigation efforts (MT of CO_2)

$EM_{Reforest}$: Sequestration capacity gained through reforestation (MT of CO_2)

EM_{Resoil}: Sequestration capacity gained through soil used for reforestation (MT of CO_2)

C~density: Carbon density obtained from component database from Appendix K (MT of C/ha)

$N_{Reforest}$: Number of trees re-planted by tree type; input by user

Spacing: Spacing per tree used for reforestation e.g., 12'x10' per tree or 0.00035 ha/tree (ha/tree)

A_{Resoil}: Area of land that was re-soiled; input by user (ha)

CC: Carbon Conversion = Ratio of CO_2 to carbon i.e. 44units CO_2/1 unit C = 3.67

5.3.5 Offsets

The introduction of the American Clean Energy and Security Act of 2009 (ACES) for approval by the U.S. Senate that proposes a cap-and-trade system in the U.S., highlights the importance of estimating offsets for or from a project [U.S. House of Representatives, 2009]. With the future establishment of a carbon market, it would be beneficial for construction agencies to determine if their project would either require the purchase of carbon credits or if the project has the ability to generate offsets that may be sold as carbon credits in the market. To support this, the carbon footprint estimation tool, incorporates an offsets component to the model that will enable the estimation of offsets, if any, from reforestation efforts by a construction project.

Input

To estimate carbon offsets, the user must first re-define the conditions of deforestation and reforestation within a project. For both processes, the user would choose the class and number of trees removed and replanted (hardwood or conifers). Under deforestation, the user must enter the duration of construction. The number of trees removed through deforestation may be determined from the area of deforestation and an average forest density in the U.S. of 12 trees per hectare (trees with 15-16.9 diameters) [Smith, B et al., 2009]. For the reforestation segment of this component, the average age of trees re-planted, the time of reforestation within the construction period, and the number of years the user wishes to calculate offsets for must be input. If the user is unaware of the species of trees removed or re-planted, Table L-1 of Appendix L may used to estimate tree species from tree type.

Database

To estimate the carbon offsets, the annual sequestration rates for two general species of urban trees typically used for reforestation, hardwood and conifers, were obtained from U.S. DOE documents [U.S. DOE, 1998]. The document lists sequestration rates and survival rates for slow-, medium- and fast-growing trees under these species for ages 0 to 60 years. For the purpose of this model, however average values of sequestration rates for these species of trees were determined for ages 0 to 50 years to establish the component's database [Table L-2 of Appendix L].

Assumptions

This component estimates offsets only due to the emissions produced and sequestered from biogenic sources on the construction project, i.e. the carbon accounting is for only deforestation and reforestation processes on a project, and does not account for emissions from equipment usage or materials production. Based on the popular use of hardwood and conifers in reforestation efforts, the database only accounts for the two general species of trees (hardwood and conifers). This is further reflected in the reforestation component of the model (Section 5.3.4), where the list of trees offered to the user can be classified to belonging to either hardwood or conifer tree species. Also, to determine the appropriate sequestration rate of the forests removed, the average age of trees deforested (baseline age of trees) were assumed to be 20 years of age.

Under the Kyoto Protocol, the crediting period to obtain a certified emission reduction (CER) is upto a maximum of 20 to 30 years from the start of a reforestation [UNFCCC, 2003]. Based on the accounting rules as developed by the Kyoto Protocol, to estimate offsets achieved from reforestation efforts, the component only offers the user to estimate carbon offsets for up to 20 years. It must be noted that this component was developed only to support the decision-making process during construction planning and must not be used as a method of quantification of CERs or similar carbon credits.

Equations Used

The following relationship was used to estimate potential offsets, if any, from a construction project. A positive value for O_{Constr} implies that the project generates offsets (i.e. reforestation produces carbon credits which may be sold in a carbon market); whereas, a negative value implies that a project requires further offsets (i.e. the project would require the purchase of carbon credits from a carbon market to offset their deforestation process).

$$O_{Constr} = [EM_{\mathrm{Re}\,forest} + (R_{ij} \cdot CC \cdot N_{\mathrm{Re}\,forest})] - [EM_{Deforest} + (R_{ij} \cdot CC \cdot N_{Deforest})]$$
$$For\ \mathrm{Re}\ forest: j = P + T - t_R$$
$$For\ D\mathrm{e}\ forest: j = 20 + P + T$$

<u>Notation</u>

O_{Constr}: Offsets due to reforestation efforts on a construction project (MT of CO_2)

$EM_{Reforest}$: Sequestration capacity gained through reforestation; output from environmental impact mitigation component (MT of CO_2)

R_{ij}: Annual sequestration rate of tree species i and age j (MT C/tree)

CC: Ratio of CO_2 to carbon, i.e. 44 units CO_2/ 1 unit C = 3.67

P: Duration of construction; input by user (years)

T: Period of offset determination; input by user (years)

t_R: Time period during construction at which reforestation was conducted; input by user (years)

$N_{Reforest}$: Number of trees re-planted by tree type (same as in environmental impact mitigation component); input by user

$EM_{Deforest}$: Emissions from clearing and grubbing/deforestation; from site-preparation component (MT of CO_2)

$N_{Deforest}$: Estimated number of trees removed by tree type; input by user

5.4 Output

The net emission of a construction project is estimated from the total emissions computed in each component of the model. The output of model displays the sequestration capacity lost during site-preparation ($\sum EM_{Site\text{-}Prep}$), the emissions produced by the use of all construction equipment on site ($\sum EM_{Total\ Equip}$) and those emitted during the production of construction materials ($\sum EM_{Total\ Mat}$), and the emissions offset through any reforestation efforts ($\sum EM_{Environ\text{-}Mit}$). A user-interface screenshot displaying an example of the output is shown below in Figure 5-7.

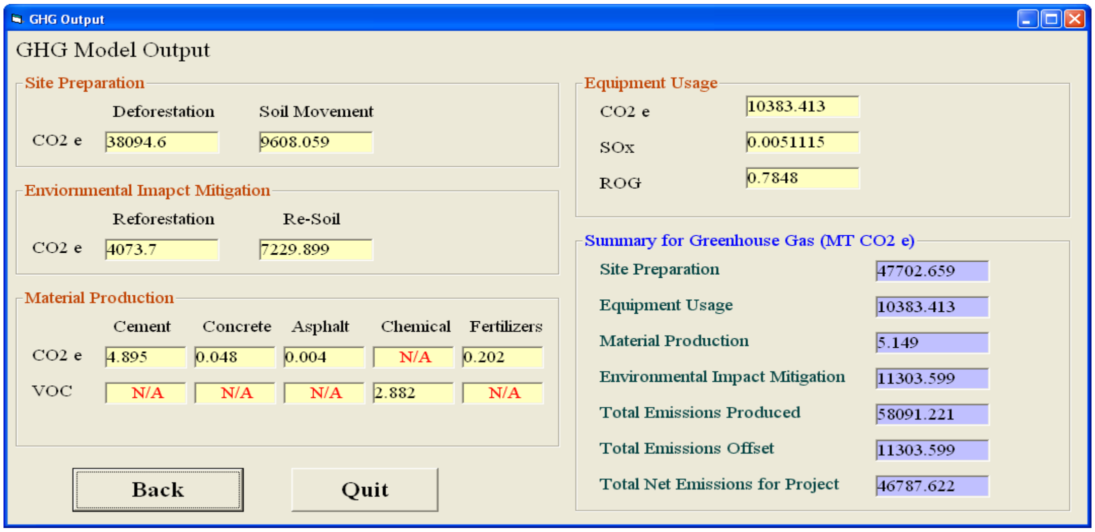

Figure 5-7. Screenshot of user-interface of output from model.

Equations

The individual component emissions were used to calculate the total emission (MT CO2e) for a project using the following relationship.

$$EM_{Project} = \Sigma EM_{Site-Prep} + \Sigma EM_{TotalEquip} + \Sigma EM_{TotalMat} - \Sigma EM_{EnvironMit}$$

Notation

$EM_{Project}$: Net emissions of a construction project (MT of CO_2)

$\sum EM_{Site\text{-}Prep}$: Total emissions from site-preparation (MT of CO_2)

$\sum EM_{TotalEquip}$: Total emissions from equipment usage (MT of CO_2)

$\sum EM_{TotalMat}$: Total emissions from on-site materials production (MT of CO_2)

$\sum EM_{EnvironMit}$: Total emissions sequestered by reforestation (MT of CO_2)

Emissions of other air pollutants (SOx, ROG, VOC etc) from each component are listed separately.

Chapter 6. ICC Case Study

6.1 Description of ICC Project

The proposed carbon footprint estimation tool was demonstrated on a case study involving construction of a major new roadway facility by the Maryland State Highway Administration (MD SHA) called the Maryland's Intercounty Connector (ICC). This 18.8 mile toll road will link highways I-270/I-370 in Montgomery County to I-95 and US Route-1 in Prince George's County in Maryland, and will provide cost-effective community mobility to serve existing and future development patterns reflecting local land use planning objectives. The length of this $2.4 billion roadway is broken into five segments of sequencing contracts A, B, C, D and E, for which contracts to various design-builders were awarded (Figure 6-1): Contract A from I-270/370 to MD 97, Contract B from MD 97 to US 29, Contract C from US 29 to I-95 and collector-distributor lanes along I-95 south of the ICC, Contract D from the collector-distributor lanes along I-95 north of the ICC, and Contact E from I-95 to US Route-1.

The ICC project has addressed the environmental impact of construction by incorporating into construction contracts, a $370 million environmental mitigation and stewardship package. This package resulted from close coordination with, and guidance of almost 16 federal, state and local agencies. The package aims to not only minimize environmental impact from the ICC project itself but also correct environmental problems unrelated to the ICC caused by decades of past development in Montgomery and Prince George's Counties. The package will protect the environment via many methods including state-of the-art storm water and roadway controls, use of sound barriers, stream and park restorations, air quality studies and extensive reforestation.

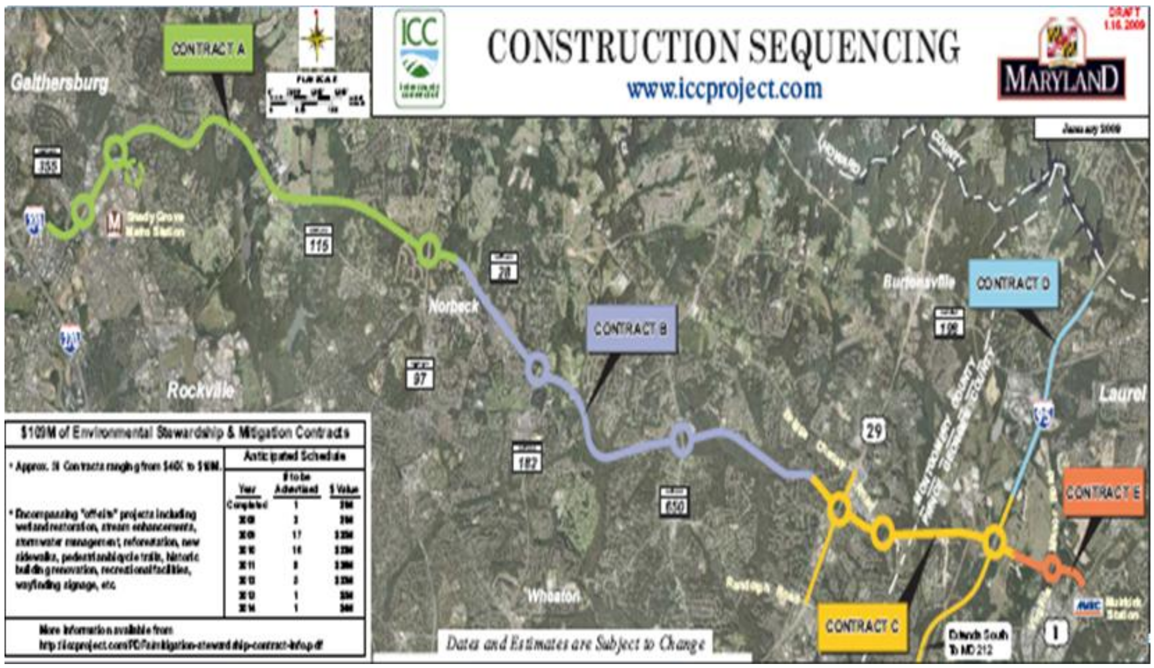

Figure 6-1. Map featuring the various segment of the ICC roadway project. *Source: ICC, 2010*

Contract A of this sequence is the furthest along in its construction and, therefore, was able to provide the greatest amount of input data for the model. Hence, it was chosen to illustrate the proposed tool's (carbon footprint estimation model) utility and potential benefits that can be derived from its application. Contract A is a 7.2 mile, 6-lane portion of the ICC, extending from I-370 and Georgia Avenue. Construction started in mid 2007. The roadway is due to open in early 2011 [ICC, 2010].

6.2 List of Data Obtained from the ICC Project

Data obtained from Contract A of the ICC project was used as input into the carbon footprint estimation model. This data was used directly or estimates from the data were made before feeding input into the model. The data was provided in two construction quarters: Quarter 1 extending from November 2007 to June 2009 and Quarter 2 extending from July 2009 to January 2010. The list of data provided for use in the model is listed in Table 6-1 below.

Table 6-1. Data provided for use in case study by ICC Contract A.

Name of Data File	Content of Data File
CPM Gantt Chart	Timeline of construction including estimated and completed task durations.
ICC Equipment Emissions Tracking Report	List of heavy equipment present on site by tier level and length on site.
Major Quantities	Volume and major quantities of materials placed on-site including total on-site fuel consumption.
Forest Map	Depicting and quantifying areas of deforestation and reforestation of entire project.
Chemicals List	List of chemicals delivered on site.
2002 Land Use File	Base mapping for the pre-ICC conditions.
Contract Document for ICC Reforestation at Seneca Creek State Creek Park / ICC Forest Mitigation Agreement	Lists contract provisions, terms and conditions for drainage, landscaping and utilities used and maintained post-construction in relation with the ICC environmental impact mitigation efforts.
Access and Mobility Plan	Blue-prints of project site depicting temporary roadways for access into and out of the site.

6.3 Estimates Made from ICC Project Data

The data received from the ICC project-Contract A was processed before it was fed into the model for emissions estimation. The inventory of equipment as provided were listed by equipment type, make, dates of arrival and exit from site, fuel type, and tier level classification. The 184 pieces of equipment on the list were categorized to fit the 33 equipment categories in the model. Moreover, based on the tier level of each piece of equipment, a maximum rated power (hp), and a median model year was assumed (refer to Section 5.3.2 and Table E-1 of Appendix E). The length of stay of equipment on-site was calculated from the entrance and exit dates provided in the inventory. Based on communication with the lead contractor, the activity duration of all equipment was estimated at 8 hours per day, 7 days per week. However, the exit dates listed in the inventory represented the reporting dates, and not the actual dates the equipment left the site. To accommodate for times equipment spent being stored on-site, and therefore, allow for a more accurate representation of the equipment activity on the project, the activity duration of all equipment was assumed to be at 6 hours per day, 7 days a week. Table M-1 of Appendix M lists the processed data used in the model to estimate emissions from equipment on the ICC Contract A site.

Since data related to types of forests were not available, it was assumed that all of the forest types found in the state of Maryland were involved; whereas, the data from the Forest Map was used to estimate the area of deforestation. The volume of soil moved was obtained from the Major Quantities list. However, an estimate for the surface area of the soil moved was made based on the assumption that 1m depth of organic soil was excavated from the site (i.e. Area = volume/depth). Collectively, this data was used as input into the site-preparation component of the carbon footprint estimation tool (Appendix N).

Inputs for the materials production component were also determined from the Major Quantities list in conjunction with information obtained from communication with the lead contractors. To estimate emissions from the use of concrete structures on-site, it was assumed that the cement used to make the concrete was produced on-site. 1 % of emissions from the cement production were used to determine emissions from concrete use on the ICC Contract A project site. Specifically, the quantities of place substructures concrete, place superstructures concrete, culvert wingwalls/headwalls, and bridge approach slabs were used to establish the amount of cement used on-site. This amount was determined based on the estimates of 377 lbs cement/ cubic yard substructure, and 459 lbs cement per cubic yard superstructure, as provided by the lead contractors. The cement estimate of 459 lbs cement per cubic yard of structure was extended to culverts and bridge slabs, as well. The quantities of asphalt, fertilizer, and other chemicals were not provided. Hence, an estimate of the contribution of these materials to total emissions was made in reporting the results of the analysis. Based on opinions from contractors, it was assumed that emissions from these materials account for 2% of cement emissions.

The Forest Mitigation Agreement provided number and types of trees that will be re-planted post construction. Although the Agreement provided this data for a few sites on contract A, not all of reforestation on Contract A was covered. In order to establish a more detailed representation of the ICC Contract A reforestation efforts, the total area of reforestation and tree spacing requirements for reforestation, as provided in the Forest Map and Mitigation Agreement, were used to estimate an approximate total number of trees re-planted. The number of trees was then divided appropriately amongst tree types in the mix of reforestation vegetation stated in the Mitigation Agreement.

Some trees, especially, floral and fruit trees listed in the Agreement, were entered in the model component by matching them with trees types of similar characteristics (e.g., type of foliage and size). Also, the ICC reforestation effort uses 6”-12” saplings, which corresponds to 0 years in the component, and hence the C-density values for tree types of age 0 years were used. The type of soil used to support reforestation was assumed to be a mixture of organic soils from all tree types found in Maryland, and therefore, an average of soil C-density was determined and used in calculating emissions sequestration by soil. A 1 m depth of re-soil was assumed to estimate the area of re-soil. Collectively, this data was used in the environmental mitigation component of the model to calculate emissions sequestered by reforestation. The input data and emissions calculations for this component are documented in Appendix P.

6.4 Results & Discussion

After the inputs are entered into the model, the model provides outputs for each component and calculates the net emissions from the ICC project. Since the primary purpose of this model is the estimation of GHGs from construction, the table only lists results in CO_2e; although, the equipment usage component and coatings/solvent sub-component quantifies other air pollutants, as well. A summary of these results are shown in Table 6-2 below.

Assuming that all equipment on-site was in use for 6 hours per day, 7 days per week, Contract A of the ICC Project emitted a net total of 493,227.17 MT CO_2e from the period beginning November 2007 to January 2010 (i.e. 2.5 years). Subsequently, Contract A of the ICC generated approximately 68,504 MT CO_2e per mile of roadway that was constructed. The calculations performed by each component on the ICC data are documented in Appendices M-P.

It must be noted that the model calculates net emissions for the entire project duration and not net annual emissions. Thus, the total impact of the construction project in terms of emissions was estimated. If a rudimentary comparison of the ICC annual average of emissions of 197,291 MT CO_2e per year (i.e. total emissions divided by 2.5 years) is made to annual emissions of 131 MMT of CO_2e (2006) by the entire U.S. construction industry [USEPA 2008], Contract A of the ICC project alone contributed approximately 0.2% annually to the national emissions from the industry.

The summary below shows that the majority of emissions from the ICC construction project under Contract A can be attributed to the use of equipment (83%). This is followed by site-preparation at 17%, and almost negligible materials production emissions at 0.0002% (Figure 6-2). The environmental mitigation efforts undertaken within Contract A offer minor carbon sequestration capabilities, accounting for only 4% of the total emissions (Table 6-2) generated by the other construction activities (i.e. site-preparation, equipment usage and materials production).

Table 6-2. Summary of results of ICC case study from the carbon foot-print estimation model.

Construction Process	Total Emissions (MT CO_2 or CO_2e/ project)
Site-Preparation	89,328.03
- *Deforestation*	43,394.58
- *Soil Movement*	45,933.45
Equipment Usage	421,689.27
Materials Production	117.72
- *Concrete**	39.24
- *Solvents, Asphalt & Fertilizers***	78.48
Environmental Mitigation	17,907.86
- *Reforestation*	681.72
- *Resoil*	17,226.14
TOTAL EMISSIONS PRODUCED	511,135.02
TOTAL EMISSIONS OFFSET	17,907.86 (4%)
NET EMISSIONS	493,227.17

**Assumes 1% of cement emissions due to lack of data, **Assumes 2% of cement emissions due to lack of data*

Within biogenic emissions sequestration, it is generally observed that organic soil absorb more carbon than trees did, particularly in the case of young trees (6-12” seedlings) as used in the reforestation efforts of the ICC. Soil systems are typically more stable and therefore, sequester more carbon over time as compared to young trees. If older trees be used for reforestation, the combined absorption of re-planted trees and organic soil would be substantial, as reflected in the reforestation C-density tables in Appendix K.

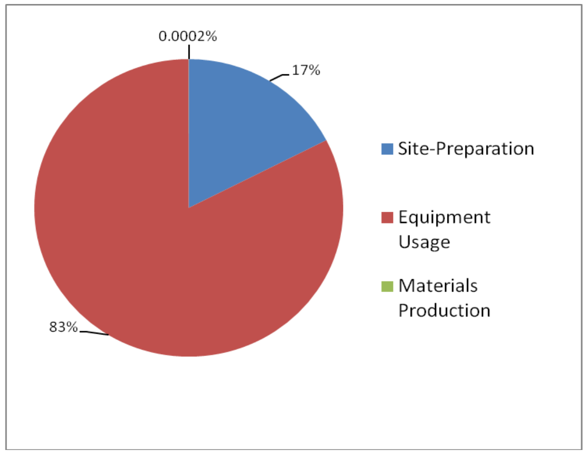

Figure 6-2. Chart illustrating the contribution of activities on the ICC Contract A to emissions produced.

Moreover, based on the mix of trees for reforestation, it would be beneficial to increase the number of trees that fall into the oak/pine category, since this category accounts for only 6 % of the vegetation population, but results in almost 11% of the total sequestration capacity achieved through reforestation on the project (Figure 6-3).

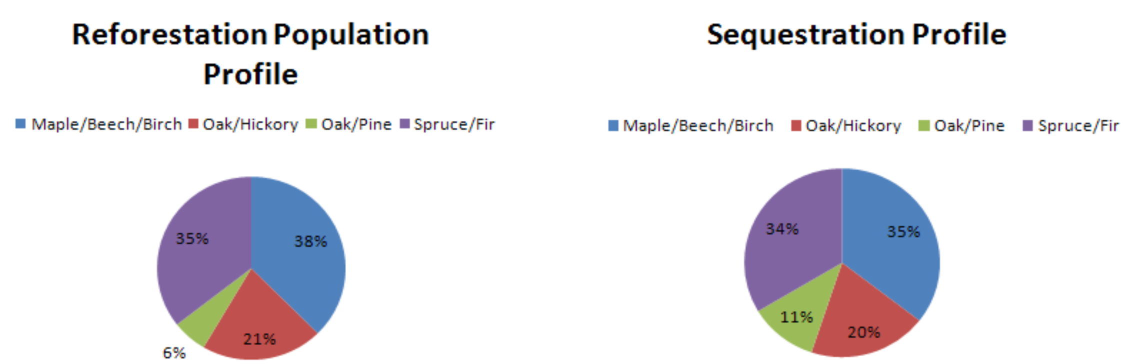

Figure 6-3. Comparison of population profile to sequestration profile of reforestation vegetation.

Results from the equipment usage component are listed in Table M-2 of Appendix M. The model estimated a total of 421,689 MT of CO_2e (GHGs), 0.9 MT of SOx and 101 MT of ROG (air pollutants) from the 184 pieces of equipment used on the project from the start to January 2010. Of the fleet of equipment on-site for the duration of the project, cranes, off-highway trucks, dozers and excavators contributed the most, accounted for 17%, 16%, 14% and 10% of the total emissions from equipment usage, respectively (Figure 6-4). Specifically, these top emitters included tier 1and 3 cranes, tier 3 excavators, tier 2 and 3 off-highway trucks, tier 2 dozers, and tier 2 tractors/loaders/backhoes, each producing greater than 25,000 MT CO_2e. Of these, tier 2

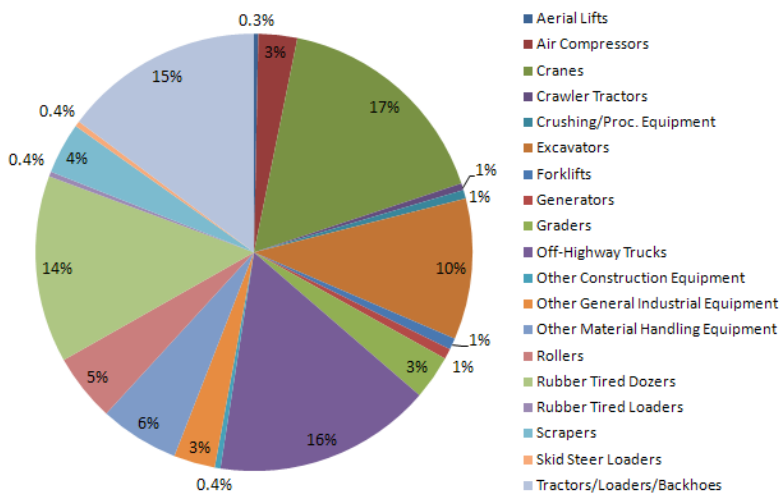

Figure 6-4. Emissions profile of the ICC Contract A equipment usage by equipment type.

dozers ranked the highest, emitting 38,000 MT CO_2e. Amongst the group of equipment that produced the least emissions were tier 2 aerial lifts, tier 2 forklifts, tier 3 rollers, and

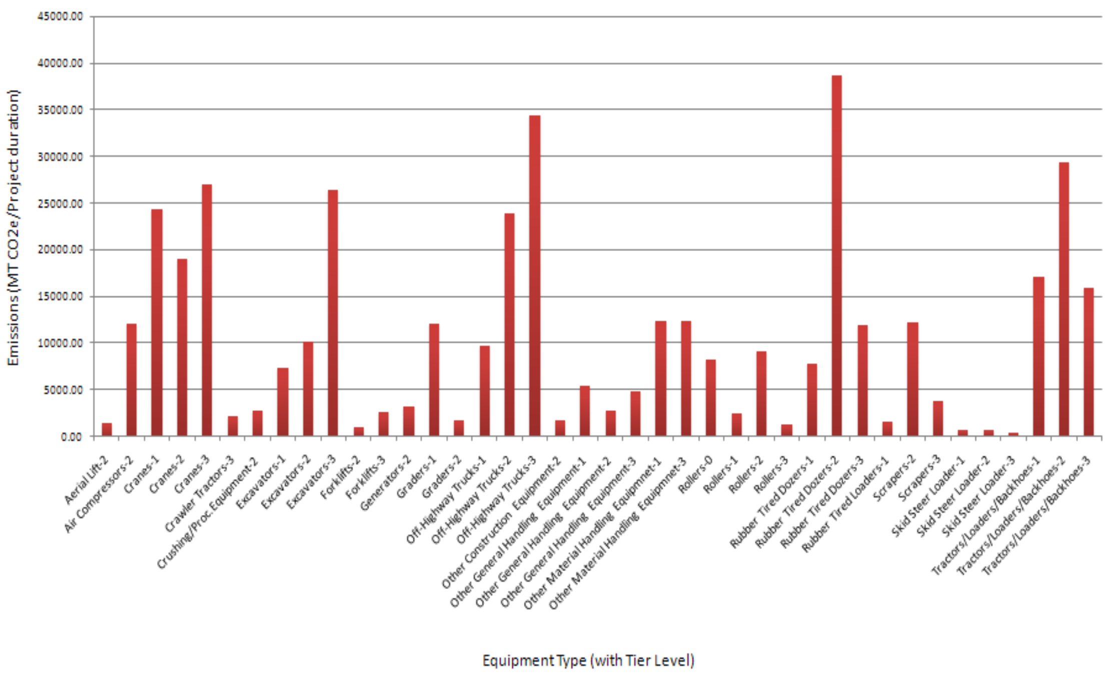

Figure 6-5. Total emissions produced on the ICC Contract A by equipment type

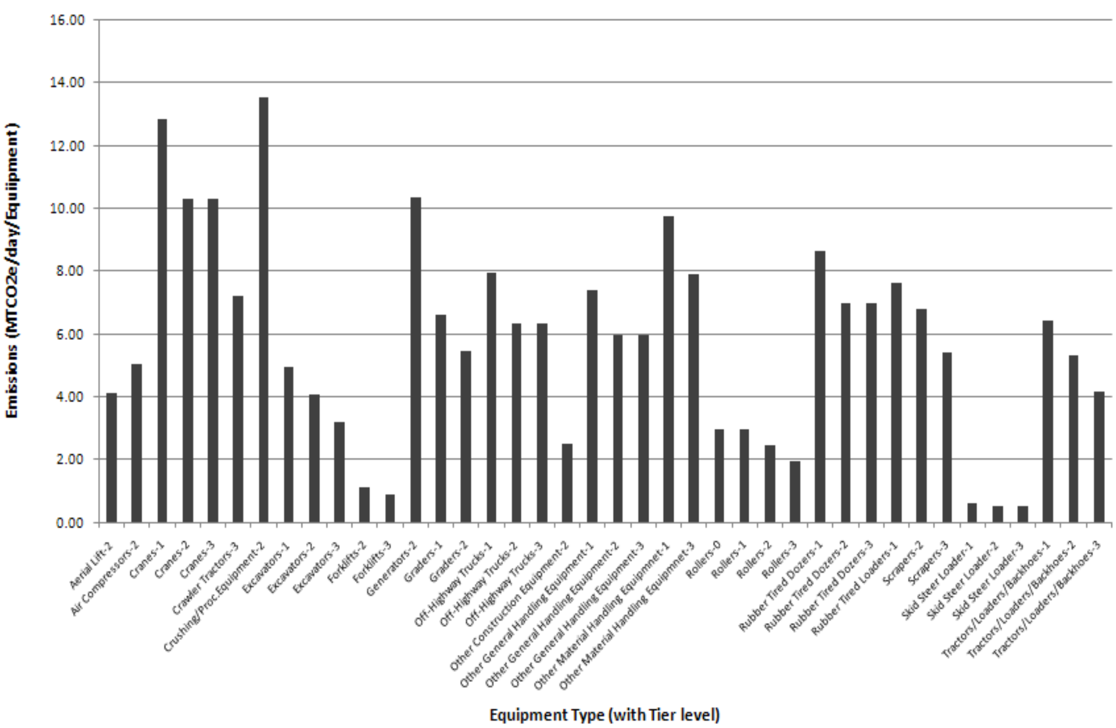

Figure 6-6. Emissions per equipment type on the ICC Contract A.

tier 1, 2 and 3 skid steered loaders. Within this group, each piece of equipment contributed less than 1,500 MT CO_2e (Figure 6-5).

It can be noticed that both groups of high and low emitting equipment, have equipment belonging to the higher tiers (1 and 2). The graph in Figure 6-6 depicting the emissions from individual equipment pieces shows that individually, cranes, crushing equipment, generators, and other material handling equipment are large emitters, while forklifts, skid steered loaders and rollers are amongst the lowest emitters. Moreover, a general trend can be reasonably deduced from the same graph that the equipment falling in the lowest tiers has the highest individual emissions, and that equipment in the highest tiers has lowest emissions. However, this general relationship is not always reflected in total emissions per equipment type (Figure 6-5). This is because, the number, and duration of stay of each piece of equipment belonging to an equipment category (i.e. type and tier level) vary within the Contract A fleet, and the variations are, thus, translated to variations in total emissions despite the tier level.

Additionally, this graph demonstrates that for each equipment type, emissions decrease with the increase in tier levels. Since emissions were estimated using the EF database created specifically for the carbon footprint estimation tool, this general trend implies that the PM analysis used to extend the database was reasonable (Chapter 5, section 5.3.2). Collectively, the emissions and the database used to calculate them are consistent with the concepts of the EPA tier system, where equipment in the higher tiers would emit less than equipment in their lower counterparts.

The equipment fleet on Contract A of the ICC was also categorized by tier levels to determine the contribution of each level to total emissions from equipment usage. Table 6-3 shows the average emissions per equipment type belonging to each tier level. It must be noted that these values are average estimates i.e. total emissions per tier divided by number of pieces of equipment per tier. Therefore, although the table depicts that tier 0 category account for the least emissions, it only represents one category of equipment (i.e. rollers), whereas, the other tier levels (tier 1 to 3) include a wide variety of equipment types. Hence, tiers 1 to 3 illustrate that emissions from the higher tier level equipment are typically less than those equipment belonging to lower tiers. This further supports the successful extension of the equipment usage component's database using PM analysis.

Table 6-3 Contribution of equipment emissions by tier level on the ICC Contract A site.

Tier Level	Number of pieces	% Total Equipment Population	Avg. Emissions per Equipment per Tier (MT of CO_2e/Equipment)
0	7	4	1174.50
1	34	18	2965.15
2	76	41	2232.40
3	67	36	2134.18
TOTAL	**184**	**100**	

Although several assumptions and estimates were made from the data obtained from the ICC to fit the model requirements, these were relatively easy to make and required minimal time. It must be noted that estimation of emissions was limited to those produced by activities performed on-site only. For example, emissions produced by movement of waste and materials to and from locations outside the construction site were not estimated.

However, the use of vehicles for purposes of materials transport within the ICC Contract A site was accounted for while calculating emissions from trucks used on-site.

The implication of the deforestation process and reforestation efforts (1:1) by the ICC was estimated by using the offset component of the carbon footprint estimation model for a variety of offset years. Specifically, the component was used to determine the extent of positive impact the ICC Contract A reforestation efforts had on diminishing the negative impact of deforestation. 5, 10, 20 and 30 years were used as the crediting time period to calculate potential offset. As seen in Table 6-4, for a 20 year crediting period, the deforestation on the project had a significant negative effect and the reforestation efforts would not be able to fully offset this impact. Also, with the increase in offset years, offset due to reforestation improves. For a 20 year offset period, the ICC Contract A would achieve a zero carbon footprint created by deforestation (i.e. net offset = 0) by re-planting 1,037,548 tree saplings.

An analysis of the annual sequestration rates of tree by their age as in Table 6-5 reveals that although the younger trees have a significantly higher sequestration rate than the older trees, the older trees still sequester more carbon annually than the younger trees. For example, between 5 and 10 offset years, the younger trees used in reforestation sequester 86% faster whereas the older trees sequestration rate only increases by 21%. However, for the same period, the older trees sequester almost six times more than the younger trees.

Table 6-4. Summary of offset determination for ICC Contract A.

Offset Period	Process (MT CO_2)			Purchase Credit? (Yes/No)
	Deforestation	Reforestation	Net Offset	
5	43469.5004	1491.7217	-42712.9429	Yes
10	43485.4085	2184.8203	-41300.5883	Yes
20	43519.491	3813.184	-39706.3066	Yes

Table 6-5. Analysis of annual sequestration rates of trees.

Offset Period	Age of Tree (years)		Annual Sequestration Rate (MT CO_2/tree)		Increase in Sequestration Rate (%)	
	Deforestation	Reforestation	Deforestation	Reforestation	Deforestation	Reforestation
5	28	5	0.01653	0.00291	21	86
10	33	10	0.02004	0.0054	38	108
20	43	20	0.02756	0.01125	n/a	n/a

Furthermore, the minor offset provided by reforestation may also be explained by the effect of units of measurements of the rates of growth of trees. For example, the average growth rate of a hardwood species in year 1 is 2.77 lbs/year/tree (0.00125 MT C/year/tree) and increases significantly in year 20 when the growth rate is 25 lbs/year/tree (0.00939 MT C/year/tree). However, this effect un-hinders the outcome that the ICC Contract would need to purchase carbon credits to offset the deforestation on the project, regardless of the duration of the offset period.

Chapter 7. Conclusions

As support for emissions reduction continues to grow, an increasing number of policies and regulations are being developed to encourage all industries to reduce their carbon footprint. With the construction industry ranking third in emissions production in the country, these policies are bound to have a significant effect on the industry, and will define how construction contracts are developed and chosen. Since the construction industry supports the development of the nation's long-standing infrastructures and other civil structures, the industry holds a novel position in facilitating the reduction of emissions from construction projects. Moreover, as public and political sentiment for greener ways strengthens, the construction industry will increase its support for greener construction practices. Thus, a green construction industry will not only aid national efforts to diminish the industry's environmental impact, but will also help improve the environment.

The carbon footprint estimation tool described herein was developed specifically to aid in the quantification of emissions from all major processes observed on a construction project such as, site-preparation, equipment usage, on-site materials production and environmental impact mitigation efforts, while meeting federally mandated programs such as the NCDC. It was developed to facilitate a construction agency's transition to accommodate efforts by this industry to go green and to meet future reduction programs (e.g., cap, tax, or imposition of stricter standards).

The tool was developed using the state-of-the-practice methodologies available nationally and is in accordance with global regulations under the IPCC Guidelines for National Greenhouse Gas Inventories. Several GHG models, research papers and national methodologies were studied to determine appropriate methods of estimation. Basic conceptual equations for emissions estimation were obtained and customized to calculate emissions specifically from construction projects. Additionally, extensive research was conducted to accumulate recent data from various sources such that the most accurate determination of these emissions can be made. Collectively, the proposed tool encompasses the most recent data available, and utilizes adapted equations for calculations and emission factors with high AP-42 ratings, in accordance with IPCC guidelines. The tool has been developed to function as a single, stand-alone tool specific to the estimation of all activities undertaken during a construction project.

The potential benefits of this tool are in the broad scope of its potential use in terms of its users, and its applications to a variety of project types and sizes. The tool may be used not only by construction agencies for purposes of emissions reduction, but also by federal and state agencies to monitor these agencies to comply with emission standards and rules. Moreover, the tool may be used by either independent contractors or design/build firms to estimate emissions from small projects, or by state DOT or environmental agency to support carbon footprint estimation of both large projects such as the construction of a roadway or smaller operations such as maintenance of roads.

The scope of the model is limited to estimating emissions due to process only within a construction site. Therefore, emissions produced due to transport of material outside the construction site are not accounted for in the model. Additionally, only the major materials that are produced on-site that are known to contribute high emissions, such as cement production, were accounted for in the model. Thus, the use of end product construction materials such as steel, insulation materials, etc. were not included in the model due to their inability to emit GHGs during their use on-site; although, GHGs are emitted during their production in the factory.

The results from the model would be primarily used to help agencies make decisions about emissions reduction strategies and identify sources of improvement in construction planning. The accuracy of the emissions estimates is dependent on the accuracy of the input data, and how the user accounts for the effect of variables on results.

Also, the tool ensures wide applicability, since it incorporates current standards and anticipates new regulations that might affect construction. With the potential establishment of the American Clean Energy and Security Act of 2009, which proposes a cap-and-trade system in the U.S., this tool will help contractors determine their base-line emissions (business as usual), and also the final project emissions after making appropriate modifications to the construction process that may produce offsets or enable purchase or sale of carbon allowances. Thus, the tool will enable the easy transition of contractors to a future involving a cap-and-trade system.

The proposed tool is also particularly advantageous in its extent of simplicity to the end-user. The tool has been configured to use minimal input data (via a set of drop-down menus), employing appropriate estimations and assumptions in calculating emissions. It is also flexible in performing emissions calculations should the user have access to more detailed information, as the model requires the user to classify the information to fit the categories in the tool. Furthermore, the databases and input data used in the model development are relevant nation-wide, ensuring the applicability of the model to projects over a large geographic extent.

The simplicity and effectiveness of this tool was demonstrated on the ICC case study, a major transportation infrastructure construction project undertaken by the Maryland State Highway Administration, where data that was easily obtained from the contractors was used to estimate the project's net emissions. The quantification of the ICC Contract A emissions highlighted the major sources of emissions on the project and subsequently emphasized the need to use construction management practices that support emissions reduction.

In conclusion, this research has provided a widely applicable tool that will specifically enable both private and government agencies in the construction industry to estimate and, thereby, reduce emissions and optimize processes used on most construction projects, especially those in the transportation sector .

Appendix A: GWP Values for all species of air pollutants as mandated by the IPCC.

Species	Chemical Formula	Lifetime (years)	Global Warming Potential (Time Horizon)		
			20 years	100 years	500 years
CO2	CO_2	variable	1	1	1
Methane	CH_4	12+/-3	56	21	6.5
Nitrous oxide	N_2O	120	280	310	170
HFC-23	CHF_3	264	9100	11700	9800
HFC-32	CH_2F_2	5.6	2100	650	200
HFC-41	CH_3F	3.7	490	150	45
HFC-43-10mee	$C_5H_2F_{10}$	17.1	3000	1300	400
HFC-125	C_2HF_5	32.6	4600	2800	920
HFC-134	$C_2H_2F_4$	10.6	2900	1000	310
HFC-134a	CH_2FCF_3	14.6	3400	1300	420
HFC-152a	$C_2H_4F_2$	1.5	460	140	42
HFC-143	$C_2H_3F_3$	3.8	1000	300	94
HFC-143a	$C_2H_3F_3$	48.3	5000	3800	1400
HFC-227ea	C_3HF_7	36.5	4300	2900	950
HFC-236fa	$C_3H_2F_6$	209	5100	6300	4700
HFC-245ca	$C_3H_3F_5$	6.6	1800	560	170
Sulfur hexfluoride	SF_6	3200	16300	23900	34900
Perfluromenthane	CF_4	50000	4400	6500	10000
Perfluroethane	C_2F_6	10000	6200	9200	14000
Perfluropropane	C_3F_8	2600	4800	7000	10100
Perflurobutane	C_3F_{10}	2600	4800	7000	10100
Perflurocyclobutane	$c\text{-}C_4F_8$	3200	6000	8700	12700
Perfluropentane	C_5F_{12}	4100	5100	7500	11000
Perflurohexane	C_6F_{14}	3200	5000	7400	10700

Source: IPCC, 2007

Appendix B: Nonroad exhaust emissions standards: EPA tier system.

Rated Power (kW)	Tier	Model year	NMHC	NMHC+NOx	NOx	PM	CO	Smoke Percentage
			(g/kW-hr)					
kW < 8	1	2000-2004	-	10.5	-	1	8	20/15/50
	2	2005-2007	-	7.5	-	0.8	8	
	4	2008+	-	7.5	-	0.4	8	
8 ≤ kW < 19	1	2000-2004	-	9.5	-	0.8	6.6	
	2	2005-2007	-	7.5	-	0.8	6.6	
	4	2008+	-	7.5	-	0.4	6.6	
19 ≤ kW < 37	1	1999-2003	-	9.5	-	0.8	5.5	
	2	2004-2007	-	7.5	-	0.6	5.5	
	4	2008-2012	-	7.5	-	0.3	5.5	
37 ≤ kW < 56	1	1998-2003	-	-	9.2	-	-	
	2	2004-2007	-	7.5	-	0.4	5	
	3	2008-2011	-	4.7	-	0.4	5	
	4	2008-2012	-	4.7	-	0.3	5	
56 ≤ kW < 75	1	1998-2003	-	-	9.2	-	-	
	2	2004-2007	-	7.5	-	0.4	5	
	3	2008-2011	-	4.7	-	0.4	5	
	4	2012-2013	-	4.7	-	0.02	5	
75 ≤ kW < 130	1	1997-2002	-	-	9.2	-	-	
	2	2003-2006	-	6.6	-	0.3	5	
	3	2007-2011	-	4	-	0.3	5	
	4	2012-2013	-	4	-	0.02	5	
130 ≤ kW < 225	1	1996-2002	1.3	-	9.2	0.54	11.4	

	2	2003-2005	-	6.6	-	0.2	3.5	
	3	2006-2010	-	4	-	0.2	3.5	
	4	2011-2013	-	4	-	0.02	3.5	
225 ≤ kW < 450	1	1996-2000	1.3	-	9.2	0.54	11.4	
	2	2001-2005	-	6.4	-	0.2	3.5	
	3	2006-2010	-	4	-	0.2	3.5	
	4	2011-2013	-	4	-	0.02	3.5	
450 ≤ kW < 560	1	1996-2001	1.3	-	9.2	0.54	11.4	
	2	2002-2005	-	6.4	-	0.2	3.5	
	3	2006-2010	-	4	-	0.2	3.5	
	4	2011-2013	-	4	-	0.02	3.5	
560 ≤ kW < 900	1	2000-2005	1.3	-	9.2	0.54	11.4	
	2	2006-2010	-	6.4	-	0.2	3.5	
	4	2011-2014	0.4	-	3.5	0.1	3.5	
kW > 900	1	2000-2005	1.3	-	9.2	0.54	11.4	
	2	2006-2010	-	6.4	-	0.2	3.5	
	4	2011-2014	0.4	-	3.5	0.1	3.5	

Source: USEPA, 2009e

Appendix C: Database used in site-preparation component of carbon footprint estimation model.

REGION	FOREST TYPE	CARBON DENSITY (MT/ha)	
		NON-SOIL	SOIL
Northeast (CT,DE,MA,MD,ME,NH,NJ,NY,OH,PA,RI,VT,WV)	White/Red/Jack Pine	135.8	78.1
	Spruce/Fir	104.2	98
	Oak/Pine	127.1	66.9
	Oak/Hickory	115	53.1
	Elm/Ash/Cottonwood	96.2	111.7
	Maple/Beech/Birch	129.4	69.6
	Aspen/Birch	72.6	87.4
	Minor Types & Nonstocked	80.1	82.7
	All	118.2	69.7
Northern Lake States (MI,MN,WI)	White/Red/Jack Pine	86.6	120.8
	Spruce/Fir	89.9	261.8
	Oak/Hickory	103.8	97.1
	Elm/Ash/Cottonwood	94.6	179.9
	Maple/Beech/Birch	121.5	134.3
	Aspen/Birch	65.6	146.1
	Minor Types & Nonstocked	62.4	125.8
	All	92.2	152.9

Northern Prairie States ((IA,IL,IN,KS,MO,ND,NE,SD)	Ponderosa Pine	70.7	48.5
	Oak/Pine	94.1	39.9
	Oak/Hickory	100.1	48.9
	Elm/Ash/Cottonwood	121.2	83.2
	Maple/Beech/Birch	111.4	70.7
	Minor Types & Nonstocked	61.7	57.5
	All	99.8	55.7
South Central (AL,AR,KY,LA,MS,OK,TN,TX)	Longleaf/Slash Pine	64	55.5
	Loblolly/Shortleaf Pine	69.7	41.9
	Oak/Pine	72.6	41.7
	Oak/Hickory	88.6	38.6
	Oak/Gum/Cypress	108.1	52.8
	Elm/Ash/Cottonwood	78.7	49.9
	Minor Types & Nonstocked	60.9	49.6
	All	81.5	42.7
Southeast (FL,GA,NC,SC,VA)	Longleaf/Slash Pine	54.8	110
	Loblolly/Shortleaf Pine	73.7	72.9
	Oak/Pine	76.7	61.4
	Oak/Hickory	100.4	45.3
	Oak/Gum/Cypress	104.2	158
	Elm/Ash/Cottonwood	83.7	95.7
	Minor Types & Nonstocked	65.1	101.4

	All	84.6	78.1
Coastal Alaska	Fir/Spruce/Mt.Hemlock	177.5	62.1
	Lodgepole Pine	83.9	52
	Hemlock/Sitka Spruce	251	116.3
	Aspen/Birch	61.2	42.5
	Minor Types & Nonstocked	171.2	77.3
	All	196.6	89.7
Pacific Northwest, Westside (Western OR & WA)	Douglas-fir	238.7	94.8
	Fir/Spruce/Mt.Hemlock	261.6	62.1
	Hemlock/Sitka Spruce	295.7	116.3
	Alder/Maple	129.9	115.2
	Minor Types & Nonstocked	104.2	85.7
	All	222.5	95.5
Pacific Northwest, Eastside (Eastern OR & WA)	Pinyon/Juniper	38.2	46.9
	Douglas-fir	146.7	94.8
	Ponderosa Pine	91.3	50.7
	Fir/Spruce/Mt.Hemlock	176	62.1
	Lodgepole Pine	82.1	52
	Western Larch	133	45.1
	Minor Types & Nonstocked	82.5	81.9
	All	110	64.4
Pacific Southwest (CA)	Pinyon/Juniper	49.2	26.3

	Douglas-fir	265.1	40.1
	Ponderosa Pine	120.6	41.3
	Fir/Spruce/Mt.Hemlock	267.9	51.9
	Lodgepole Pine	183.6	35.2
	Redwood	347.6	53.8
	California Mixed Conifer	224.5	49.8
	Western Oak	114.5	27.6
	Tanoak/Laurel	207.4	27.6
	Minor Types & Nonstocked	94.7	40.1
	All	160.7	37.6
Rocky Mountain, North (ID,MT)	Douglas-fir	139.5	38.8
	Ponderosa Pine	79.9	34.3
	Fir/Spruce/Mt.Hemlock	140.5	44.1
	Lodgepole Pine	96.1	37.2
	Western Larch	124.8	34.2
	Minor Types & Nonstocked	73.1	43.2
	All	113.7	40.1
Rocky Mountain, South (AZ,CO,NM,NV,UT,WY)	Pinyon/Juniper	49.7	19.7
	Douglas-fir	144.7	30.9
	Ponderosa Pine	89.7	24.1
	Fir/Spruce/Mt.Hemlock	158.7	31.5
	Lodgepole Pine	101.6	27

	Aspen/Birch	110.2	58.8
	Western Oak	53.5	38
	Minor Types & Nonstocked	50.6	25.6
	All	75.8	26.7

Source: USEPA, 2009a

Appendix D: Summary of extrapolation trend as applied to model year & rated power in equipment usage emission factor database.

Applicable Rated Power Range	2007-2006	2006-2005	2005-2004	2004-2003	2003-2002	2002-2001	2001-2000	2000-1999	1999-1998	1998-1997	1997-1996	1996-1995
>11 to 25 hp	same	same	21	same	same	same	same	21	same	same	same	same
>25-50 hp	same	same	same	21	same	same	same	same	21	same	same	same
>100-175 hp	21	same	same	same	21	same	same	same	same	same	21	same
>175-300 hp	same	21	same	same	21	same	same	same	same	same	same	21
>300-600 hp	same	21	same	same	same	same	21	same	same	same	same	21
>600-750 hp	same	21	same	same	same	21	same	same	same	same	same	21
>750-1200 hp	same	21	same	same	same	same	same	21	same	same	same	same
>1210-9999 hp	same	21	same	same	same	same	same	21	same	same	same	same

Appendix E: Analysis of EPA tier system's PM standards used to determine extrapolation trend for equipment usage emission factor database.

0-11 hp

for reference			Pollutant (g/bhp-hr)	% difference /yr
Tier	**Start Year**	**End year**	**PM**	**PM**
	1988	1999	1	25
1	2000	2004	0.75	20
2	2005	2007	0.6	
3	-	-		

11-25 hp

for reference			Pollutant (g/bhp-hr)	% difference /yr
Tier	**Start Year**	**End year**	**PM**	**PM**
	1988	1999	0.8	25
1	2000	2004	0.6	0
2	2005	2007	0.6	
3				

25-50 hp

for reference			Pollutant (g/bhp-hr)	% difference /yr
Tier	**Start Year**	**End year**	**PM**	**PM**
	1988	1998	0.8	25
1	1999	2003	0.6	25
2	2004	2007	0.45	
3	-	-		

50-75 hp

for reference			Pollutant (g/bhp-hr)	% difference /yr
Tier	**Start Year**	**End year**	**PM**	**PM**
	1988	1997	0.72	16.67
1	1998	2003	0.6	50
2	2004	2007	0.3	0
3	2008	2011	0.3	

75-100 hp

for reference			Pollutant (g/bhp-hr)	% difference /yr
Tier	**Start Year**	**End year**	**PM**	**PM**
	1988	1997	0.72	16.67
1	1998	2003	0.6	50
2	2004	2007	0.3	0
3	2008	2011	0.3	

100-175 hp

for reference			Pollutant (g/bhp-hr)	% difference /yr
Tier	**Start Year**	**End year**	**PM**	**PM**
	1988	1996	0.4	-50
1	1997	2002	0.6	63.33
2	2003	2006	0.22	0
3	2007	2011	0.22	

175-300 hp

for reference			Pollutant (g/bhp-hr)	% difference /yr
Tier	**Start Year**	**End year**	**PM**	**PM**
	1988	1995	0.4	0
1	1996	2002	0.4	62.5
2	2003	2005	0.15	0
3	2006	2010	0.15	

300-600 hp

for reference			Pollutant (g/bhp-hr)	% difference /yr
Tier	**Start Year**	**End year**	**PM**	**PM**
	1988	1995	0.4	0
1	1996	2000	0.4	62.5
2	2001	2005	0.15	0
3	2006	2010	0.15	

600-750 hp

for reference			Pollutant (g/bhp-hr)	% difference /yr
Tier	**Start Year**	**End year**	**PM**	**PM**
	1988	1995	0.4	0
1	1996	2001	0.4	62.5
2	2002	2005	0.15	0
3	2006	2010	0.15	

750-1200 hp

for reference			Pollutant (g/bhp-hr)	% difference /yr
Tier	**Start Year**	**End year**	**PM**	**PM**
	1988	1999	0.4	0
1	2000	2005	0.4	62.5
2	2006	2010	0.15	
3	-	-	-	

1200-9999 hp

for reference			Pollutant (g/bhp-hr)	% difference /yr
Tier	**Start Year**	**End year**	**PM**	**PM**
	1988	1999	0.4	0
1	2000	2005	0.4	62.5
2	2006	2010	0.15	
3	-	-	-	

Average % increase = 20.68452

Source: USEPA, 2009c

Appendix F: Intermediary database used to estimate median model year by tier level & maximum rated power by equipment type based on the EPA tier system.

Table F-1. Database used to estimate median model year

EPA Tier	EPA Rated Power Range		EPA Model Year Range		Database Med. Yr
	Min Hp	Max Hp	Start Year	End Year	
1	0	11	2000	2004	2002
1	11	25	2000	2004	2002
1	25	50	1999	2003	2001
1	50	75	1998	2003	2000
1	75	100	1998	2003	2000
1	100	175	1997	2002	1999
1	175	300	1996	2002	1999
1	300	600	1996	2000	1998
1	600	750	1996	2001	1998
1	750	1200	2000	2005	2002
1	1200	9999	2000	2005	2002
2	0	11	2005	2007	2006
2	11	25	2005	2007	2006
2	25	50	2004	2007	2005
2	50	75	2004	2007	2005
2	75	100	2004	2007	2005
2	100	175	2003	2006	2004
2	175	300	2003	2005	2004
2	300	600	2001	2005	2003
2	600	750	2002	2005	2003
2	750	1200	2006	2010	2008
2	1200	9999	2006	2010	2008
3	0	11	-	-	2008*
3	11	25	-	-	2008*
3	25	50	-	-	2008*
3	50	75	2008	2011	2009
3	75	100	2008	2011	2009
3	100	175	2007	2011	2009
3	175	300	2006	2010	2008
3	300	600	2006	2010	2008
3	600	750	2006	2010	2008
3	750	1200	-	-	2008*
3	1200	9999	-	-	2008*

4	0	11	2008	CY	2008
4	11	25	2008	CY	2008
4	25	50	2008	2012	2010
4	50	75	2008	2012	2010
4	75	100	2012	2013	2012
4	100	175	2012	2013	2012
4	175	300	2011	2013	2012
4	300	600	2011	2013	2012
4	600	750	2011	2013	2012
4	750	1200	2011	2014	2012
4	1200	9999	2011	2014	2012

Note: Median year was determined by calculating the arithmetic mean of model years.

2008: Assumed due to lack of data to be model year 2008 based on previous tier levels*

Source: USEPA, 2009c

Table F-2. Database used to estimate maximum rated power of equipment

Equipment List	Min. Hp	Min. Hp
Aerial Lifts	15	750
Air Compressors	15	1000
Bore/Drill Rigs	15	1000
Cement/Mortar Mixers	15	25
Concrete/Industrial Saws	25	175
Cranes	50	9999
Crawler Tractors	50	1000
Crushing/Proc. Equipment	50	9999
Dumpers/Tenders	0	25
Excavators	25	750
Forklifts	50	500
Generators	15	9999
Graders	50	750
Off-Highway Tractors	120	1000
Off-Highway Trucks	175	1000
Other Construction Equipment	15	500
Other General Industrial Equipment	15	1000
Other Material Handling Equipment	50	9999
Pavers	25	500
Paving Equipment	25	250
Plate Compactors	0	15
Pressure Washers	15	120
Pumps	15	9999
Rollers	15	500
Rough Terrain Forklifts	50	500
Rubber Tired Dozers	175	1000
Rubber Tired Loaders	25	1000
Scrapers	120	750
Signal Boards	15	250
Skid Steer Loaders	25	120
Surfacing Equipment	50	750
Sweepers/Scrubbers	15	250
Tractors/Loaders/Backhoes	25	750
Trenchers	15	750
Welders	15	500

Source: USEPA,2009c & USEPA,2004

Appendix G: Example of emission factor database for equipment usage component (2006) of carbon footprint estimation model.

Year	Equipment	MaxHP	ROG	CO	NOX	SOX	CO2	CH4
2006	Aerial Lifts	15	0.0120	0.0539	0.0784	0.0001	8.6527	0.0011
2006	Aerial Lifts	25	0.0268	0.0678	0.1103	0.0001	10.9601	0.0024
2006	Aerial Lifts	50	0.0867	0.2042	0.2062	0.0003	19.6128	0.0078
2006	Aerial Lifts	120	0.0990	0.3101	0.6183	0.0005	46.0669	0.0089
2006	Aerial Lifts	500	0.1827	0.7381	2.2160	0.0021	212.8560	0.0165
2006	Aerial Lifts	750	0.3397	1.3341	4.1001	0.0039	384.7561	0.0306
2006	Air Compressors	15	0.0163	0.0539	0.0928	0.0001	7.2231	0.0015
2006	Air Compressors	25	0.0376	0.0934	0.1473	0.0002	14.4462	0.0034
2006	Air Compressors	50	0.1306	0.2933	0.2468	0.0003	22.2713	0.0118
2006	Air Compressors	120	0.1402	0.4132	0.8182	0.0007	56.8098	0.0126
2006	Air Compressors	175	0.1736	0.6232	1.3888	0.0012	107.0646	0.0157
2006	Air Compressors	250	0.1459	0.4071	1.6003	0.0015	131.2199	0.0132
2006	Air Compressors	500	0.2288	0.8865	2.5465	0.0023	231.7415	0.0206
2006	Air Compressors	750	0.3607	1.3701	4.0281	0.0036	358.1459	0.0325
2006	Air Compressors	1000	0.6027	2.3256	6.5406	0.0049	486.3562	0.0544
2006	Bore/Drill Rigs	15	0.0124	0.0632	0.0788	0.0002	10.3456	0.0011
2006	Bore/Drill Rigs	25	0.0222	0.0689	0.1397	0.0002	15.9887	0.0020
2006	Bore/Drill Rigs	50	0.0980	0.2886	0.2959	0.0004	31.0368	0.0088
2006	Bore/Drill Rigs	120	0.1461	0.6063	1.0179	0.0011	93.3174	0.0132
2006	Bore/Drill Rigs	175	0.1673	0.9122	1.5628	0.0019	170.7025	0.0151
2006	Bore/Drill Rigs	250	0.1125	0.3532	1.6315	0.0021	188.1019	0.0102

2006	Bore/Drill Rigs	500	0.1628	0.5678	2.2334	0.0031	311.3085	0.0147
2006	Bore/Drill Rigs	750	0.3368	1.1219	4.6545	0.0062	615.0932	0.0304
2006	Bore/Drill Rigs	1000	0.7011	1.9338	9.8820	0.0093	928.2825	0.0633
2006	Cement and Mortar Mixers	15	0.0092	0.0399	0.0596	0.0001	6.3202	0.0008
2006	Cement and Mortar Mixers	25	0.0428	0.1084	0.1763	0.0002	17.5562	0.0039
2006	Concrete/Industrial Saws	25	0.0215	0.0689	0.1402	0.0002	16.4777	0.0019
2006	Concrete/Industrial Saws	50	0.1513	0.3517	0.3238	0.0004	30.2092	0.0136
2006	Concrete/Industrial Saws	120	0.2001	0.6234	1.2327	0.0011	89.7212	0.0181
2006	Concrete/Industrial Saws	175	0.2827	1.0816	2.3817	0.0022	193.8421	0.0255
2006	Cranes	50	0.1555	0.3455	0.2666	0.0003	23.1867	0.0140
2006	Cranes	120	0.1619	0.4664	0.9277	0.0007	60.6790	0.0146
2006	Cranes	175	0.1715	0.6019	1.3320	0.0011	97.2170	0.0155
2006	Cranes	250	0.1478	0.4119	1.4665	0.0013	112.1589	0.0133
2006	Cranes	500	0.2121	0.8483	2.1049	0.0018	180.1013	0.0191
2006	Cranes	750	0.3600	1.4213	3.6197	0.0030	303.0446	0.0325
2006	Cranes	9999	1.2786	5.2275	13.5665	0.0098	970.6057	0.1154
2006	Crawler Tractors	50	0.1727	0.3812	0.2897	0.0003	24.8796	0.0156
2006	Crawler Tractors	120	0.2232	0.6313	1.2752	0.0009	79.6308	0.0201
2006	Crawler Tractors	175	0.2730	0.9455	2.1014	0.0016	146.6372	0.0246
2006	Crawler Tractors	250	0.2386	0.6707	2.2824	0.0019	166.1316	0.0215
2006	Crawler Tractors	500	0.3324	1.5264	3.1976	0.0025	259.2295	0.0300
2006	Crawler Tractors	750	0.5988	2.7193	5.8408	0.0047	464.6869	0.0540
2006	Crawler Tractors	1000	0.9273	4.2839	9.5523	0.0066	658.1057	0.0837
2006	Crushing/Proc. Equipment	50	0.2623	0.5917	0.4879	0.0006	44.0158	0.0237
2006	Crushing/Proc. Equipment	120	0.2481	0.7371	1.4427	0.0012	100.6006	0.0224
2006	Crushing/Proc. Equipment	175	0.3277	1.1882	2.6047	0.0023	202.3848	0.0296

2006	Crushing/Proc. Equipment	250	0.2682	0.7429	2.9565	0.0028	244.5324	0.0242
2006	Crushing/Proc. Equipment	500	0.3634	1.3803	4.0348	0.0037	373.6455	0.0328
2006	Crushing/Proc. Equipment	750	0.5796	2.0915	6.5366	0.0059	588.8341	0.0523
2006	Crushing/Proc. Equipment	9999	1.6038	5.9800	17.5501	0.0131	1307.7594	0.1447
2006	Dumpers/Tenders	25	0.0137	0.0383	0.0709	0.0001	7.6244	0.0012
2006	Excavators	25	0.0206	0.0677	0.1353	0.0002	16.4401	0.0019
2006	Excavators	50	0.1510	0.3526	0.2778	0.0003	25.0176	0.0136
2006	Excavators	120	0.2161	0.6660	1.2470	0.0010	89.0839	0.0195
2006	Excavators	175	0.2169	0.8177	1.6815	0.0015	135.7881	0.0196
2006	Excavators	250	0.1726	0.4642	1.8559	0.0018	158.6827	0.0156
2006	Excavators	500	0.2295	0.7653	2.3809	0.0023	233.7354	0.0207
2006	Excavators	750	0.3841	1.2645	4.0758	0.0039	387.4146	0.0347
2006	Forklifts	50	0.0932	0.2119	0.1643	0.0002	14.6719	0.0084
2006	Forklifts	120	0.0951	0.2828	0.5274	0.0004	37.7821	0.0086
2006	Forklifts	175	0.1130	0.4045	0.8499	0.0008	67.8258	0.0102
2006	Forklifts	250	0.0762	0.1920	0.8930	0.0009	77.1218	0.0069
2006	Forklifts	500	0.0988	0.2777	1.1190	0.0011	110.9801	0.0089
2006	Generator Sets	15	0.0198	0.0761	0.1277	0.0002	10.2077	0.0018
2006	Generator Sets	25	0.0349	0.1140	0.1798	0.0002	17.6314	0.0032
2006	Generator Sets	50	0.1294	0.3076	0.3197	0.0004	30.6230	0.0117
2006	Generator Sets	120	0.1982	0.6274	1.2509	0.0011	94.3188	0.0179
2006	Generator Sets	175	0.2353	0.9158	2.0495	0.0019	171.7950	0.0212
2006	Generator Sets	250	0.1982	0.5974	2.3843	0.0024	212.5050	0.0179
2006	Generator Sets	500	0.2824	1.1211	3.4731	0.0033	336.8529	0.0255
2006	Generator Sets	750	0.4695	1.8098	5.7390	0.0055	543.7900	0.0424
2006	Generator Sets	9999	1.1949	4.4076	13.2584	0.0105	1048.6050	0.1078

2006	Graders	50	0.1733	0.3929	0.3101	0.0004	27.5381	0.0156
2006	Graders	120	0.2302	0.6845	1.3340	0.0011	90.7075	0.0208
2006	Graders	175	0.2508	0.9124	1.9672	0.0017	149.9450	0.0226
2006	Graders	250	0.2088	0.5808	2.1482	0.0019	172.1132	0.0188
2006	Graders	500	0.2487	0.9672	2.5414	0.0023	229.4842	0.0224
2006	Graders	750	0.5320	2.0374	5.5148	0.0049	485.7415	0.0480
2006	Off-Highway Tractors	120	0.3424	0.9345	1.9532	0.0013	113.4223	0.0309
2006	Off-Highway Tractors	175	0.3195	1.0696	2.4452	0.0018	157.8050	0.0288
2006	Off-Highway Tractors	250	0.2149	0.6125	1.9515	0.0015	130.4173	0.0194
2006	Off-Highway Tractors	750	0.8341	4.3552	7.8223	0.0057	568.1303	0.0753
2006	Off-Highway Tractors	1000	1.2771	6.7362	12.5734	0.0082	814.2930	0.1152
2006	Off-Highway Trucks	175	0.2533	0.9314	1.9216	0.0017	151.3562	0.0229
2006	Off-Highway Trucks	250	0.1933	0.5096	1.9993	0.0019	166.5454	0.0174
2006	Off-Highway Trucks	500	0.2870	0.9451	2.8530	0.0027	272.3339	0.0259
2006	Off-Highway Trucks	750	0.4689	1.5279	4.7727	0.0044	441.7384	0.0423
2006	Off-Highway Trucks	1000	0.7528	2.6058	8.3284	0.0063	624.7241	0.0679
2006	Other Construction Equipment	15	0.0121	0.0617	0.0770	0.0002	10.1073	0.0011
2006	Other Construction Equipment	25	0.0183	0.0570	0.1155	0.0002	13.2173	0.0017
2006	Other Construction Equipment	50	0.1356	0.3262	0.2942	0.0004	27.9896	0.0122
2006	Other Construction Equipment	120	0.2070	0.6785	1.2801	0.0011	97.8391	0.0187
2006	Other Construction Equipment	175	0.1772	0.7206	1.4894	0.0015	128.8842	0.0160
2006	Other Construction Equipment	500	0.2095	0.7692	2.4473	0.0025	254.2385	0.0189
2006	Other General Industrial Equipment	15	0.0067	0.0391	0.0470	0.0001	6.3955	0.0006
2006	Other General Industrial Equipment	25	0.0192	0.0632	0.1266	0.0002	15.3491	0.0017
2006	Other General Industrial Equipment	50	0.1476	0.3260	0.2499	0.0003	21.7446	0.0133
2006	Other General Industrial Equipment	120	0.2022	0.5754	1.1296	0.0009	75.0636	0.0182

2006	Other General Industrial Equipment	175	0.2064	0.7115	1.5747	0.0013	116.0777	0.0186
2006	Other General Industrial Equipment	250	0.1630	0.4366	1.7266	0.0015	135.5838	0.0147
2006	Other General Industrial Equipment	500	0.2851	1.0467	3.0123	0.0026	265.4117	0.0257
2006	Other General Industrial Equipment	750	0.4755	1.7251	5.0871	0.0044	437.4497	0.0429
2006	Other General Industrial Equipment	1000	0.7280	2.7744	7.7949	0.0056	559.6030	0.0657
2006	Other Material Handling Equipment	50	0.2034	0.4495	0.3473	0.0004	30.3346	0.0184
2006	Other Material Handling Equipment	120	0.1960	0.5598	1.1003	0.0009	73.4097	0.0177
2006	Other Material Handling Equipment	175	0.2604	0.9007	1.9959	0.0017	147.7145	0.0235
2006	Other Material Handling Equipment	250	0.1729	0.4654	1.8395	0.0016	145.0140	0.0156
2006	Other Material Handling Equipment	500	0.2038	0.7541	2.1690	0.0019	191.6257	0.0184
2006	Other Material Handling Equipment	9999	0.9597	3.6689	10.2941	0.0073	741.3470	0.0866
2006	Pavers	25	0.0368	0.0997	0.1770	0.0002	18.6597	0.0033
2006	Pavers	50	0.1881	0.4131	0.3234	0.0004	27.9896	0.0170
2006	Pavers	120	0.2324	0.6570	1.3518	0.0010	83.7277	0.0210
2006	Pavers	175	0.2859	0.9939	2.2456	0.0017	155.2254	0.0258
2006	Pavers	250	0.2844	0.8186	2.7050	0.0022	194.3719	0.0257
2006	Pavers	500	0.3028	1.4943	2.9397	0.0023	233.2463	0.0273
2006	Paving Equipment	25	0.0175	0.0544	0.1103	0.0002	12.6279	0.0016
2006	Paving Equipment	50	0.1593	0.3498	0.2759	0.0003	23.9266	0.0144
2006	Paving Equipment	120	0.1817	0.5139	1.0591	0.0008	65.9442	0.0164
2006	Paving Equipment	175	0.2229	0.7759	1.7596	0.0014	122.2381	0.0201
2006	Paving Equipment	250	0.1774	0.5124	1.6935	0.0014	122.2913	0.0160
2006	Plate Compactors	15	0.0054	0.0263	0.0351	0.0001	4.3138	0.0005
2006	Pressure Washers	15	0.0095	0.0365	0.0612	0.0001	4.8906	0.0009
2006	Pressure Washers	25	0.0142	0.0462	0.0729	0.0001	7.1479	0.0013
2006	Pressure Washers	50	0.0491	0.1223	0.1449	0.0002	14.2957	0.0044

2006	Pressure Washers	120	0.0560	0.1850	0.3697	0.0003	29.1332	0.0051
2006	Pumps	15	0.0168	0.0554	0.0954	0.0001	7.4238	0.0015
2006	Pumps	25	0.0507	0.1260	0.1987	0.0002	19.4874	0.0046
2006	Pumps	50	0.1541	0.3621	0.3619	0.0004	34.3349	0.0139
2006	Pumps	120	0.2039	0.6371	1.2690	0.0011	94.3188	0.0184
2006	Pumps	175	0.2392	0.9177	2.0523	0.0019	169.5493	0.0216
2006	Pumps	250	0.1941	0.5771	2.2926	0.0023	201.3693	0.0175
2006	Pumps	500	0.2982	1.2024	3.5991	0.0034	345.2047	0.0269
2006	Pumps	750	0.5068	1.9878	6.0902	0.0057	570.7010	0.0457
2006	Pumps	9999	1.5682	5.9197	17.3104	0.0136	1354.8351	0.1415
2006	Rollers	15	0.0076	0.0386	0.0482	0.0001	6.3202	0.0007
2006	Rollers	25	0.0185	0.0575	0.1165	0.0002	13.3427	0.0017
2006	Rollers	50	0.1520	0.3436	0.2884	0.0003	25.9831	0.0137
2006	Rollers	120	0.1755	0.5235	1.0466	0.0008	71.3764	0.0158
2006	Rollers	175	0.2116	0.7742	1.7175	0.0015	130.8567	0.0191
2006	Rollers	250	0.1867	0.5391	1.9194	0.0017	153.0898	0.0168
2006	Rollers	500	0.2375	1.0016	2.4749	0.0022	219.1010	0.0214
2006	Rough Terrain Forklifts	50	0.2019	0.4635	0.3746	0.0004	33.8583	0.0182
2006	Rough Terrain Forklifts	120	0.1825	0.5564	1.0671	0.0009	75.5643	0.0165
2006	Rough Terrain Forklifts	175	0.2397	0.8941	1.8996	0.0017	151.1286	0.0216
2006	Rough Terrain Forklifts	250	0.1880	0.5203	2.0303	0.0019	170.7965	0.0170
2006	Rough Terrain Forklifts	500	0.2518	0.8995	2.6920	0.0025	256.5710	0.0227
2006	Rubber Tired Dozers	175	0.3281	1.0846	2.4745	0.0018	156.6669	0.0296
2006	Rubber Tired Dozers	250	0.3139	0.8843	2.8004	0.0021	183.4870	0.0283
2006	Rubber Tired Dozers	500	0.4045	2.1197	3.6630	0.0026	264.8726	0.0365
2006	Rubber Tired Dozers	750	0.6094	3.1710	5.5926	0.0040	398.7885	0.0550

2006	Rubber Tired Dozers	1000	0.9543	5.0610	9.2959	0.0060	591.8939	0.0861
2006	Rubber Tired Loaders	25	0.0221	0.0708	0.1440	0.0002	16.9292	0.0020
2006	Rubber Tired Loaders	50	0.1938	0.4399	0.3495	0.0004	31.1497	0.0175
2006	Rubber Tired Loaders	120	0.1791	0.5347	1.0407	0.0008	71.2853	0.0162
2006	Rubber Tired Loaders	175	0.2129	0.7774	1.6758	0.0014	128.6414	0.0192
2006	Rubber Tired Loaders	250	0.1781	0.4959	1.8452	0.0017	148.9767	0.0161
2006	Rubber Tired Loaders	500	0.2528	0.9705	2.6039	0.0023	237.0084	0.0228
2006	Rubber Tired Loaders	750	0.5240	1.9793	5.4711	0.0049	485.5287	0.0473
2006	Rubber Tired Loaders	1000	0.7317	2.8295	8.0073	0.0060	593.8755	0.0660
2006	Scrapers	120	0.3198	0.9018	1.8311	0.0013	113.6196	0.0289
2006	Scrapers	175	0.3349	1.1574	2.5856	0.0020	179.1693	0.0302
2006	Scrapers	250	0.3046	0.8606	2.9011	0.0024	209.4702	0.0275
2006	Scrapers	500	0.4168	1.9484	4.0046	0.0032	321.4284	0.0376
2006	Scrapers	750	0.7239	3.3467	7.0442	0.0056	555.2767	0.0653
2006	Signal Boards	15	0.0072	0.0377	0.0453	0.0001	6.1697	0.0007
2006	Signal Boards	50	0.1740	0.4062	0.3843	0.0005	36.1908	0.0157
2006	Signal Boards	120	0.2145	0.6682	1.3162	0.0011	97.0500	0.0193
2006	Signal Boards	175	0.2694	1.0333	2.2732	0.0021	186.9988	0.0243
2006	Signal Boards	250	0.2504	0.7317	2.9189	0.0029	255.2918	0.0226
2006	Skid Steer Loaders	25	0.0315	0.0814	0.1358	0.0002	13.7941	0.0028
2006	Skid Steer Loaders	50	0.1126	0.2842	0.2606	0.0003	25.5192	0.0102
2006	Skid Steer Loaders	120	0.1016	0.3537	0.6359	0.0006	51.7418	0.0092
2006	Surfacing Equipment	50	0.0708	0.1644	0.1519	0.0002	14.1076	0.0064
2006	Surfacing Equipment	120	0.1760	0.4496	0.9017	0.0007	63.7665	0.0131
2006	Surfacing Equipment	175	0.1550	0.5924	1.3107	0.0012	103.7871	0.0140
2006	Surfacing Equipment	250	0.1521	0.4563	1.6282	0.0015	134.8690	0.0137

2006	Surfacing Equipment	500	0.2227	0.9888	2.4265	0.0022	221.2077	0.0201
2006	Surfacing Equipment	750	0.3558	1.5437	3.8879	0.0035	347.0479	0.0321
2006	Sweepers/Scrubbers	15	0.0125	0.0729	0.0878	0.0002	11.9382	0.0011
2006	Sweepers/Scrubbers	25	0.0251	0.0821	0.1673	0.0002	19.6128	0.0023
2006	Sweepers/Scrubbers	50	0.1973	0.4427	0.3522	0.0004	31.5510	0.0178
2006	Sweepers/Scrubbers	120	0.2281	0.6703	1.2826	0.0011	90.7985	0.0206
2006	Sweepers/Scrubbers	175	0.2779	0.9871	2.1386	0.0019	168.1836	0.0251
2006	Sweepers/Scrubbers	250	0.1660	0.4343	1.9127	0.0018	162.0184	0.0150
2006	Tractors/Loaders/Backhoes	25	0.0254	0.0741	0.1443	0.0002	15.8633	0.0023
2006	Tractors/Loaders/Backhoes	50	0.1684	0.3985	0.3286	0.0004	30.3471	0.0152
2006	Tractors/Loaders/Backhoes	120	0.1427	0.4535	0.8445	0.0007	62.5909	0.0129
2006	Tractors/Loaders/Backhoes	175	0.1831	0.7161	1.4623	0.0014	122.6782	0.0165
2006	Tractors/Loaders/Backhoes	250	0.1714	0.4715	1.9310	0.0019	171.7370	0.0155
2006	Tractors/Loaders/Backhoes	500	0.3074	1.0278	3.3772	0.0039	344.8535	0.0277
2006	Tractors/Loaders/Backhoes	750	0.4689	1.5370	5.2373	0.0058	517.2803	0.0423
2006	Trenchers	15	0.0099	0.0517	0.0622	0.0001	8.4646	0.0009
2006	Trenchers	25	0.0429	0.1377	0.2800	0.0004	32.9178	0.0039
2006	Trenchers	50	0.2110	0.4651	0.3764	0.0004	32.9178	0.0190
2006	Trenchers	120	0.2138	0.6087	1.2617	0.0009	78.5231	0.0193
2006	Trenchers	175	0.3149	1.1046	2.5079	0.0020	174.1165	0.0284
2006	Trenchers	250	0.3246	0.9471	3.0938	0.0025	222.9008	0.0293
2006	Trenchers	500	0.4018	2.0679	3.9323	0.0031	311.3086	0.0363
2006	Trenchers	750	0.7640	3.8743	7.5254	0.0059	586.8779	0.0689
2006	Welders	15	0.0140	0.0463	0.0798	0.0001	6.2074	0.0013
2006	Welders	25	0.0294	0.0730	0.1151	0.0001	11.2861	0.0026
2006	Welders	50	0.1392	0.3169	0.2825	0.0003	25.9581	0.0126

2006	Welders	120	0.1126	0.3386	0.6722	0.0006	47.7967	0.0102
2006	Welders	175	0.1835	0.6740	1.5043	0.0013	118.8089	0.0166
2006	Welders	250	0.1264	0.3603	1.4180	0.0013	119.0684	0.0114
2006	Welders	500	0.1582	0.6316	1.8085	0.0016	167.5987	0.0143

Source: ARB, 2008

Appendix H: Calculation of fuel-based correction factors used in equipment usage emissions component.

Fuel	Reductions in PM from Base Case	Total Reduction in PM	Source
Diesel	0 (Base case)	0 (Base case)	n/a
Low Sulfur Diesel (LSD)	25%	25%	Low Sulfur Diesel Fact Sheet, California ARB
Ultra-Low Sulfur Diesel (ULSD)	7%	(25+7)% = 32%	Cleaner Diesel, EPA Sector Strategies Program
Biodiesel B5	2%	(32+2)% = 34%	EPA Verified Retrofit Technologies - Biodiesel
Biodiesel B20	10%	(34+10)% =44%	
Biodiesel B100	37%	(44+37)%=81%	

Source: ARB, 2003 & USEPA, 2007b & USEPA, 2010a

Appendix I: Typical coatings/solvents & their percent solids and density data.

Type of Coating	Solids (% Volume)	Density (kg/L)
Enamel, air dry	39.6	0.91
Enamel, baking	42.8	1.09
Acrylic enamel	30.3	1.07
Alkyd enamel	47.2	0.96
Primer surfacer	49	1.13
Primer, epoxy	57.2	1.26
Varnish, baking	35.3	0.79
Lacquer, spraying	26.1	0.95
Vinyl, roller coat	12	0.92
Polyurethane	31.7	1.1
Stain	21.6	0.88
Sealer	11.7	0.84
Magnet wire enamel	25	0.94
Solvents (all types)*	33	0.88
** Average values*		

Source: USEPA, 2009b

Appendix J: N-content of some common fertilizers used in materials production component.

Fertilizer Type	Average % Nitrogen by weight
Nitrogen	
Ammonia, Anhydrous	82
Ammonia, Aqua *	20.5
Ammonium Nitrate	33.5
Ammonium Nitrate-Limestone Mixture	20.5
Ammonium Sulfate	21
Ammonium Sulfate-nitrate	26
Calcium cyanamide	21
Calcium nitrate	15
Nitrogen solutions *	35
Sodium nitrate	16
Urea	46
Urea-form	38
Phosphate	
Bone-meal *	3.25
Multiple Nutrient	
Ammoniated superphosphate	4.5
Ammonium phosphate-nitrate	27
Ammonium phosphate-sulfate *	14.5
Diammonium phosphate *	18.5
Monoammonium phosphate	11
Nitric phosphates *	18
Nitrate of soda-potash	15
Potassium nitrate	12
Note: * are average values determined from a range of N-content values	

Source: USEPA, 2009b

Appendix K: Database used in environmental impact mitigation component of carbon footprint estimation model.

REGION	FOREST TYPE	AGE (Yrs)	CARBON DENSITY (MT C/ha)	
			NON-SOIL	SOIL
Northeast (CT,DE,MA,MD,ME,NH,NJ,NY,OH,PA,RI,VT,WV)	White/Red/Jack Pine	0	2.1	58.6
		5	13.8	58.8
		15	41.9	60.3
		25	62.3	62.9
		35	77.9	66.2
	Spruce/Fir	0	2.1	73.5
		5	15.1	73.7
		15	38.5	75.6
		25	59.3	78.9
		35	79.7	83
	Oak/Pine	0	4.2	50.2
		5	15.2	50.3
		15	44.9	51.6
		25	73.3	53.9
		35	98.3	56.6
	Oak/Hickory	0	2.1	39.8
		5	11	39.9
		15	54	40.9
		25	86.6	42.7
		35	114	44.9
	Maple/Beech/Birch	0	2.1	52.2

		5	15	52.3
		15	50	53.7
		25	79.8	56
		35	105.4	58.9
	Aspen/Birch	0	2	65.6
		5	11.5	65.8
		15	30.9	67.4
		25	49.6	70.4
		35	67.1	74
Nothern Lake States (MI,MN,WI)	White/Red/Jack Pine	0	2	90.6
		5	5.7	90.9
		15	18.5	93.2
		25	52.9	97.3
		35	85.3	102.3
	Spruce/Fir	0	2.1	196.4
		5	11.1	197
		15	26.5	202
		25	49.7	210.8
		35	74.2	221.7
	Oak/Hickory	0	2.1	72.8
		5	11	73.1
		15	24.5	74.9
		25	45	78.2
		35	64.8	82.2
	Elm/Ash/Cottonwood	0	2	134.9
		5	10.7	135.4
		15	24.7	138.8
		25	41.1	144.9
		35	56.2	152.4

	Maple/Beech/Birch	0	2.1	100.7
		5	12.2	101
		15	28.3	103.6
		25	53	108.1
		35	76.5	113.7
	Aspen/Birch	0	2	109.6
		5	12.1	109.9
		15	22.5	112.7
		25	39.6	117.6
		35	57.4	123.7
Northern Prairie States (IA,IL,IN,KS,MO,ND,NE,SD)	Oak/Pine	0	4.2	27.1
		5	13.9	27.2
		15	30.6	27.9
		25	53.6	29.1
		35	77.2	30.6
	Oak/Hickory	0	2.1	34.5
		5	11	34.6
		15	22.9	35.4
		25	37.9	37
		35	53	38.9
	Elm/Ash/Cottonwood	0	2.1	63.6
		5	10.8	63.8
		15	23.7	65.4
		25	36.4	68.3
		35	54.3	71.8
	Maple/Beech/Birch	0	2.1	48.6
		5	12.4	48.8
		15	25	50
		25	39	52.2

		35	55.7	54.9
South Central (AL,AR,KY,LA,MS,OK,TN,TX)	Loblolly/Shortleaf Pine	0	4.2	31.4
		5	20.1	31.5
		15	47	32.3
		25	70.5	33.7
		35	87.8	35.5
	Oak/Pine	0	4.2	31.3
		5	17.5	31.4
		15	46	32.2
		25	68.5	33.6
		35	88.2	35.3
	Oak/Hickory	0	4.2	29
		5	17.1	29.1
		15	40.8	29.8
		25	61.5	31.1
		35	81.2	32.7
	Oak/Gum/Cypress	0	1.8	39.6
		5	9.5	39.7
		15	37.8	40.7
		25	61.3	42.5
		35	81.8	44.7
	Elm/Ash/Cottonwood	0	4.2	37.4
		5	16	37.5
		15	38.2	38.5
		25	59.4	40.2
		35	80.2	42.2
Southeast (FL,GA,NC,SC,VA)	Longleaf/Slash Pine	0	4.2	82.5
		5	13.6	82.8
		15	34.9	84.9

		25	56.6	88.6
		35	75.1	93.2
	Loblolly/Shortleaf Pine	0	4.2	54.7
		5	19.8	54.9
		15	46.1	56.3
		25	69.4	58.7
		35	87.9	61.8
	Oak/Pine	0	4.2	46.1
		5	15.6	46.2
		15	42.8	47.4
		25	63.7	49.5
		35	83.9	52
	Oak/Hickory	0	4.2	33.9
		5	14.7	34.1
		15	41	34.9
		25	63.1	36.4
		35	82.5	38.3
	Oak/Gum/Cypress	0	1.8	118.5
		5	10.9	118.9
		15	37.2	121.9
		25	58.9	127.2
		35	77	133.8
Pacific Northwest, Westside (Western OR & WA)	Douglas-fir	0	4.6	71.1
		5	18.1	71.3
		15	50.3	73.1
		25	147.3	76.3
		35	240.6	80.2
	Fir/Spruce/Mt.Hemlock	0	4.8	46.6
		5	14	46.8

		15	31.4	47.9
		25	73.2	50
		35	126.9	52.6
	Hemlock/Sitka Spruce	0	4.7	87.3
		5	15.3	87.6
		15	41	89.8
		25	112.1	93.7
		35	190.5	98.5
	Alder/Maple	0	4.7	86.4
		5	16.1	86.7
		15	45.2	88.9
		25	127.8	92.8
		35	193.9	97.6
Pacific Northwest, Eastside (Eastern OR & WA)	Douglas-fir	0	4.6	71.1
		5	12.7	71.3
		15	27.5	73.1
		25	68.3	76.3
		35	116.7	80.2
	Ponderosa Pine	0	4.8	38
		5	10.8	38.1
		15	19.7	39.1
		25	33.7	40.8
		35	47	42.9
	Fir/Spruce/Mt.Hemlock	0	4.8	46.6
		5	13	46.8
		15	23.7	47.9
		25	40.5	50
		35	66.6	52.6
	Lodgepole Pine	0	4.8	39

		5	9.5	39.1
		15	19.6	40.1
		25	41.4	41.9
		35	62.8	44.1
Pacific Southwest (CA)	Fir/Spruce/Mt.Hemlock	0	4.8	38.9
		5	13.8	39.1
		15	26.7	40
		25	43	41.8
		35	61.5	43.9
	California Mixed Conifer	0	4.8	37.4
		5	14.8	37.5
		15	27.4	38.4
		25	43	40.1
		35	54.5	42.2
	Western Oak	0	4.7	20.7
		5	11.3	20.8
		15	20.8	21.3
		25	28.8	22.2
		35	57.3	23.4
Rocky Mountain, North (ID,MT)	Douglas-fir	0	4.7	29.1
		5	13	29.2
		15	24.8	30
		25	47	31.3
		35	77	32.9
	Ponderosa Pine	0	4.8	25.7
		5	10.9	25.8
		15	18.2	26.5
		25	31.8	27.6
		35	51.6	29

	Fir/Spruce/Mt.Hemlock	0	4.7	33.1
		5	13.6	33.2
		15	24.7	34
		25	42.4	35.5
		35	71.2	37.4
	Lodgepole Pine	0	4.8	27.9
		5	9.2	28
		15	15.9	28.7
		25	29.8	29.9
		35	49.6	31.5
Rocky Mountain, South (AZ,CO,NM,NV,UT,WY)	Douglas-fir	0	4.8	23.2
		5	13.1	23.3
		15	26.3	23.8
		25	46.2	24.9
		35	68.6	26.2
	Ponderosa Pine	0	4.8	18.1
		5	9.4	18.1
		15	15.6	18.6
		25	25.7	19.4
		35	37.5	20.4
	Fir/Spruce/Mt.Hemlock	0	4.8	23.6
		5	12.1	23.7
		15	22.5	24.3
		25	37	25.3
		35	54.5	26.7
	Lodgepole Pine	0	4.8	20.2
		5	9.7	20.3
		15	16.4	20.8
		25	25.5	21.7

		35	36.2	22.8
	Aspen/Birch	0	4.7	44.1
		5	12.1	44.2
		15	22	45.4
		25	35.3	47.4
		35	52.5	49.8

Source: Smith.J et al., 2006

Appendix L: Classification of tree species and database used in offset component.

Table L-1. Classification of common trees used in reforestation.

Species	Type	Growth Rate	Species	Type	Growth Rate
Ailanthus, *Ailanthus altissima*	H	F	Maple, bigleaf, *Acer macrophyllum*	H	S
Alder, European, Alnus glutinosa	H	F	Maple, Norway, *Acer platanoides*	H	M
Ash, green, Fraxinus pennsylvanica	H	F	Maple, red, *Acer rubrum*	H	M
Ash, mountain, American, *Sorbus americana*	H	M	Maple, silver, *Acer saccharinum*	H	M
Ash, white, *Fraxinus americana*	H	F	Maple, sugar, *Acer saccharum*	H	S
Aspen, bigtooth, *Populus grandidentata*	H	M	Mulberry, red, *Morus rubra*	H	F
Aspen, quaking, *Populus tremuloides*	H	F	Oak, black, *Quercus velutina*	H	M
Baldcypress, *Taxodium distichum*	C	F	Oak, blue, *Quercus douglasii*	H	M
Basswood, American, *Tilia americana*,	H	F	Oak, bur, *Quercus macrocarpa*	H	S
Beech, American, *Fagus grandifolia*	H	S	Oak, California black, *Quercus kelloggii*	H	S
Birch, paper (white), *Betula papyrifera*	H	M	Oak, California White, *Quercus lobata*	H	M
Birch, river, *Betula nigra*	H	M	Oak, canyon live, *Quercus chrysolepsis*	H	S
Birch, yellow, *Betula alleghaniensis*	H	S	Oak, chestnut, *Quercus prinus*	H	S
Boxelder, *Acer negundo*	H	F	Oak, Chinkapin, *Quercus muehlenbergii*	H	M
Buckeye, Ohio, *Aesculus glabra*	H	S	Oak, Laurel, *Quercus laurifolia*	H	F
Catalpa, northern, *Catalpa speciosa*	H	F	Oak, live, *Quercus virginiana*	H	F
Cedar-red, eastern, *Juniperus virginiana*	C	M	Oak, northern red, *Quercus rubra*	H	F
Cedar-white, northern, *Thuja occidentalis*	C	M	Oak, overcup , *Quercus lyrata*	H	S
Cherry, black, *Prunus serotina*	H	F	Oak, pin, *Quercus palustris*	H	F
Cherry, pin, *Prunus pennsylvanica*	H	M	Oak, scarlet, *Quercus coccinea*	H	F
Cottonwood, eastern, *Populus deltoides*	H	M	Oak, swamp white, *Quercus bicolor*	H	M
Crabapple, *Malus* spp.	H	M	Oak, water, *Quercus nigra*	H	M
Cucumbertree, *Magnolia acuminata*	H	F	Oak, white, *Quercus alba*	H	S
Dogwood, flowering, *Cornus florida*	H	S	Oak, willow, *Quercus phellos*	H	M
Elm, American, *Ulmus americana*	H	F	Pecan, *Carya illinoensis*	H	S
Elm, Chinese, *Ulmus parvifolia*	H	M	Pine, European black, *Pinus nigra*	C	S
Elm, rock, *Ulmus thomasii*	H	S	Pine, jack, *Pinus banksiana*	C	F
Elm, September, *Ulmus serotina*	H	F	Pine, loblolly, *Pinus taeda*	C	F
Elm, Siberian, *Ulmus pumila*	H	F	Pine, longleaf, *Pinus palustris*	C	F
Elm, slippery, *Ulmus rubra*	H	M	Pine, ponderosa, *Pinus ponderosa*	C	F
Fir, balsam, *Abies balsamea*	C	S	Pine, red, *Pinus resinosa*	C	F
Fir, Douglas, Pseudotsuga menziesii	C	F	Pine, Scotch, *Pinus sylvestris*	C	S
Ginkgo, *Ginkgo biloba*	H	S	Pine, shortleaf, *Pinus echinata*	C	F
Hackberry, *Celtis occidentalis*	H	F	Pine, slash, *Pinus elliottii*	C	F
Hawthorne, *Crataegus* spp.	H	M	Pine, Virginia, *Pinus virginiana*	C	M
Hemlock, eastern, *Tsuga canadensis*	C	M	Pine, white eastern, *Pinus strobus*	C	F
Hickory, bitternut, *Carya cordiformis*	H	S	Poplar, yellow, *Liriodendron tulipifera*	H	F
Hickory, mockernut, *Carya tomentosa*	H	M	Redbud, eastern, *Cercis canadensis*	H	M
Hickory, shagbark, *Carya ovata*	H	S	Sassafras, *Sassafras albidum*	H	M
Hickory, shellbark, Carya laciniosa	H	S	Spruce, black, *Picea mariana*	C	S
Hickory, pignut, *Carya glabra*	H	M	Spruce, blue, *Picea pungens*	C	M
Holly, American, *Ilex opaca*	H	S	Spruce, Norway, *Picea abies*	C	M
Honeylocust, *Gleditsia triacanthos*	H	F	Spruce, red, *Picea rubens*	C	S
Hophornbeam, eastern, *Ostrya virginiana*	H	S	Spruce, white, *Picea glauca*	C	M
Horsechestnut, common, *Aesculus hippocastanum*	H	F	Sugarberry, *Celtis laevigata*	H	F
Kentucky coffeetree, *Gymnocladus dioicus*	C	F	Sweetgum, *Liquidambar styraciflua*	H	F
Linden, little-leaf, *Tilia cordata*	H	F	Sycamore, *Platanus occidentalis*	H	F
Locust, black, *Robinia pseudoacacia*	H	F	Tamarack, *Larix laricina*	C	F
London plane tree *Platanus_X_acerifolia*	H	F	Walnut, black, *Juglans nigra*	H	F
Magnolia, southern, *Magnolia grandifolia*	H	M	Willow, black, *Salix nigra*	H	F

Type: H = Hardwood, C = Conifer   Growth Rate: S = Slow, M = Moderate, F = Fast

Table L-2. Database used in the offset component of the carbon footprint estimation model.

Tree Age (yrs)	Average Sequestration Rate (MT C/yr/tree)	
	Hardwood	Conifers
0	0.00089	0.00047
1	0.00125	0.00069
2	0.00164	0.00093
3	0.00204	0.00120
4	0.00248	0.00149
5	0.00291	0.00180
6	0.00339	0.00213
7	0.00387	0.00248
8	0.00438	0.00282
9	0.00489	0.00321
10	0.00540	0.00362
11	0.00594	0.00401
12	0.00650	0.00444
13	0.00705	0.00486
14	0.00762	0.00530
15	0.00821	0.00578
16	0.00879	0.00624
17	0.00939	0.00672
18	0.00999	0.00723
19	0.01061	0.00773
20	0.01125	0.00824
21	0.01187	0.00878
22	0.01253	0.00932
23	0.01316	0.00987
24	0.01382	0.01041
25	0.01449	0.01098
26	0.01517	0.01157
27	0.01584	0.01215
28	0.01653	0.01275
29	0.01722	0.01335
30	0.01785	0.01397
31	0.01863	0.01460
32	0.01935	0.01523
33	0.02004	0.01586
34	0.02078	0.01650
35	0.02151	0.01718
36	0.02225	0.01785

37	0.02300	0.01851
38	0.02373	0.01920
39	0.02450	0.01989
40	0.02525	0.02058
41	0.02603	0.02129
42	0.02679	0.02199
43	0.02756	0.02273
44	0.02834	0.02345
45	0.02912	0.02418
46	0.02993	0.02493
47	0.03071	0.02568
48	0.03152	0.02643
49	0.03231	0.02721
50	0.03314	0.02798

Appendix M: ICC input data & emissions calculation for equipment usage component of model.

Table M-1. ICC equipment inventory as processed to fit analogous equipment categories in the model.

Equip #	Equip Type	Model #	Tier	Analogous GHG Equip	Start date	End date	No.Days	No. hrs
46-4905	Manlift	S80	2	Aerial Lifts	7/31/09	1/19/10	172	1032
46-2529	manlift	601S	2	Aerial Lifts	8/18/09	1/19/10	154	924
13-132	Compressor	185 CFM	2	Air Compressors	11/21/07	1/19/10	790	4740
13-133	Compressor	185 CFM	2	Air Compressors	11/21/07	1/19/10	790	4740
13-135	Compressor	185 CFM	2	Air Compressors	12/5/08	1/19/10	410	2460
13-134	Compressor	185 CFM	2	Air Compressors	12/5/08	1/19/10	410	2460
C.04006	Crawler Crane	275 TN	1	Cranes	5/28/08	1/19/10	601	3606
11-553	Crane	RT700E	1	Cranes	4/9/08	1/19/10	650	3900
11-122	Crane	RT760E	1	Cranes	4/10/08	1/19/10	649	3894
11-552	Crane	RT700E	2	Cranes	5/2/08	1/19/10	627	3762
11-128	Crane	RT760E	2	Cranes	6/5/08	1/19/10	593	3558
W.0104 0	Crawler Crane	110 TN	2	Cranes	4/29/08	1/19/10	630	3780
11-554	Crane	RT700E	3	Cranes	10/19/07	1/19/10	823	4938
11-555	Crane	RT700E	3	Cranes	2/1/08	1/19/10	718	4308
46-4790	Crane	RT760	3	Cranes	2/12/09	1/19/10	341	2046
W.0107 0	Crane	165 TN	3	Cranes	8/7/08	1/19/10	530	3180
46-4829	Crane	RT760	3	Cranes	6/30/09	1/19/10	203	1218
T443	Tractor	8230	3	Crawler Tractors	3/30/09	1/19/10	295	1770
T415	Power Track	800	2	Crushing/Proc. Equipment	7/2/09	1/19/10	201	1206
30-419	Excavator	330 DL	1	Excavators	6/5/08	1/19/10	593	3558

T308	Excavator	330-EXC	1	Excavators	7/25/08	4/21/09	270	1620
T33	Excavator	EX330LC-5	1	Excavators	1/27/09	4/21/09	84	504
T304	Excavator	EX330LC-C	1	Excavators	10/23/07	4/21/09	546	3276
T412	Excavator	320CL	2	Excavators	1/27/09	1/19/10	357	2142
T425	Excavator	325CL	2	Excavators	3/13/08	1/19/10	677	4062
T393	Excavator	330CL	2	Excavators	3/14/08	1/19/10	676	4056
T377	Excavator	330CL	2	Excavators	1/27/09	1/19/10	357	2142
W.0514 2	Excavator	PC300LC-7L	2	Excavators	8/10/09	1/19/10	162	972
W.0513 8	Excavator	PC400	2	Excavators	5/12/09	1/19/10	252	1512
46-4648	Excavator	315 CL	3	Excavators	7/1/08	1/19/10	567	3402
30-490	Excavator	325 DL	3	Excavators	9/19/07	1/19/10	853	5118
46-4669	Excavator	325 DL	3	Excavators	7/9/08	1/19/10	559	3354
46-4582	Excavator	325 DL	3	Excavators	11/21/08	1/19/10	424	2544
46-4706	Excavator	330 D	3	Excavators	9/5/08	1/19/10	501	3006
30-492	Excavator	330 DL	3	Excavators	10/19/07	1/19/10	823	4938
30-496	Excavator	330 DL	3	Excavators	11/12/07	1/19/10	799	4794
46-4580	Excavator	330 DL	3	Excavators	6/20/08	1/19/10	578	3468
46-4670	Excavator	330 DL	3	Excavators	7/10/08	1/19/10	558	3348
46-4744	Excavator	330 DL	3	Excavators	10/23/08	1/19/10	453	2718
46-4761	Excavator	330 DL	3	Excavators	11/19/08	1/19/10	426	2556
46-4784	Excavator	345 CL	3	Excavators	2/9/09	1/19/10	344	2064
T437	Excavator	330DL	3	Excavators	7/22/08	1/19/10	546	3276
T900	Excavator	345	3	Excavators	3/23/09	1/19/10	302	1812
T457	Excavator	330	3	Excavators	6/17/09	1/19/10	216	1296
T801	EXCAVATOR	330DL	3	Excavators	3/30/09	1/19/10	295	1770
W.0370 7	Manlift	60 S	2	Forklifts	3/12/09	1/19/10	313	1878
46-4871	Forklift	506	2	Forklifts	6/29/09	1/19/10	204	1224

46-003	Forklift	10054	2	Forklifts	7/10/09	1/19/10	193	1158
46-4879	Forklift	1054	2	Forklifts	7/6/09	1/19/10	197	1182
08-1263	Forklift	TH1255	3	Forklifts	9/20/07	1/19/10	852	5112
08-1269	Telehandler	TH1255	3	Forklifts	10/23/07	1/19/10	819	4914
46-4719	Forklift	6000 LB	3	Forklifts	9/23/08	1/19/10	483	2898
46-4787	Forklift	10054	3	Forklifts	2/6/08	1/19/10	713	4278
W.2521 1	Generator	50KW	2	Generators	3/12/09	1/19/10	313	1878
T246	Compactor	815F	1	Graders	4/2/08	1/19/10	657	3942
T332	Compactor	815F	1	Graders	5/7/08	1/19/10	622	3732
T287	Compactor	963C	1	Graders	7/25/08	1/19/10	543	3258
T441	Compactor	815F	2	Graders	3/9/09	1/19/10	316	1896
T330	6-Wheel truck	TA30	1	Off-Highway Trucks	7/3/08	1/19/10	565	3390
T312	6-Wheel truck	TA30	1	Off-Highway Trucks	6/24/08	4/21/09	301	1806
T329	6-wheel Truck	TA30	1	Off-Highway Trucks	1/27/09	1/19/10	357	2142
C.06051	Articulated Truck	730	2	Off-Highway Trucks	1/15/09	1/19/10	369	2214
W.0850 1	Articulated Truck	A35D	2	Off-Highway Trucks	3/17/09	1/19/10	308	1848
T389	Articulated Truck	730	2	Off-Highway Trucks	2/14/08	4/21/09	432	2592
T388	Articulated Truck	730	2	Off-Highway Trucks	3/22/08	1/19/10	668	4008
T372	Articulated Truck	730	2	Off-Highway Trucks	4/3/08	1/19/10	656	3936
T379	Articulated Truck	730	2	Off-Highway Trucks	4/22/08	4/21/09	364	2184
T387	Articulated Truck	730	2	Off-Highway Trucks	7/22/08	4/21/09	273	1638
T402	Articulated	730	2	Off-Highway Trucks	1/27/09	4/21/09	84	504

	Truck							
T373	Articulated Truck	730	2	Off-Highway Trucks	1/27/09	4/21/09	84	504
T381	Articulated Truck	730	2	Off-Highway Trucks	1/27/09	4/21/09	84	504
T380	Articulated Truck	730	2	Off-Highway Trucks	1/27/09	4/21/09	84	504
T381	Articulated Truck	730	2	Off-Highway Trucks	1/27/09	1/19/10	357	2142
46-4649	Articulated Truck	30 TN	3	Off-Highway Trucks	6/26/08	1/19/10	572	3432
46-4717	Articulated Truck	31 TN	3	Off-Highway Trucks	9/23/08	1/19/10	483	2898
46-4716	Articulated Truck	32 TN	3	Off-Highway Trucks	9/23/08	1/19/10	483	2898
T447	Articulated Truck	730	3	Off-Highway Trucks	1/27/09	1/19/10	357	2142
T411	Articulated Truck	730	3	Off-Highway Trucks	1/27/09	4/21/09	84	504
T444	Articulated Truck	730	3	Off-Highway Trucks	1/27/09	1/19/10	357	2142
T446	Articulated Truck	730	3	Off-Highway Trucks	1/27/09	4/21/09	84	504
T448	Articulated Truck	730	3	Off-Highway Trucks	1/27/09	1/19/10	357	2142
T445	Articulated Truck	730	3	Off-Highway Trucks	1/27/09	1/19/10	357	2142
T703	Articulated Truck	730	3	Off-Highway Trucks	2/18/09	4/21/09	62	372
T702	Articulated	730	3	Off-Highway Trucks	2/19/09	1/19/10	334	2004

	Truck							
T446	Articulated Truck	730	3	Off-Highway Trucks	4/9/09	1/19/10	285	1710
T449	Articulated Truck	730	3	Off-Highway Trucks	5/20/09	1/19/10	244	1464
T453	Articulated Truck	730	3	Off-Highway Trucks	5/20/09	1/19/10	244	1464
T452	Articulated Truck	730	3	Off-Highway Trucks	5/20/09	1/19/10	244	1464
T451	Articulated Truck	730	3	Off-Highway Trucks	5/20/09	1/19/10	244	1464
T450	Articulated Truck	730	3	Off-Highway Trucks	5/20/09	1/19/10	244	1464
T454	Articulated Truck	730	3	Off-Highway Trucks	7/10/09	1/19/10	193	1158
T455	Articulated Truck	730	3	Off-Highway Trucks	7/10/09	1/19/10	193	1158
16-1487	Concrete Finisher	4800	2	Other Construction Equipment	2/11/08	1/19/10	708	4248
T395	Gradail	XL4200S-II	1	Other General Industrial Equipment	1/27/09	1/19/10	357	2142
T422	Track Grinder	6600	1	Other General Industrial Equipment	7/3/08	4/21/09	292	1752
T382	Track Grinder	6600	1	Other General Industrial Equipment	1/27/09	4/21/09	84	504
8-1267	Power Broom	CR350	2	Other General Industrial Equipment	10/17/08	1/19/10	459	2754
59-341	Straw Blower	B260	3	Other General Industrial Equipment	11/13/07	1/19/10	798	4788
T391	Chipper	WCL23	1	Other Material Handling	11/14/07	1/19/10	797	4782

				Equipment				
T363	Hydo-Buncher	260HP	1	Other Material Handling Equipment	1/5/08	4/21/09	472	2832
59-338	Hydro seeder	*not given*	3	Other Material Handling Equipment	9/17/07	1/19/10	855	5130
T423	Feiler Buncher	643J	3	Other Material Handling Equipment	5/11/07	4/21/09	711	4266
T211	Roller	SD100D	0	Rollers	4/25/08	4/21/09	361	2166
T206	Roller	SD100D	0	Rollers	7/25/08	4/21/09	270	1620
T213	Roller	SD115D	0	Rollers	7/25/08	1/19/10	543	3258
T324	Roller	SD115D	0	Rollers	1/27/09	1/19/10	357	2142
T223	Roller	SD115D	0	Rollers	1/27/09	1/19/10	357	2142
T340	Roller	SD122DX	0	Rollers	8/5/08	1/19/10	532	3192
T230	Roller	SD100D	0	Rollers	1/27/09	1/19/10	357	2142
T253	Roller	SD100D	1	Rollers	5/29/08	1/19/10	600	3600
T364	Roller	SD122DX	1	Rollers	1/27/09	4/21/09	84	504
W.1110 3	Roller	SD110D 84"	1	Rollers	8/10/09	1/19/10	162	972
46-4588	SD Roller	50"	2	Rollers	4/9/08	1/19/10	650	3900
46-4615	SD Roller	50"	2	Rollers	5/22/08	1/19/10	607	3642
46-4552	SD Roller	50"	2	Rollers	3/13/09	1/19/10	312	1872
46-4587	66" SD Roller	66"	2	Rollers	8/1/08	1/19/10	536	3216
46-4681	SD Roller	66"	2	Rollers	8/6/08	1/19/10	531	3186
46-4751	Roller	CS323C	2	Rollers	10/31/08	1/19/10	445	2670
W.1110 4	Roller	SD-122	2	Rollers	3/12/09	1/19/10	313	1878
10-441	Compactor	CS563E	2	Rollers	3/23/09	1/19/10	302	1812
T461	Roller	CS533	3	Rollers	7/2/09	1/19/10	201	1206
T807	Roller	CS563E	3	Rollers	4/28/09	1/19/10	266	1596
T808	Roller	CS563E	3	Rollers	6/17/09	1/19/10	216	1296

T275	Dozer	D8R	1	Rubber Tired Dozers	6/13/08	4/21/09	312	1872
T274	Dozer	D8R	1	Rubber Tired Dozers	6/13/08	1/19/10	585	3510
46-4686	Dozer	550 J	2	Rubber Tired Dozers	8/6/08	1/19/10	531	3186
T398	Dozer	D5GLGP	2	Rubber Tired Dozers	7/3/08	1/19/10	565	3390
T397	Dozer	D5GLGP	2	Rubber Tired Dozers	7/22/08	4/21/09	273	1638
T396	Dozer	D5GLGP	2	Rubber Tired Dozers	1/27/09	4/21/09	84	504
T399	Dozer	D5GLGP	2	Rubber Tired Dozers	1/27/09	4/21/09	84	504
T401	Dozer	D5GLGP	2	Rubber Tired Dozers	4/14/08	1/19/10	645	3870
T400	Dozer	D5GLGP	2	Rubber Tired Dozers	7/22/08	1/19/10	546	3276
T421	Dozer	D6NLGP	2	Rubber Tired Dozers	2/11/09	1/19/10	342	2052
T414	Dozer	D6NLGP	2	Rubber Tired Dozers	1/27/09	1/19/10	357	2142
T420	Dozer	650J	2	Rubber Tired Dozers	1/27/09	1/19/10	357	2142
T390	Dozer	850CX	2	Rubber Tired Dozers	1/27/09	1/19/10	357	2142
C.05032	Dozer	D6N	2	Rubber Tired Dozers	8/27/09	1/19/10	145	870
T366	Dozer	D3GXL	2	Rubber Tired Dozers	1/27/09	1/19/10	357	2142
T371	Dozer	D5GLGP	2	Rubber Tired Dozers	1/27/09	1/19/10	357	2142
T370	Dozer	D5GLGP	2	Rubber Tired Dozers	1/27/09	1/19/10	357	2142
T431	Dozer	DN5	2	Rubber Tired Dozers	7/2/09	1/19/10	201	1206
46-4710	Dozer	D4K	3	Rubber Tired Dozers	9/15/08	1/19/10	491	2946
T440	Dozer	D-6N	3	Rubber Tired Dozers	2/11/09	1/19/10	342	2052
T413	Dozer	750J	3	Rubber Tired Dozers	9/7/08	4/21/09	226	1356
W.0702 9	Dozer	D6N XL	3	Rubber Tired Dozers	6/25/09	1/19/10	208	1248
T805	Dozer	D6N	3	Rubber Tired Dozers	5/13/09	1/19/10	251	1506
T804	Dozer	*D6NLGP*	3	Rubber Tired Dozers	7/2/09	1/19/10	201	1206
T394	Wheel Loader	962G	1	Rubber Tired Loaders	7/2/09	1/19/10	201	1206
T319	Scraper	621G	2	Scrapers	1/27/09	1/19/10	357	2142
T320	Scraper	621G	2	Scrapers	1/27/09	1/19/10	357	2142
T318	Scraper	621G	2	Scrapers	1/17/09	1/19/10	367	2202
T322	Scraper	621G	2	Scrapers	1/27/09	1/19/10	357	2142

T321	Scraper	621G	2	Scrapers	1/27/09	1/19/10	357	2142
T434	Tractor Scraper	627G	3	Scrapers	5/14/08	1/19/10	615	3690
T433	Tractor Scraper	627G	3	Scrapers	1/27/09	4/21/09	84	504
T496	Skidder	460D	1	Skid Steer Loaders	11/2/08	4/21/09	170	1020
08-6137.	Loader	950G	1	Skid Steer Loaders	4/14/09	1/19/10	280	1680
T384	Track Loader	T-250	1	Skid Steer Loaders	4/22/09	1/19/10	272	1632
T310	Loader	963C	1	Skid Steer Loaders	1/9/09	1/19/10	375	2250
T407	Log Loader	535	2	Skid Steer Loaders	3/24/08	4/21/09	393	2358
T385	Skidder	648G	2	Skid Steer Loaders	4/22/08	1/19/10	637	3822
W.0702 4	Dozer	D65	2	Skid Steer Loaders	8/17/09	1/19/10	155	930
08-1268	Loader wheel	950G	3	Skid Steer Loaders	10/17/07	1/19/10	825	4950
T295	Loader	963C	1	Tractors/Loaders/Backhoes	3/13/08	1/19/10	677	4062
T337	Loader	963C	1	Tractors/Loaders/Backhoes	7/22/08	1/19/10	546	3276
T335	Loader	963C	1	Tractors/Loaders/Backhoes	7/22/08	1/19/10	546	3276
T348	Loader	963C	1	Tractors/Loaders/Backhoes	1/27/09	4/21/09	84	504
T303	Loader	IT38G	1	Tractors/Loaders/Backhoes	11/7/07	4/21/09	531	3186
T356	Loader	644G	1	Tractors/Loaders/Backhoes	7/22/08	4/21/09	273	1638
C.08037	Track Loader	963C	2	Tractors/Loaders/Backhoes	1/14/09	1/19/10	370	2220
46-4743	Loader	IT3B	2	Tractors/Loaders/Backhoes	10/23/08	1/19/10	453	2718
08-1284	Backhoe	410 J	2	Tractors/Loaders/Backhoes	9/6/07	1/19/10	866	5196
08-1285	Backhoe	411 J	2	Tractors/Loaders/Backhoes	10/22/07	1/19/10	820	4920
08-1278	Backhoe 4x4	412 J	2	Tractors/Loaders/Backhoes	11/23/07	1/19/10	788	4728
07-308	Tractor Tracked	550 J	2	Tractors/Loaders/Backhoes	10/8/07	1/19/10	834	5004
07-309	Tractor Tracked	550 J	2	Tractors/Loaders/Backhoes	11/12/07	1/19/10	799	4794
T430	Loader	963C	2	Tractors/Loaders/Backhoes	5/23/08	1/19/10	606	3636
46-4800	Wheel Loader	930H	3	Tractors/Loaders/Backhoes	3/3/09	1/19/10	322	1932
08-1266	Wheel Loader	950H	3	Tractors/Loaders/Backhoes	10/22/07	1/19/10	820	4920
D8-1276	Wheel Loader	950H	3	Tractors/Loaders/Backhoes	4/22/08	1/19/10	637	3822
46-4759	Wheel Loader	950H	3	Tractors/Loaders/Backhoes	11/14/08	1/19/10	431	2586

46-4776	Track Loader	953C	3	Tractors/Loaders/Backhoes	1/21/09	1/19/10	363	2178
07-311	Loader	963	3	Tractors/Loaders/Backhoes	12/4/07	1/19/10	777	4662
46-4711	Loader	IT3B	3	Tractors/Loaders/Backhoes	9/15/08	1/19/10	491	2946

Table M- 2. Results from emissions calculation of the ICC equipment fleet.

#	Equipment type	Tier	Activity (hrs/ Quarter)	Equip Max hp	Yr from Max Hp	EMISSIONS (MT)						Total /equip (MT CO_2 e/quarter)
						ROG	CO	NOx	SOx	CO_2	CH_4	
1	Aerial Lifts	2	1956	750	2003	0.27	1.08	3.30	0.00	310.07	0.02	1,338.11
2	Air Compressors	2	14400	1000	2008	2.82	10.59	31.25	0.02	2,384.70	0.25	12,109.18
3	Cranes	1	11400	9999	2002	6.01	24.55	63.72	0.05	4,558.80	0.54	24,396.93
4	Cranes	2	11100	9999	2008	4.57	18.17	49.48	0.04	3,668.45	0.41	19,069.24
5	Cranes	3	15690	9999	2008	6.46	25.68	69.94	0.05	5,185.41	0.58	26,954.63
6	Crawler Tractors	3	1770	1000	2008	0.53	2.38	5.56	0.00	396.63	0.05	2,128.35
7	Crushing/Proc. Equipment	2	1206	9999	2008	0.63	2.28	7.01	0.01	537.02	0.06	2,718.67
8	Excavators	1	8958	750	1998	1.72	5.65	18.20	0.02	1,730.11	0.15	7,392.85
9	Excavators	2	14886	750	2003	2.36	7.76	25.00	0.02	2,376.06	0.21	10,153.08
10	Excavators	3	49464	750	2008	6.13	19.75	63.92	0.07	6,525.03	0.55	26,411.78
11	Forklifts	2	5442	500	2003	0.22	0.62	2.51	0.00	248.83	0.02	1,028.90
12	Forklifts	3	17202	500	2008	0.55	1.51	6.08	0.01	650.04	0.05	2,540.36
13	Generators	2	1878	9999	2008	0.72	2.64	8.24	0.01	670.54	0.07	3,235.42
14	Graders	1	10932	750	1998	2.90	11.10	30.05	0.03	2,647.24	0.26	12,003.08
15	Graders	2	1896	750	2003	0.42	1.59	4.31	0.00	379.44	0.04	1,720.47
1	Off-Highway	1	7338	1000	2002	2.28	7.88	25.18	0.02	1,888.72	0.21	9,722.17

6	Trucks											
17	Off-Highway Trucks	2	22578	1000	2008	5.46	18.50	61.36	0.05	4,802.76	0.49	23,891.22
18	Off-Highway Trucks	3	32526	1000	2008	7.87	26.64	88.40	0.07	6,918.88	0.71	34,417.84
19	Other Construction Equipment	2	4248	500	2003	0.37	1.35	4.28	0.00	444.97	0.03	1,777.50
20	Other General Industrial Equipment	1	4398	1000	2002	1.32	5.03	14.12	0.01	1,014.00	0.12	5,410.11
21	Other General Industrial Equipment	2	2754	1000	2008	0.65	2.41	7.12	0.01	524.76	0.06	2,740.28
22	Other General Industrial Equipment	3	4788	1000	2008	1.14	4.19	12.38	0.01	912.33	0.10	4,764.14
23	Other Material Handling Equipment	1	7614	9999	2002	3.01	11.51	32.29	0.02	2,325.61	0.22	12,375.61
24	Other Material Handling Equipment	3	9396	9999	2008	2.94	10.88	32.08	0.02	2,371.82	0.27	12,356.07
25	Rollers	0	16662	500	1997	1.97	8.32	20.56	0.02	1,819.95	0.18	8,221.51
26	Rollers	1	5076	500	1998	0.60	2.53	6.26	0.01	554.44	0.05	2,504.64
27	Rollers	2	22176	500	2003	2.17	9.15	22.61	0.02	2,001.84	0.20	9,043.13
2	Rollers	3	4098	500	2008	0.31	1.28	3.26	0.00	305.73	0.03	1,321.48

8												
29	Rubber Tired Dozers	1	5382	1000	2002	2.12	11.22	20.61	0.01	1,312.47	0.19	7,740.10
30	Rubber Tired Dozers	2	33348	1000	2008	10.39	53.96	102.43	0.07	6,720.95	0.94	38,654.77
31	Rubber Tired Dozers	3	10314	1000	2008	3.21	16.69	31.68	0.02	2,078.68	0.29	11,955.30
32	Rubber Tired Loaders	1	1206	1000	2002	0.36	1.41	3.98	0.00	295.08	0.03	1,533.37
33	Scrapers	2	10770	750	2003	3.21	14.85	31.26	0.02	2,463.93	0.29	12,204.31
34	Scrapers	3	4194	750	2008	0.99	4.40	9.56	0.01	792.97	0.09	3,770.42
35	Skid Steer Loaders	1	6582	120	1999	0.28	0.96	1.72	0.00	140.31	0.02	678.33
36	Skid Steer Loaders	2	7110	120	2004	0.25	0.86	1.54	0.00	125.26	0.02	605.54
37	Skid Steer Loaders	3	4950	120	2004	0.17	0.60	1.07	0.00	87.21	0.02	421.58
38	Tractors/Loaders/ Backhoes	1	15942	750	1998	3.73	12.22	41.62	0.05	4,111.09	0.34	17,058.01
39	Tractors/Loaders/ Backhoes	2	33216	750	2003	6.42	21.03	71.67	0.08	7,079.06	0.58	29,372.93
40	Tractors/Loaders/ Backhoes	3	23046	750	2008	3.46	11.26	38.22	0.05	4,059.18	0.31	15,947.85
	TOTAL		**467892**			**100.97**	**394.47**	**1073.9**	**0.90**	**87,420.38**	**9.06**	**421,689.27**

Appendix N: ICC input data & emissions calculation for site-preparation component of model.

DEFORESTATION EMISSIONS:

Type of trees	Area Trees		EF (MT C/ha)	C Conversion	EM (MT of CO_2)
	Acres	ha			
All	247	100.035	118.2	3.67	43394.583
1 unit C = 3.67 unit CO_2					

SOIL MOVEMENT EMISSIONS:

Type of Organic soil	Volume of Soil		Area (assuming 1 m depth removed)		EF (MT of C/ha)	C Conversion	EM (MT of CO_2)
	Cubic yds	cubic meters	square meter	ha			
All	2347301	1795685.265	1795685.265	179.569	69.7	3.67	45933.450
1 unit C = 3.67 unit CO_2							

Total Site-preparation emissions	89328.032	MT of CO_2

Appendix O: ICC input data & emissions calculation for materials component of model.

Cement Type	Portland
Fraction of Clinker (since Portland)	0.96
Clinker Blend (assumed)	65% $CaCO_3$
Emission Factor Used (for $CaCO_3$ blend)	0.51 tons CO_2/ton clinker

Constructed Structure	Quantity of Structure Used (Cubic Yds)	Cement Content in Structure	Quantity of Cement	
			lbs	MT
Place Substructure Concrete	17302	377 lbs/Cubic yd	6522854	2935.28
Place Superstructure Concrete	10203	459 lbs/Cubic Yd	4683177	2107.43
Culvert Wingwalls/Headwalls	2639	459 lbs/Cubic Yd	1211301	545.09
Bridge Approach Slabs	11750	459lbs/Cubic Yd	5393250	2426.96
TOTAL			17810582	8014.78

Emissions from cement use	**3924.03**	**MT of CO_2**
Emissions from concrete use on-site (assumed to be 1% of cement emissions)	**0.01(3924.03) = 39.24**	**MT of CO_2**
Emissions from coatings/solvents & fertilizers use on-site (assumed to be 2% of cement emissions)	**0.02(3924.03) = 78.48**	**MT of CO_2**
Total Materials Production Emissions	**117.72**	**MT of CO_2**

Appendix P: ICC input data & emissions calculation for environmental impact mitigation of model.

Tree Type	Analogous Tree Type	Quantity	% of Total
Red Maple	Maple/Beech/Birch	144	
Black Gum	Maple/Beech/Birch	144	
River Birch	Maple/Beech/Birch	144	
Silver maple	Maple/Beech/Birch	144	
Sycamore	Maple/Beech/Birch	144	
Musclewood	Maple/Beech/Birch	144	
Red Maple	Maple/Beech/Birch	463	
Black Gum	Maple/Beech/Birch	463	
Sycamore	Maple/Beech/Birch	463	
Red Maple	Maple/Beech/Birch	514	
Sycamore	Maple/Beech/Birch	514	
Black Gum	Maple/Beech/Birch	513	0.38
Swamp White Oak	Oak/Hickory	143	
Northern Red Oak	Oak/Hickory	462	
White Oak	Oak/Hickory	462	
Northern Red Oak	Oak/Hickory	513	
White Oak	Oak/Hickory	513	0.21
Pin Oak	Oak/Pine	144	
Sassafras	Oak/Pine	463	0.06
Yellow Poplar	Spruce/Fir	144	
Eastern Red Cedar	Spruce/Fir	463	
Eastern Redbud	Spruce/Fir	463	
Yellow Poplar	Spruce/Fir	463	
Yellow Poplar	Spruce/Fir	514	0.36

Eastern Red Cedar	Spruce/Fir	513	
RedBud	Spruce/Fir	513	
Persimmon	Spruce/Fir	513	

	Acres	ha
Total Area of Reforestation (1:1)	206	83.43
Tree spacing used for reforestation	(10'x12')	0.0011
Number of trees reforested	75845	

Tree Type	Percentage of Reofrestation Population (%/100)	Number of Trees estimated to be planted *[a] (Total number of trees x Percent population)	Non-Soil EF (MT of C/ha)	EM (MT of CO_2) *[b]
Maple/Beech/Birch	0.38	28547	2.1	242.02
Oak/Hickory	0.21	15748	2.1	133.51
Oak/Pine	0.06	4567	4.2	77.44
Spruce/Fir	0.36	26982	2.1	228.75
TOTAL	**1.00**	**75845**		**681.72**
*[a] *Rounded up to whole numbers*				
*[b] *Coversion factor used: 1 unit C = 3.67 units* CO_2				

Total area resoiled (assuming 1m depth)	Acres	ha
	206	83.43
Average soil EF(MT C/ha)	56.26	
C Conversion	3.67	
EM Resoil (MT CO2)	17226.14	

Total Environmental Impact Mitigation	17907.86 MT CO_2

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