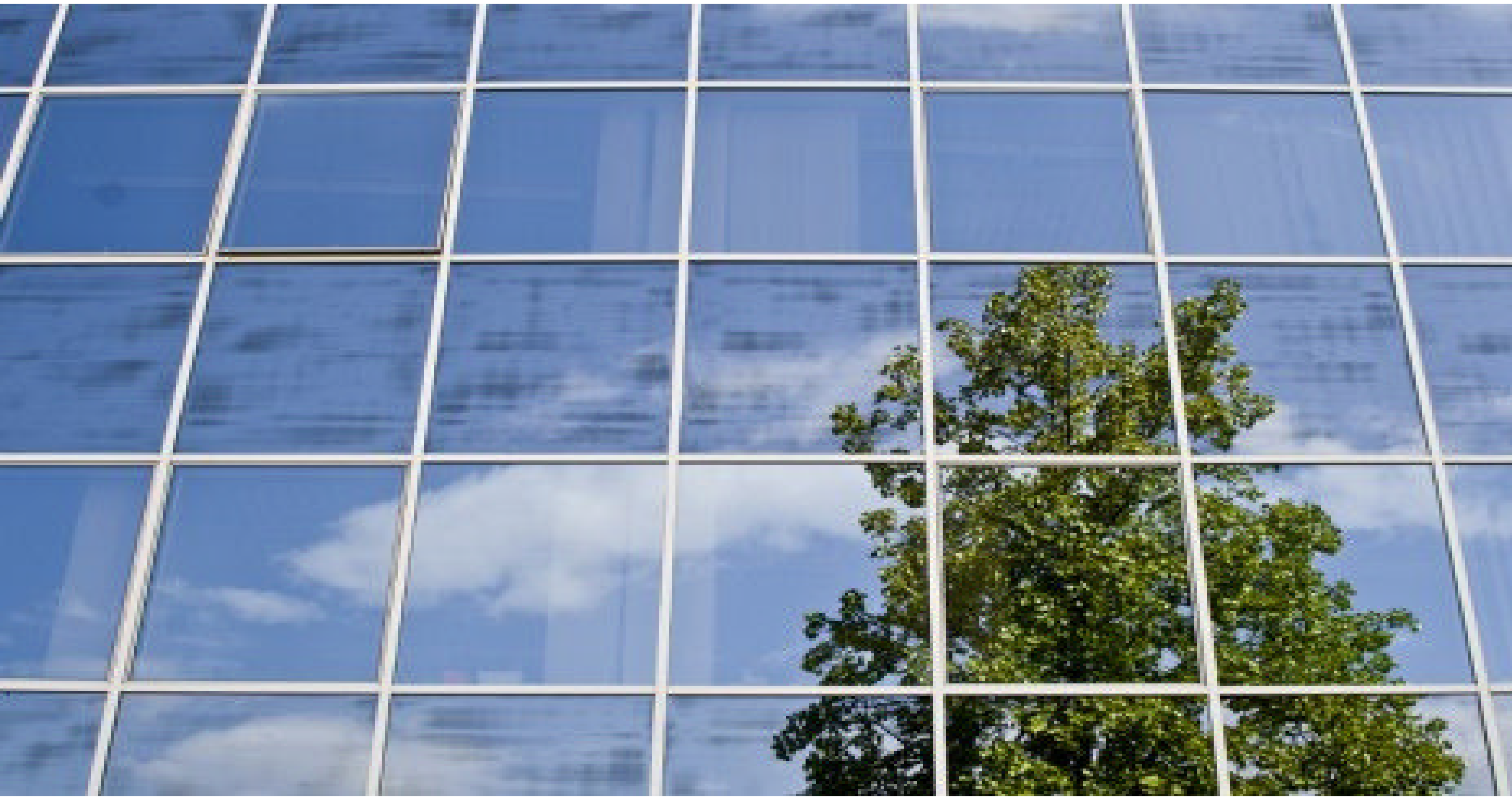
Potential for Reducing Greenhouse Gas Emissions in the Construction Sector



February 2009

SectorStrategies

FOR MORE INFORMATION

ABOUT THIS REPORT OR EPA'S SECTOR STRATEGIES PROGRAM

WITH THE CONSTRUCTION INDUSTRY, PLEASE CONTACT:

Peter Truitt

National Construction Sector Lead

U.S. Environmental Protection Agency (Mailcode 1807T)

1200 Pennsylvania Ave, NW

Washington, DC 20460

truitt.peter@epa.gov

Table of Contents

Acronyms and Abbreviations ____ ii

Introduction ____ 1

1 Characterizing the Construction Sector's Greenhouse Gas Emissions ____ 3

1.1 Characterization of Emissions ____ 3
Breakdown of Emissions Sources ____ 4
Comparing Emissions Estimates ____ 5
Subsector Emissions ____ 6
Emissions Intensity ____ 7

1.2 Projections of the Future Greenhouse Gas Impacts of Construction ____ 9

2 Evaluating Opportunities to Reduce Emissions ____ 11

2.1 Reducing Fuel Use ____ 11
Reduced Idling ____ 12
Equipment Maintenance ____ 14
Driver Training ____ 14
Properly Sized Equipment ____ 15
Replaced or Repowered Equipment ____ 15
Biofuels for Trucks and Nonroad Equipment ____ 16
Alternatives to Diesel Generators ____ 18
Employee Commuting ____ 19

2.2 Conserving Electricity ____ 20

2.3 Reducing Impacts of Construction Materials ____ 21
Recycling and Reuse ____ 21
Materials Selection, Procurement, and Shipment Methods ____ 24

3 Calculating Company-Specific Greenhouse Gas Emissions ____ 26

3.1 Existing Calculation Guidance ____ 26

3.2 Current Approaches in Construction Industry Inventories ____ 27

3.3 Construction-Specific Calculation Tool ____ 28

4 Summary ____ 29

Appendix A: Subsector Size and Sources of Emissions ____ 31

Appendix B: Details of 2002 Construction Subsector Emissions Intensity ____ 34

Appendix C: Construction Subsector Descriptions of 2002 NAICS Codes ____ 36

Endnotes ____ 39

Acronyms and Abbreviations

AEO	*Annual Energy Outlook*
ANL	Argonne National Laboratory
ASTM	American Society for Testing and Materials
C&D	Construction and demolition
CH_4	Methane
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalents
DOE	U.S. Department of Energy
EIA	Energy Information Association
FLEET	Freight Logistics Environmental and Energy Tracking
GDP	Gross domestic product
GHG	Greenhouse gas
HFC	Hydrofluorocarbon
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
kWh	Kilowatt-hour
MMT	Million metric tons
Mpg	Miles per gallon
N_2O	Nitrous oxide
NAICS	North American Industry Classification System
PFC	Perfluorocarbon
SF_6	Sulfur hexafluoride
WBCSD	World Business Council for Sustainable Development
WRI	World Resources Institute

INTRODUCTION

With growing attention to the impact of greenhouse gas (GHG) emissions on climate change, and in an effort to better understand the construction industry's emissions, EPA's Sector Strategies Division has developed this report on the sources and magnitude of construction GHG emissions and ways to reduce them. Although numerous studies are available that help companies identify and quantify their GHG emissions, none of them are specific to the construction industry. This document examines opportunities explicitly for construction companies.

GHGs are necessary to life as we know it, because they keep the planet's surface warmer than it otherwise would be. But, as the concentrations of these gases continue to increase in the atmosphere, the Earth's temperature is climbing above past levels. According to NOAA and NASA data, the Earth's average surface temperature has increased by about 1.2 to 1.4ºF in the last 100 years. The eight warmest years on record (since 1850) have all occurred since 1998, with the warmest year being 2005. Most of the warming in recent decades is very likely the result of human activities. Other aspects of the climate are also changing, such as rainfall patterns, snow and ice cover, and sea level.[1]

If greenhouse gases continue to increase, climate models predict that the average temperature at the Earth's surface could increase from 3.2 to 7.2ºF above 1990 levels by the end of this century. Scientists are certain that human activities are changing the composition of the atmosphere, and that increasing the concentration of greenhouse gases will change the planet's climate. But they are not sure by how much it will change, at what rate it will change, or what the exact effects will be.[2]

The construction sector plays an essential role in improving the environment by continuing to improve the environmental performance of the country's buildings and infrastructure. Because of its products' longevity, the construction industry is in a unique position to support environmental benefits both through everyday jobsite practices and through lasting structural improvements. Throughout this document, the construction industry is defined as the national economic sector engaged in "the preparation of land and the construction, alteration, and repair of buildings, structures, and other real property."[3] This report's definition of construction activities does not include activities prior to construction, such as design, siting of buildings, or specification of materials, nor does it include the operation of structures following construction.

The purpose of this report is not to suggest or propose GHG policies for the construction industry; this paper does not recommend nor discuss any government actions to reduce emissions. Instead, the information presented represents an overview of current knowledge on the sources of construction GHG emissions. The opportunities to reduce emissions presented within this document are meant to illustrate possible approaches to GHG reductions, based on the best available information. Topics such as biofuels and materials recycling have been included to better address the GHG implications of increasingly popular "green construction" practices.

Characterizing the GHG emissions of the construction sector presents challenges, most notably due to the large number of firms (estimated at more than 800,000) and the even larger number of construction sites where the majority of emissions occur.[4] Limited data are available to accurately estimate collective, sector-wide emissions from the hundreds of thousands of construction firms. The estimates that are available are presented in Section 1, which also highlights key assumptions made in the calculations. In addition to total emissions, an overview of emissions intensity (emissions per dollar value added) provides another metric to assess the construction sector's impact compared with those of other industrial sectors. Both emissions and emissions intensity are characterized for the three major subsectors: Buildings, Heavy and Civil Engineering, and Specialty Trades.

If a large number of small GHG emissions sources within the construction industry were to adopt energy- and climate-conscious practices, aggregate emissions could be reduced substantially. Opportunities for reducing emissions are presented in Section 2, including practical and low-cost changes in operations. Consistency and clarity in calculating emissions are important in order to compare emissions within and across sectors, and for companies to plan and assess progress. Section 3 presents information on GHG inventory protocols that are publicly available and frequently used, and examines the attributes of a protocol that would be useful for companies in the construction sector.

1 Characterizing the Construction Sector's Greenhouse Gas Emissions

In 2002, the construction industry produced approximately 1.7% of total U.S. greenhouse gas emissions. Equivalent to 6% of total U.S. industrial-related greenhouse gas emissions, this quantity places construction as one of the top emitting sectors.[5] Although construction practices typically do not produce large quantities of GHGs compared to the operations of many other sectors, the sheer number of construction projects results in significant aggregate emissions for the sector.

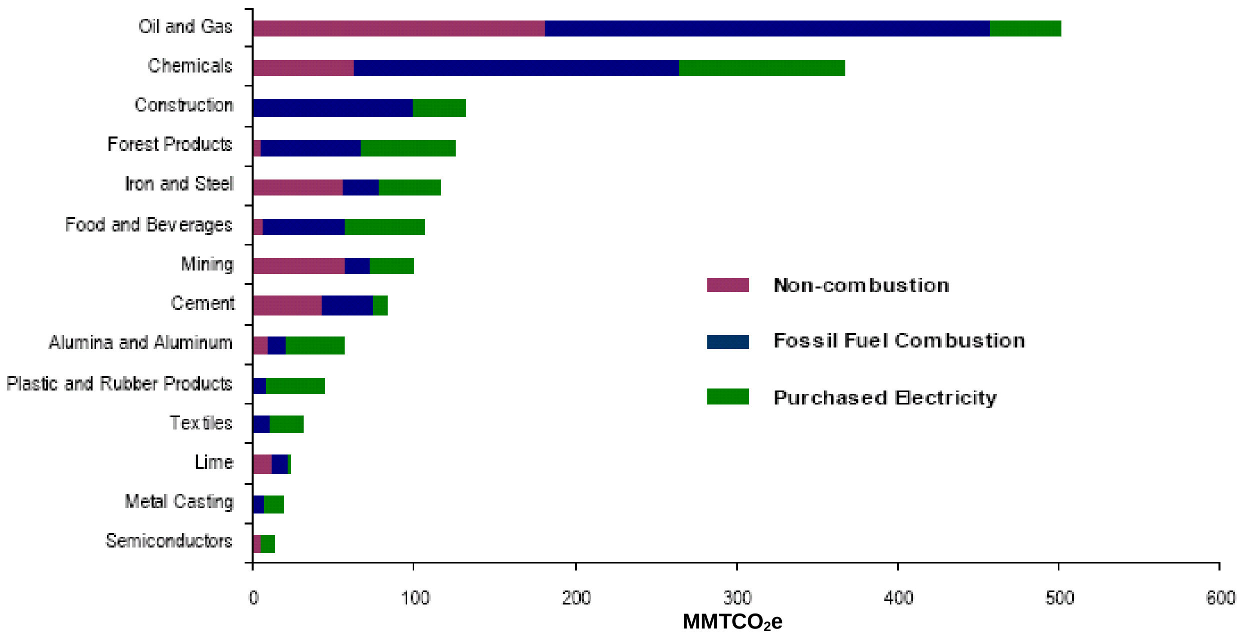
To provide a better understanding of the sector's GHG emissions, Section 1 discusses the data and methods used to calculate the tons of GHG emissions for the sector. Current emissions accounting includes only traditionally quantified emissions sources: fossil fuel combustion and purchased electricity. Future accounting may include lifecycle emissions, such as emissions from the production and transport of the materials used or waste disposed, which would provide a more complete estimate of the impact of construction activities.

In addition to the measure of the tons of GHGs emitted, "emissions intensity" (emissions per dollar of value added) provides another metric of environmental performance that also takes into account economic performance. Emissions intensity may be useful to identify sectors or subsectors with highly emissive processes. To meaningfully interpret the emissions intensities of construction subsectors requires prior knowledge of the factors and processes that affect both emissions and value added.

1.1 Characterization of Emissions

The Sector Strategies Division of EPA recently released the report *Quantifying Greenhouse Gas Emissions in Key Industrial Sectors in the U.S.*, which presents historical emissions estimates for 14 industrial sectors that produce 84% of industrial GHG emissions in the United States. According to this report, the construction sector produced 6% of total U.S. industrial GHG emissions in 2002.[6] As shown in Figure 1, the construction sector has the third highest GHG emissions among the industrial sectors analyzed. In this figure, GHG emissions are grouped by three broad categories of activities: fossil fuel combustion, purchased electricity, and non-combustion activities. Fossil fuel combustion is the use of fossil fuels, such as gasoline, diesel, or coal, to produce heat or run equipment. Purchased electricity is the quantity of GHGs resulting from the generation of purchased electric power. Non-combustion activities include the production of GHGs from other processes or reactions, such as when CO_2 is released during the calcination stage of lime production.

Figure 1: 2002 Greenhouse Gas Emissions from Key Industrial Sectors



Notes: Depending on the sector, emissions may include CO_2, methane (CH_4), and nitrous oxide (N_2O). For construction, only CO_2 emissions are reported for fossil fuel combustion.
$MMTCO_2e$ = million metric tons of CO_2 equivalents.
Source: Reprinted from U.S. EPA, *Quantifying Greenhouse Gas Emissions in Key Industrial Sectors in the U.S.*, Sector Strategies Division, May 2008, Figure 1-4.

Breakdown of Emissions Sources

For the construction industry, the two major sources of emissions included in the *Quantifying Greenhouse Gas Emissions in Key Industrial Sectors* report relate to fossil fuel combustion, primarily from construction equipment, and fuel use from purchased electricity. The report estimated that in 2002 the construction sector released 131 million metric tons of CO_2 equivalents, as shown in Table 1.

Table 1: Construction Sector Greenhouse Gas Emissions, 2002

Emissions source	*Million metric tons of CO_2e*	*Percent of total*
Fossil Fuel Combustion	100	*76 %*
Purchased Electricity	31	*24 %*
Total	**131**	

Source: U.S. EPA, *Quantifying Greenhouse Gas Emissions in Key Industrial Sectors in the U.S.*, Sector Strategies Division, May 2008.

Note: Fossil fuel combustion is an estimate of CO_2 emissions only. Purchased electricity is an estimate of CO_2, CH_4, and N_2O emissions. To remain consistent with the source report cited above, the total quantity is presented in units of CO_2e.

FOSSIL FUEL COMBUSTION—For 2002, the *Quantifying Greenhouse Gas Emissions in Key Industrial Sectors* report estimated that the construction sector released 100 million metric tons of CO_2 from fossil fuel combustion. This estimate was derived using the *2002 Economic Census* data of the dollars the sector spent on fuel purchases, divided by the average 2002 cost per gallon of diesel and gasoline from EIA's *State Energy Data Report* to calculate the gallons of fuel purchased. Gallons were then converted to CO_2 emissions using EPA emissions factors for mobile combustion fuels. Fossil fuel combustion includes emissions from on- and off-highway construction vehicle combustion of gasoline and diesel fuel, natural gas combustion for office power, heating and tools, and diesel used for generators. Gasoline and diesel fuel combustion accounted for approximately 88 million metric tons of CO_2, and consumption of natural gas accounted for approximately 12 million metric tons. The data sources used to calculate the emissions do not provide information on gasoline and diesel consumption separately. Therefore, the report used the following assumptions: 50% of on-highway construction vehicles use diesel and 50% use gasoline, and all off-highway vehicles consume only diesel fuel. The emissions calculation does not take into account emissions of N_2O or CH_4, which can vary by vehicle emissions control technologies. These additional GHG emissions could be significant for older heavy-duty equipment without recent emissions control technologies.[7]

PURCHASED ELECTRICITY—The *Quantifying Greenhouse Gas Emissions in Key Industrial Sectors* report estimated that the electricity that the construction sector purchased resulted in the release of 31 million metric tons of CO_2 equivalents in 2002. Emissions from purchased electricity result from fuel combusted at the power plant. The report calculated these emissions from sector-reported electricity purchases, using an average national emissions factor for 2004 from EPA's eGRID model of electricity sources.[8]

COMPARING EMISSIONS ESTIMATES

In addition to the emissions estimate of 131 million metric tons of CO_2e from construction sector fuel combustion and purchased electricity presented in the *Quantifying Greenhouse Gas Emissions in Key Industrial Sectors* report, two other sources provide estimates of the sector's GHG emissions:

- The Energy Information Association (EIA) of DOE produces an analysis of CO_2 emissions from the construction sector as a supplement to its *Annual Energy Outlook (AEO)*. For 2002, *AEO 2008* estimated construction sector emissions from fossil fuel combustion and purchased electricity as 77.4 million metric tons of CO_2. The *AEO 2008* produces estimates as model output of the EIA National Energy Modeling System's Industrial Sector Demand module, based on multiple inputs.[9]
- EPA calculates GHG emissions from the construction sector for its annual *Inventory of U.S. Greenhouse Gas Emissions and Sinks.* The most recent *Inventory* estimated CO_2 emissions from the construction and mining sectors in 2002 as 57.9 million metric tons of CO_2 for non-transportation mobile sources (i.e., sources that do not move people or goods) only. These estimates were developed from EPA's NONROAD model and FHWA's Highway Statistics.

Direct comparisons of the different emissions estimates are complicated by the widely-varying methods they use to estimate emissions. The *Quantifying Greenhouse Gas Emissions in Key Industrial Sectors* report used data on the dollars spent on electricity and fuel, which were converted to physical units based on national average purchase prices. The *AEO* and EPA *Inventory* methods use multiple inputs and each uses a different model to estimate emissions. The EPA *Inventory* estimate is less comparable in that it includes only non-transportation mobile sources, and presents construction and mining emissions as one aggregated value. The estimates of emissions reductions presented in Section 2 of this report are based on the values and methods from *Quantifying Greenhouse Gas Emissions in Key Industrial Sectors*.

Subsector Emissions

The 2002 Economic Census *Industry Series* reports fuel consumption and purchased electricity by subsector; therefore, emissions can be attributed to each of the construction subsectors defined by the North American Industry Classification System (NAICS).[10] Following the method of the *Quantifying Greenhouse Gas Emissions in Key Industrial Sectors* report, the estimated emissions for the construction subsectors are shown in the pie chart in Figure 2. As noted in Table 1, the method used to estimate emissions combines CO_2 emissions only for fossil fuel combustion, and CO_2e emissions for purchased electricity. The totals are presented in Figure 2 as CO_2e to be consistent with the source document. Also note that approximately 97% of the total CO_2e emissions from fossil fuel combustion are attributable to CO_2.[11] Subsectors in Figure 2 are defined at the five-digit NAICS level. With the exception of Industrial Building Construction, subsectors that contribute 5% or less of the total industry emissions are included in the "Other subsectors" categories.

Figure 2: Construction Industry Subsector Emissions in 2002

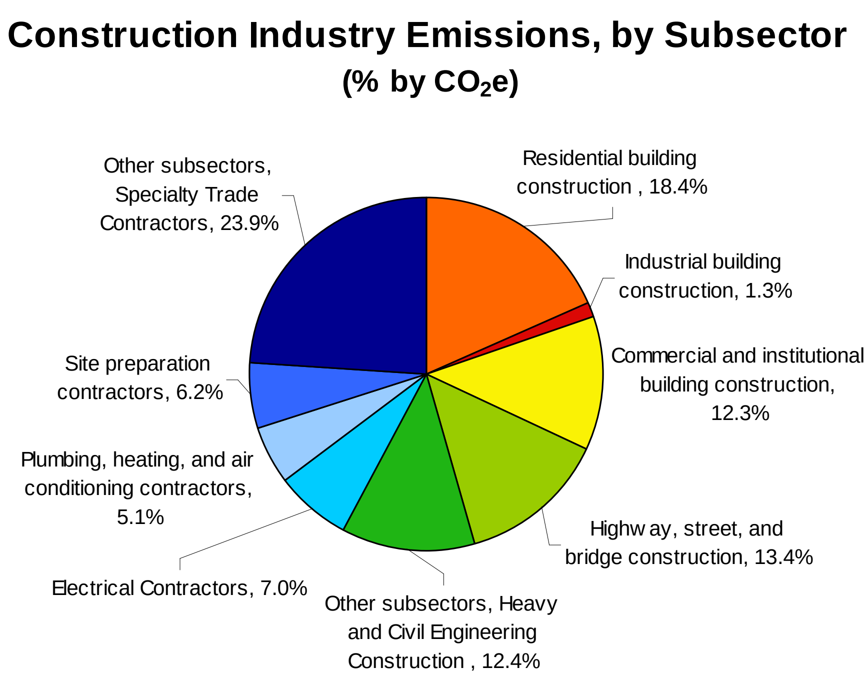


Table 2: Proportion of Construction Subsector Emissions and Establishments (by 3-digit NAICS code)

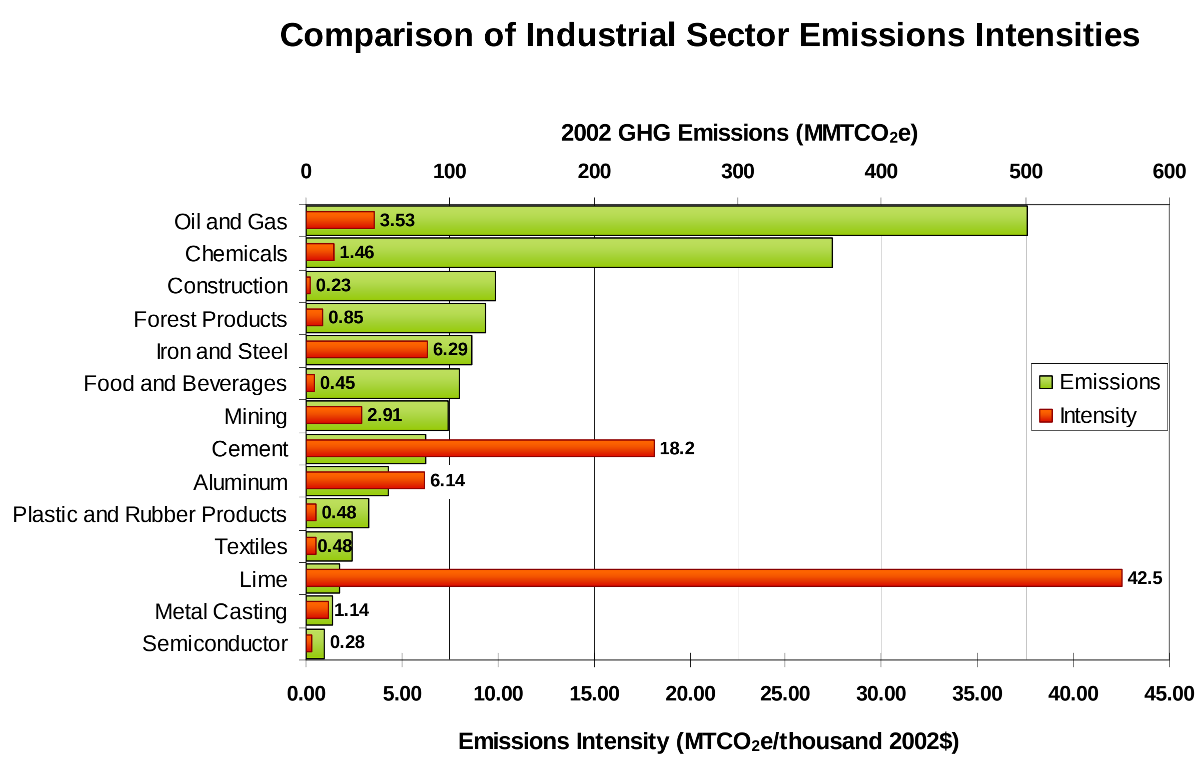
NAICS Code	Subsector Description	Proportion of Total Sector Emissions	Proportion of Total Establishments
236	*Construction of Buildings*	32%	30%
237	*Heavy and Civil Engineering*	26%	7%
238	*Specialty Trade Contractors*	42%	63%

For context, Table 2 presents the proportion of the sector's establishments in each of the three major subsectors, along with the contribution of each subsector to total construction GHG emissions. To better understand subsector emissions, it is important to consider whether the driving cause of emissions is a subsector's emissions-producing activities or its size. Appendix A provides a table of the more detailed subsectors, with the associated emissions by source (i.e., purchased electricity, natural gas consumption, or on-highway and off-highway vehicle fuel use) and the number of establishments. Emissions intensity, presented in more detail in the following section, provides a metric to view the subsector's emissions in the context of its relative economic size.

Emissions Intensity

Emissions intensity provides a means for comparing sectors' emissions while taking into account economic output. Emissions intensity is typically calculated as a ratio of the GHG emissions produced per dollar of gross domestic product (GDP). In portraying industry-specific emissions intensity, the most analogous measure to GDP is the value added by the industry. The 2002 Economic Census provides information on the value added by the construction industry and its subsectors.

Figure 3: Emissions Intensities for Key Industrial Sectors, in metric tons CO_2e/2002k$



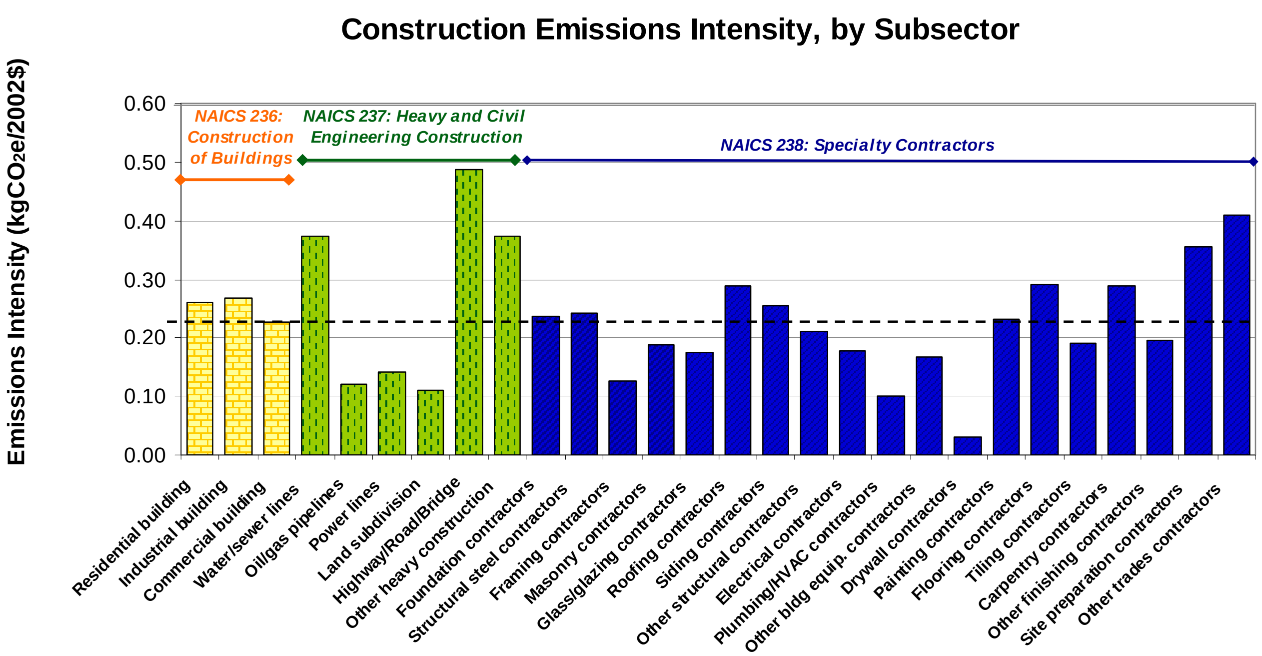
Note: $MTCO_2e$ = metric tons of CO_2 equivalents; $MMTCO_2e$= million metric tons CO_2 equivalents.

Source: Emissions values used in the emissions intensity calculations for 2002 from the *Quantifying Greenhouse Gas Emissions in Key Industrial Sectors in the U.S.* EPA report (May 2008). Value added for emissions intensity calculations taken from the 2002 Economic Census *Industry Series* reports, aggregated by sector by the method defined for emissions estimates in the *Quantifying Greenhouse Gas Emissions in Key Industrial Sectors in the U.S.* EPA report. Construction industry value added compiled from subsector 2002 Economic Census *Industry Series* reports, Table 4.

Figure 3 presents emissions intensities for the industries identified in the *Quantifying Greenhouse Gas Emissions in Key Industrial Sectors* report, in order of decreasing absolute emissions (shown in the same order as Figure 1). In comparison to other industrial sectors identified in this report, the construction industry had the lowest 2002 emissions intensity at 0.23 metric tons of CO_2 equivalents per thousand 2002 dollar ($MTCO_2e$/2002k$), and the lime and cement sectors had the highest intensities at 42.5 and 18.2 $MTCO_2e$/2002k$, respectively.

Figure 4 compares emissions intensities among construction subsectors as defined by five-digit NAICS codes. The variety of processes within the construction sector leads to significantly different emissions intensities across subsectors, as shown in Figure 4 and Appendix B. For example, the highway, street, and bridge construction subsector (NAICS code 23731) has a much higher emissions intensity than power and communication line construction (NAICS code 23713). Value added for the highway, street, and bridge construction subsector is 1.6 times greater than for the power and communication line construction subsector, yet emissions by highway, street, and bridge construction are more than five times those of the power and communication line construction.

Figure 4: Construction Industry Emissions Intensity, with Breakdown by Subsector, in $MTCO_2e$/2002k$



Note: A table of emissions and value added for each subsector is available in Appendix B, and descriptions of NAICS codes for construction subsectors are located in Appendix C.

Differences in emissions intensity may also reflect differences in the subsectors' value added. Plumbing, heating, and air conditioning contractors (NAICS 23822) and all other specialty trade contractors (NAICS 23899) produce approximately the same emissions, but the value added by plumbing, heating, and air conditioning contractors is approximately four times greater than that of the all-other-specialty trade contractor subsector. The result is that the emission intensity for the plumbing subsector is one-fourth that of the all-other-specialty trade subsector.

	Table 3: Top and Bottom Five Construction Subsector Emissions Intensities, by Five-Digit NAICS Code		
	2002 NAICS	**Subsector Description**	**Intensity ($MTCO_2e$/2002k$)**
Top 5	23731	*Highway, street, and bridge construction*	**0.49**
	23899	*All other specialty trade contractors*	**0.41**
	23711	*Water and sewer line and related structures construction*	**0.37**
	23799	*Other heavy and civil engineering construction*	**0.37**
	23891	*Site preparation contractors*	**0.36**
Bottom 5	23829	*Other building equipment contractors*	**0.17**
	23713	*Power and communication line and related structures construction*	**0.14**
	23813	*Framing contractors: Carpentry*	**0.13**
	23822	*Plumbing, heating, and air conditioning contractors*	**0.10**
	23831	*Drywall and insulation contractors*	**0.03**

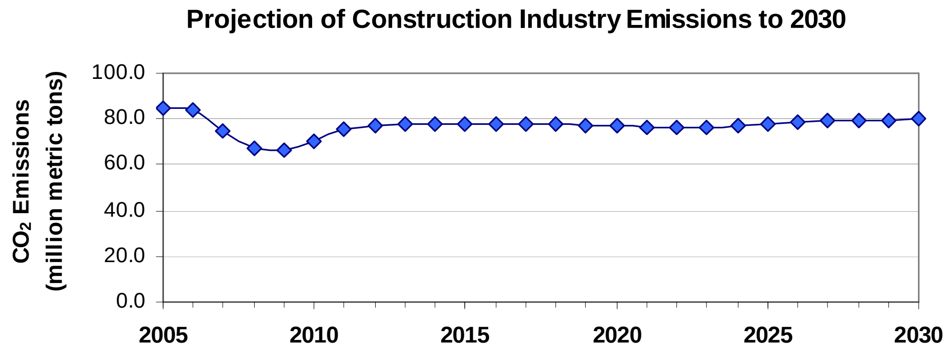
In summary, differences in an industry's emissions intensity may result from any or all of the following factors: the amount of energy used, the fuel mix used, the size and number of firms, or the economic production of the sector. Over time, decreasing emissions intensity may indicate decreasing energy use in the sector, but it may instead indicate increasing economic production. Therefore, emissions intensity is not sufficient to identify or compare any reductions in emissions unless combined with an understanding of the subsector's absolute emissions and the value added.

1.2 Projections of the Future Greenhouse Gas Impacts of Construction

EIA's *Annual Energy Outlook* provides annual projections of U.S. energy supply and demand to the year 2030. As part of its analysis of industrial sectors, the *AEO* provides annual estimates of CO_2 emissions from the construction industry's fossil fuel combustion and purchased electricity. To produce the *AEO* projections, economic factors and technology predictions are provided to an integrated economic model, which in turn produces estimates of energy consumption based on the sources' related economic impacts. As a result, both energy consumption and emissions are derived from corresponding economic factors. According to the recent *AEO 2008*, the construction sector and its CO_2 emissions are particularly affected by the recent slowdown in the U.S. economy in the near term.[12]

The sector's long-term energy consumption is not expected to grow significantly, even when the sector's growth resumes, due to expected advances in technology and changes in fuel use, including increased use of biofuels and renewable energy to generate electric power. By 2030 construction energy is not expected to surpass historic levels of consumption. Figure 5 shows that aggregate construction CO_2 emissions are expected to decline slightly from 2005 levels by 2030. Economic projections show that construction value added will increase much more significantly than emissions, suggesting an overall decrease in emissions intensity.

Figure 5: Projection of Construction Industry CO_2 Estimates to 2030



Note: AEO provides estimates of CO_2 emissions only. The dip in emissions is related to recent decreases in construction activity.
Source: EIA, *Annual Energy Outlook 2008,* June 2008.

Projections for construction and six other industrial sectors show the construction industry to have the highest average annual rate of increase in emissions from 2011 through 2030.[13,14] The construction increase, however, is only 0.3% per year. Additional emissions reduction efforts by the construction industry could possibly reverse the projected trend to bring a decline in total emissions.

2 Evaluating Opportunities to Reduce Emissions

Construction contractors may have control over many of the activities associated with GHG emissions at a construction site, such as how efficiently they use fuel and electricity. However, other decisions that result in GHG emissions (e.g., materials selection and site selection) are usually made by project owners and architects, not by contractors. The following table lists the construction activities that result in GHG emissions, and categorizes each activity by contractors' potential ability to affect emissions.

Figure 6: Contractors' Influence on Activities Resulting in GHG Emissions

Most Influence		
Fuel selection	Equipment idling	Electricity use
Equipment maintenance	Equipment selection	Materials recycling

Some Influence Possible	
Materials selection	Employee commuting
Materials shipment	Vegetation removal

Little Influence	
Site selection	Structure design and performance

This section examines options for reducing greenhouse gas emissions associated with construction activities, focusing on the activities that construction companies control or influence. The options and scenarios presented in this section are based on currently available technologies and techniques, where emissions reduction can be realized in the near term. In the long term, future changes in available technologies and fuels will likely result in additional or different options. In Sections 2.1 and 2.2, we present options for reducing GHG emissions through reductions in fuel and electricity consumption, where the most direct and measurable emissions reductions can be realized. Recent focus has also turned to considering the emissions related to the entire construction supply chain from a lifecycle perspective. In Section 2.3, we present emissions reduction options related to the construction lifecycle, such as materials reuse and recycling. We present the emissions and costs associated with each option, when these are available. In most cases, the emissions reductions and costs are rough estimates, included to provide the general magnitude of emissions reductions possible. Unfortunately, the quantitative information needed for more-precise estimates is not currently available.

2.1 Reducing Fuel Use

Estimates presented in Section 1 indicate that approximately three-quarters of the GHG emissions from the construction sector result from diesel, gasoline, and natural gas combustion. The GHG reduction options presented in this section focus on reducing the emissions from fuel combustion, primarily by improving fuel efficiency. Better fuel efficiency results in less fuel consumed to complete the same job, thereby reducing emissions as well as fuel costs. Often, the steps taken to improve fuel efficiency also result in other benefits, including increased equipment life and reduced emissions of other air pollutants such as particulate matter. Historically, fuel costs have not constituted a large portion of construction firms' operating budgets[15], and thus many contractors have not focused on reducing their fuel use. Fuel costs are rising, however, and with increased costs, fuel efficiency is expected to become a higher priority for construction contractors. As contractors implement techniques to reduce their fuel costs, they will simultaneously reduce their GHG emissions.

Table 4 presents CO_2 emissions factors for the fuels most commonly used in the construction sector. The emission factor for diesel fuel indicates that 22.37 lbs of CO_2 are emitted for every gallon of diesel combusted, and 19.54 lbs of CO_2 are emitted for one gallon of gasoline. The last two columns in the table present the estimated tons of CO_2 emissions that could be reduced in the United States if the construction sector reduced use of the fuel by 3% or by 10%. These percent values were selected as a practical way to illustrate the magnitude of emissions reductions associated with the two different levels of improvements, and are used throughout this section of the report. For example, if the construction sector as a whole reduced diesel fuel use by 10%, the reduction in CO_2 emissions would be an estimated 14.8 billion lbs (6.73 million metric tons) of CO_2. A 10% reduction in diesel fuel use would reduce construction sector CO_2 emissions from all energy sources by approximately 5%.

Table 4: GHG Emissions Reduction Scenarios from Reduced Fossil Fuel Use

Fuel	Emissions (lbs CO_2/unit material)	Estimate of Sector-Wide Emissions Reductions*	
		Using 3% less fuel	*Using 10% less fuel*
Diesel	22.37 lbs CO_2/gallon	4,455 million lbs CO_2 2.02 $MMTCO_2$	14,849 million lbs CO_2 6.73 $MMTCO_2$
Gasoline	19.54 lbs CO_2/gallon	1,383 million lbs CO_2 0.63 $MMTCO_2$	4,609 million lbs CO_2 2.09 $MMTCO_2$
Propane	12.66 lbs CO_2/gallon	NA**	NA**
Natural gas	11.7 lbs CO_2/1,000 ft^3	786 million lbs CO_2 0.36 $MMTCO_2$	2,620 million lbs CO_2 1.19 $MMTCO_2$

Notes: Emissions factor for diesel and gasoline converted from EPA's 2008 *Inventory of Greenhouse Gases 1999-2006*, Table A-29 and A-30. Emissions factor for propane and natural gas converted from EIA data sources.
$MMTCO_2$ = million metric tons of CO_2
* Estimate of possible emissions savings from percentage reductions, based on the 2002 fuel consumption estimates and assumptions used in the EPA report, *Quantifying Greenhouse Gas Emissions in Key Industrial Sectors in the U.S.* (May 2008). Numbers presented are for the purpose of illustrating the magnitude of possible reductions only and should not be interpreted as absolute quantities. No Economic Census data are available to estimate sector-wide propane consumption.
** NA = Data not available.

To achieve improvements in fuel efficiency and realize the associated reductions in GHG emissions, contractors can make changes ranging from reducing equipment idling time and improving maintenance to replacing or repowering equipment. Information on these and other options follows.

Reduced Idling

Unnecessary idling occurs when trucks wait for extended periods of time to load or unload, or when equipment that is not being used is left on, such as to maintain heating or cooling for driver comfort. Reduced idling reduces fuel consumption and the associated costs and GHG emissions. Regulations restricting idling were in place in almost half the states as of July 2008. These regulations vary by state, county, or city, but typically restrict idling to 3–10 minutes and do not distinguish between gasoline or diesel vehicles.[16] Most of these regulations are relatively new, and many have associated information campaigns to increase awareness of the fuel costs and emissions caused by idling. Idling reductions can also reduce longer-term costs; each hour of idling eliminated can save as much as 2 hours of engine life. Since an idling engine does not generate enough heat for proper combustion, deposits will form over time on the piston and cylinder walls and contaminate the oil. This contamination creates additional friction that will accelerate engine wear.[17]

To reduce idling and the associated GHG emissions, construction firms need to evaluate when and why idling occurs in the company's activities; this evaluation may include reviewing fuel receipts to understand which projects or groups are consuming more fuel, interviewing drivers, or making systematic observations of the work site. Idling reductions can be achieved through changes in work practices, such as training drivers to turn off equipment rather than idle, or through changes in equipment, such as adding fuel-efficient auxiliary power for the heat or air conditioning needed for driver comfort.

GHG Emissions Impacts: No data were identified that estimate the average GHG emissions associated with construction equipment idling, or the national average idle time for a piece of construction equipment. Some targeted studies, however, provide some information that can be used to assess emissions from idling construction equipment and vehicles. A study of long-haul truck idling indicates that GHG emissions depend upon the level of idling and on how often the idling occurs. A typical Class 8 diesel engine at high idle consumes 1.2 gallons of fuel per hour, which translates to 26.1 lbs CO_2 emissions per hour. At low idle, 0.6 gallons are consumed per hour, resulting in 12.8 lbs CO_2 emissions per hour.[18] A 2005 study of California construction equipment shows that an average heavy-heavy duty diesel truck (Class 7) idles 29.4% of its operational time.[19] An analysis by one construction firm of all its construction equipment (over 300 pieces) estimated that an idling reduction equal to 10% of the total operating time would save almost 524,660 lbs (238 metric tons) CO_2 per year, using the assumption that idling consumes 1.2 gallons fuel per hour.[20]

Without data on the total idling hours for construction vehicles and equipment in the United States, the total potential emissions reductions possible through sector-wide idling reductions could not be estimated. As an illustrative example of the potential sector-wide impact of idling reductions on GHG emissions, we examine two scenarios:

- If construction firms could reduce idling by an average of 10 hours per month per firm (be it a reduction of 10 hours/month from one piece of equipment or a 1 hour/month reduction from 10 pieces of equipment), the resulting GHG emissions savings sector-wide would total approximately 1.4 billion lbs of CO_2 (650,000 metric tons) per year.[21] For purposes of illustration, this scenario intentionally presents a simplified calculation where it is assumed that on average, each construction firm reduces idling by 10 hours per month. From a practical standpoint, we acknowledge that for some firms, such as those that do not own heavy equipment, 10 hours/month idling reduction is not feasible. Other firms that regularly operate many pieces of equipment, however, may be able to reduce idling by more than 10 hours per month; thus, we rely on the averaging across different types of firms to establish this estimate.
- If construction firms could reduce idling of off-road diesel equipment by 10%, the resulting GHG emissions savings sector-wide could total approximately 1.8 billion lbs of CO_2 (830,000 metric tons) per year. This estimate is limited in that it includes off-road vehicles only, and makes the following assumptions based on minimal available data: the sector operates 2 million off-road vehicles at 1,500 hours per year, and idling emits 20.7 lbs CO_2 per hour.[22]

Cost Impacts**:** Argonne National Laboratory (ANL) provides a simple worksheet to calculate savings from reduced idling.[23] For technology solutions to idling, the ANL worksheet may help construction firms to calculate the payback period for various products. For many construction firms, reducing idling would involve changing work practices. While implementing an idling reduction program requires staff time to raise awareness of and monitor new work practices, the external costs are minimal.

Equipment Maintenance

Proper maintenance often results in fuel savings, although the magnitude of savings varies by equipment type and condition. Maintenance may include systematic equipment inspection, detection of potential failure, and prompt correction. Two examples of maintenance activities that can reduce GHG emissions include:

- Forklift maintenance. A recent study of forklift maintenance estimated that 50% of forklifts were not properly maintained, each of which could be wasting more than 400 gallons of propane annually.[24]

  GHG Emissions Impacts: Propane emits about 12.7 lbs of CO_2 per gallon, resulting in more than 2.3 tons of CO_2 emitted by each improperly maintained forklift each year.

  Cost Impacts: At the average 2007 propane price of $1.87 per gallon, 400 gallons wasted costs about $750 per year.

- Improperly inflated tires and poor wheel alignment, which can adversely affect fuel efficiency of a small truck by 3–4%. Under-inflated tires increase the tires' rolling resistance, and increased rolling resistance requires more fuel to move the vehicle.

  GHG Emissions Impacts: A 3–4% improvement in fuel efficiency can reduce CO_2 emissions per vehicle by 650–860 lbs (0.3 to 0.4 metric tons of CO_2) annually for a typical light-duty diesel truck.[25]

  Cost Impacts: At the 2007 U.S. national average cost of diesel sold to industry of $2.34 per gallon, the above losses may save the operator up to $90 in fuel costs per vehicle.[26]

Driver Training

Driver training can also provide incremental savings by more efficiently operating equipment.

- Komatsu estimates that excavator operators who needlessly shift hydraulic levers while already at the equipment's maximum capacity in futile attempts to lift more could save a company 225 gallons of fuel per year if this practice were eliminated for even 1 hour a day.[27]

  GHG Emissions Impacts: Assuming a generic emissions factor of 22.37 lbs of CO_2 per gallon, such reductions could save 5,033 lbs (2.28 metric tons) CO_2 per year.

  Cost Impacts: At the 2007 U.S. national average cost of diesel fuel ($2.34 per gallon for regular diesel), the above fuel savings from a 1-hour per day reduction could reduce costs by $527 per year for each excavator.[28]

- Reducing the angle at which an off-road truck is parked next to a loading excavator can save fuel. Having the excavator's boom swivel 30 degrees to dump its load instead of 90 degrees could reduce fuel use for the task by 3%. [29]

  GHG Emissions Impacts: A large excavator may use up to 20 gallons fuel per hour, resulting in GHG emissions up to 440 lbs per hour. A 3% improvement in fuel efficiency could reduce emissions by up to 13 lbs for each hour the loading angle is improved.

  Cost Impacts: At the 2007 U.S. national average cost of diesel, a change of 3% could provide more than $1.40 in fuel savings for each hour the loading angle is corrected.

- Excavating a slope in two stages in a stair fashion, instead of dragging a bucket from bottom to top in one motion, shortens the cycle between dumps and uses 8% less fuel, according to Komatsu engineers.[30]

  GHG Emissions Impacts: GHG emissions and cost impacts which will vary depending on the parameters of each excavation task. For a large excavator using 20 gallons fuel per hour, an 8% improvement in fuel efficiency could reduce emissions by up to 35 lbs for each hour that stair fashion excavating is used in place of the bottom to top dragging technique.

  Cost Impacts: At the 2007 U.S. national average cost of diesel, a change in fuel efficiency of 8% could provide $3.75 in fuel savings for each hour the improved excavating technique is used.

Properly Sized Equipment

Identifying the proper size equipment for a task can also provide fuel savings and associated reductions in GHG emissions. Truck engines too large for an application burn more fuel by adding unnecessary weight. In addition, drivers may be prone to use the excess horsepower needlessly, causing additional fuel consumption. An undersized engine easily becomes overworked, leading to excess fuel consumption and accelerated engine wear.[31] Possible GHG emissions reductions are proportional to the difference between the horsepower used and the horsepower required for the task. The potential emissions savings are also firm-specific, in that the proper size equipment may not be available in the company's fleet. Given the scope of these constraints, a reasonable illustrative example of the possible GHG reductions resulting from proper sizing of equipment could not be developed.

Replaced or Repowered Equipment

Longer-term fuel-saving solutions involve replacing older, less fuel-efficient equipment with newer models. Through advances in engine technology, reduced equipment weight, and even some hybrid technologies, equipment manufacturers are offering more fuel-efficient new equipment.

Installation of hydraulic fans as part of repowering can reduce fuel consumption and the associated emissions. Hydraulic fans operate with variable speed to optimize engine cooling when needed, unlike belt-driven fans where the air flow is dependent on the engine speed, not on the cooling demand. Less power is then required for cooling, and the lowest amount of fuel per horsepower is consumed when the engine is operating consistently at optimal temperature.[32]

Replacement engine systems show promise in reducing fuel consumption and emissions by new technologies. Through repowering with a new diesel engine, an older piece of equipment is brought up to the fuel economy, emissions, and maintenance standards of new equipment, thus reducing overall equipment operating costs. The potential for emissions reductions will be based on the age of the engine replaced and the differences in technology. While a firm is not likely to replace or repower its entire fleet, these options are meant as suggestions for additional ways to achieve emissions reductions if faced with malfunctioning older equipment.

GHG Emissions Impacts: Manufacturers have reported that new engines can improve fuel economy by 5% or more.[33] A 2008 article cited that replacing a 1995 tractor hauler engine with a 2009 model increased fuel economy from 4.6 mpg to 6.2 mpg, an improvement of almost 35%.[34] By improving fuel efficiency by 5%, a track-type tractor operating 1,500 hours per year and typically using 16 gallons of fuel per hour could reduce its emissions by 26,800 lbs (12 tons) CO_2 per year.[35]

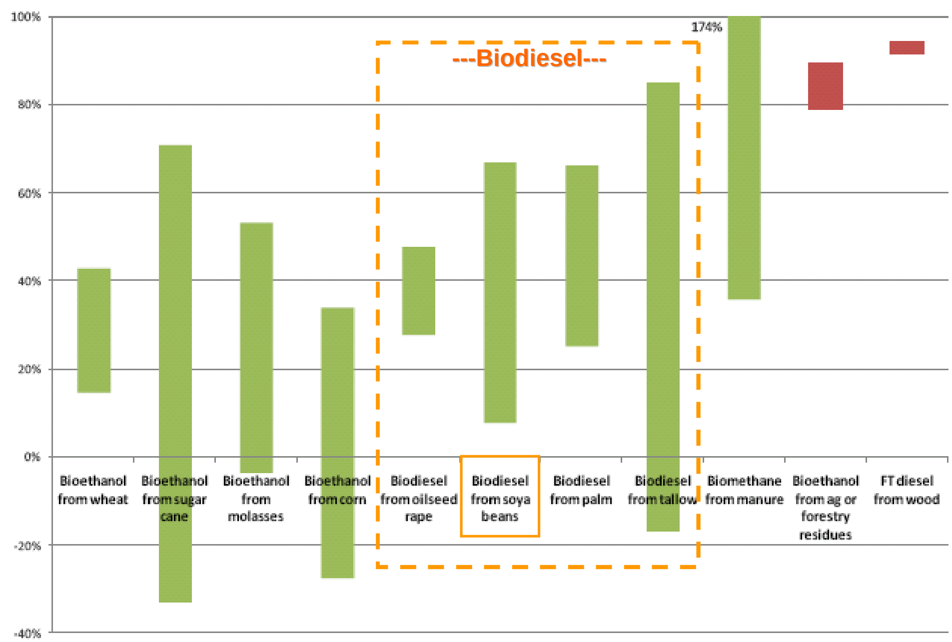
Cost Impacts: The cost of repowering a piece of equipment is high and depends on the age, make, and model of the machine. For example, the cost of repowering a single engine scraper may be as much as $120,000.[36] The likely benefits depend on the equipment replaced.[37] For the example above, assuming 2007 national average industry diesel costs, a 5% improvement in fuel economy would save an owner $2,800 per year in fuel costs.

Biofuels for Trucks and Nonroad Equipment

Using low-carbon fuels in place of petroleum gasoline or diesel also reduces GHG emissions. In particular, the growth of the biofuel industry may allow opportunities to reduce emissions, although the resulting lifecycle emissions benefits are under debate. Lifecycle emissions calculations are largely dependent on the source material, its growth process, and the fuel type used at biofuel refineries. Biofuels that require significant fertilizer applications or refining release more GHGs through additional processing, and fossil fuel combustion at refineries displaces some of the emissions benefit of using the biofuel. In the United States, approximately 89% of biodiesel is currently derived from soybeans, with less than 9% of production from recycled vegetable oils or tallow.[38] To control biodiesel quality, standards of the American Society for Testing and Materials (ASTM) require biodiesel sold in the United States to be derived only from virgin vegetable oils or animal fats.[39]

The most recent compilation of scientific literature on biofuel lifecycle emissions, the *Gallagher Review of the Indirect Effects of Biofuels Production*, presents biodiesel emissions savings ranges for various biofuels, when compared to fossil fuels (see Figure 7).[40] For example, switching from petroleum diesel to biodiesel from palm oil will reduce GHG emissions by approximately 25% – 65%, depending on the type of fuel used at the biofuel refinery (e.g., renewable energy or petroleum), for technologies in use globally as of 2008. These results suggest that switching from petroleum diesel to 100% biodiesel (B100) may reduce GHG lifecycle emissions by more than 80% or may increase emissions by almost 20%; on average, without considering land-use changes associated with crop production, biodiesel from soybeans may provide an emissions savings of 33%.[41] The *Gallagher Review* also suggests that the current uncertainty in total GHG emissions changes may be even greater than the range shown above as a result of variability in calculating emissions from land-use shifts due to increased biofuel feedstock growth.[42] According to the foremost U.S. study published in 1998 by the U.S. Department of Energy, biodiesel from soybean oil is estimated to reduce lifecycle CO_2 emissions by 78% when compared to petroleum diesel.[43] The lifecycle emissions are proportional to any blending with petroleum, so a 20% biodiesel blend (B20) may achieve approximately a 16% reduction in lifecycle CO_2 emissions.

Figure 7: Range of Possible GHG Emissions Savings for Various Biofuels



Source: Reprinted from the Renewable Fuels Agency, *The Gallagher Review of the Indirect Effects of Biofuels Production*, July 2008, http://www.dft.gov.uk/rfa/_db/_documents/Report_of_the_Gallagher_review.pdf.

The use of biodiesel has additional caveats that should be considered before converting equipment. Biodiesel has different solvent properties from petroleum diesel. Biodiesel will degrade any engine hoses or gaskets made with natural rubber (generally used on vehicles manufactured prior to 1992), and will break down any residual petroleum deposits in fuel lines, which in turn will clog fuel filters. As a result, use of biodiesel may void a vehicle's warranty without proper maintenance and dealer approval for fuel switching. Nevertheless, most construction equipment manufacturers are supportive of the use of biodiesel. For example, John Deere has been manufacturing equipment approved for B2 (2% biodiesel blend) since 2005, and Case has recently announced its acceptance of using B20 in approximately 85% of its vehicles.[44] At the Destiny USA project in Syracuse, NY, biodiesel has been successfully demonstrated to run all diesel equipment for a large construction project on B100.[45]

Although many engines are able to run on B100, a petroleum/biodiesel mix such as B20 may provide better performance. Biodiesel has better lubricity than low-sulfur or regular petroleum diesel, even at 1-2% blends, which could improve engine performance. However, vehicles running on biodiesel may experience problems in cold temperatures due to biodiesel's higher cloud and pour points compared to petroleum diesel. [46] An additional issue in using biodiesel is its decreased fuel economy in comparison to petroleum diesel. While the mechanical efficiency of biodiesel and petroleum diesel is the same, the energy content of biodiesel is 11% lower than that of petroleum diesel. Thus, EIA calculates that using B20 may decrease fuel economy by 2.2%.[47]

Table 5 presents CO_2 emissions factors for B100 and B20. Since the carbon from biofuels is assumed to be emitted from other processes if the feedstock is not used for fuel, biofuels are conventionally assumed to have zero net CO_2 emissions. The emission factor for B100 indicates that 0 lbs of CO_2 are emitted for every gallon combusted, while 17.8 lbs of CO_2 are emitted for one gallon of B20 because it contains 80% petroleum diesel. The last two columns in the table present the estimated tons of CO_2 emissions that could be reduced in the United States if all construction firms replaced 3% or 10% of their petroleum diesel with biodiesel. If all U.S. construction firms switched to using B20 for 10% of their fuel purchases, CO_2 emissions would be reduced by an estimated 2,970 million lbs (1.43 million metric tons). This would represent an approximately 1% reduction in total construction sector emissions. A 10% switch to B100 use sector-wide would reduce total sector emissions by approximately 5%.

Table 5: GHG Emissions Reduction Scenarios from Increased Biodiesel Use

Fuel	Emissions* (lbs CO_2/gallon)	Estimate of Sector-Wide Emissions Reductions **	
		Switching to 3% Biodiesel	***Switching to 10% Biodiesel***
B100	0 lbs CO_2/gallon	4,455 million lbs CO_2 2.02 $MMTCO_2$	14,850 million lbs CO_2 6.73 $MMTCO_2$
B20	17.8 lbs CO_2/gallon	891 million lbs CO_2 0.40 $MMTCO_2$	2,970 million lbs CO_2 1.43 $MMTCO_2$

Notes: $MMTCO_2$ = million metric tons of CO_2.
* 100% biodiesel is conventionally assumed to have zero net carbon emissions. As B20 is a blend of 20% biodiesel and 80% petroleum diesel, its emissions factor is calculated as 80% of the emissions of 100% petroleum diesel. Emissions factor for diesel converted from EPA's 2008 *Inventory of Greenhouse Gases 1999-2006*, Table A-29.
** Estimate of possible emissions reductions from a 3% or 10% switch from petroleum diesel to biodiesel are based on the 2002 fuel consumption estimates and assumptions used in the EPA report, *Quantifying Greenhouse Gas Emissions in Key Industrial Sectors in the U.S.* (May 2008). Numbers presented are for the purpose of illustrating the magnitude of sector-wide reductions only and should not be interpreted as absolute quantities.

Although the majority of biodiesel retail stations are located near biodiesel refineries in the Midwest, biodiesel blends are becoming increasingly available across the United States. The National Biodiesel Board maintains an interactive map to find local sales, and sites such as BioTrucker.com provide resources to locate truck-accessible locations.[48]

While biodiesel production is increasing rapidly and biodiesel is becoming more readily available, the costs of using biodiesel may yet be prohibitive for some construction projects. As of March 2008, wholesale biodiesel costs were approximately $4.60 per gallon for B100, whereas petroleum diesel was available wholesale for $3.30 per gallon. Switching entirely to biodiesel therefore has the potential to increase diesel fuel costs by 40%. The cost of biodiesel is not expected to decrease significantly in the near future, as the high cost for soybean feedstock is currently the limiting factor in reducing biodiesel production costs.[49] In addition, as mentioned previously, the reduced fuel economy of biodiesel will increase overall fuel consumption, which will further increase costs. Therefore, the use of biodiesel may provide a potential for emissions reductions but is not likely a cost-effective solution for most contractors at the present time.

Alternatives to Diesel Generators

Diesel generators may consume as much fuel as a piece of construction equipment per hour, and are generally operated over a longer period of time. For example, a large (500-kilowatt) generator that consumes 15 gallons of diesel per hour emits about 346 lbs of CO_2 (0.16 metric tons) at an average cost of $35.30 per hour.[50] Switching to dual-fuel generators using a mix of natural gas or propane and diesel could provide a modest emissions benefit. For example, the same system using 95% natural gas and 5% diesel would produce only 16.5 lbs CO_2/gallon fuel, emitting less than 250 lbs of CO_2 (0.11 metric tons) per hour.[51]

If grid electricity can be made available early at a construction site, using it may provide emissions reductions over the use of diesel generators. Diesel generators typically produce 1.54 lbs CO_2 emissions per kWh of electricity, which is 15% more than the national average for purchased electricity emissions.[52] However, the marginal benefit from using purchased (grid) electricity will vary depending on regional differences in the fuel used for electricity generation (discussed further in Section 2.2).

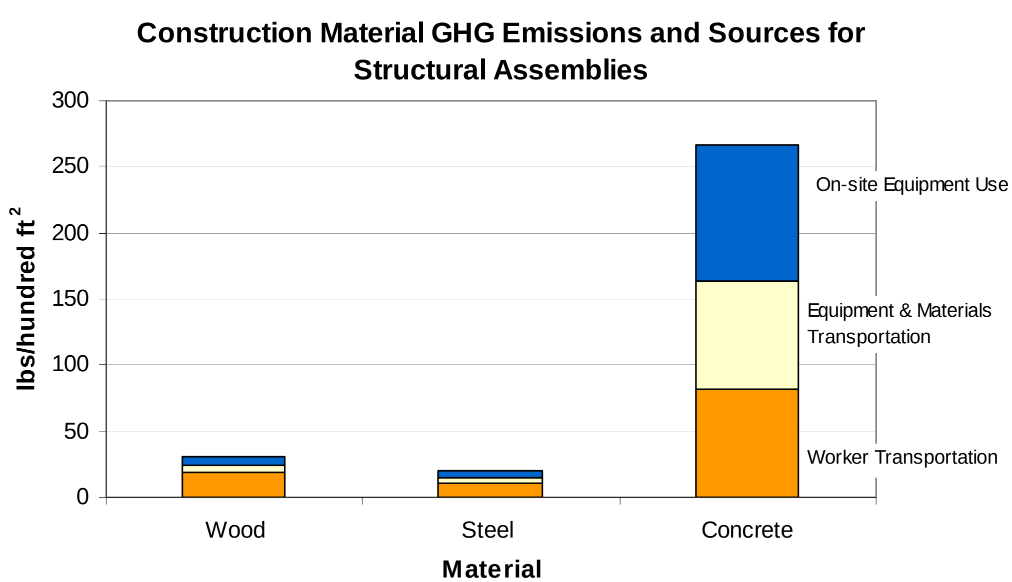
Alternative energies, such as solar panels at offices or on-site trailers, may also provide an emissions reduction solution that could also have long-term cost savings. For example, the SolaRover company designs 5-, 10-, and 20-kilowatt solar panel trailers that provide electricity at 9 cents per kilowatt-hour (kWh), displacing the need for diesel-powered generators and producing no direct GHG emissions.[53] One construction company was able to provide power for a team of 15 staff using a stationary solar-wind generator combination.[54]

Data sources used to estimate construction industry emissions do not differentiate diesel used for generators from that used for mobile equipment. Therefore, an illustrative example of sector-wide GHG emissions reductions from using alternatives to diesel-fired generators could not be developed.

Employee Commuting

Construction is a labor-intensive industry, with more than 7 million employees in the United States.[55] Because of the large number of employees in the construction industry, employee commuting may be a significant, yet often overlooked, source of GHG emissions in the industry.

Figure 8: Average GHG Emissions for Constructing Structural Assemblies



Notes: Values presented are estimated from the graphical results in the source.
lbs/hundred ft^2= lbs GHG emissions (in CO_2 equivalents) per hundred square feet material
Source: Raymond J. Cole, "Energy and Greenhouse Gas Emissions Associated with the Construction of Alternative Structural Systems," *Building and Environment* 34 (1999), pages 335 - 348.

One study, comparing GHG emissions associated with use of wood versus steel versus concrete structural assemblies at a construction site, found that worker transportation to and from the site usually resulted in greater GHG emissions than either the on-site equipment used or the transportation of equipment and materials to the site.[56] The study concluded that the transportation of construction personnel to and from the construction site contributed 5% to 85% of the total GHG emissions, depending on the assembly. Averaged across the different structural assemblies, worker transportation accounted for 50–60% of the on-site GHG emissions associated with wood or steel assemblies and 30% of the emissions for concrete assemblies. See Figure 8 for the study's results.

Emissions associated with employee commuting are not currently included in the GHG emissions estimates for the construction sector presented in Section 1 of this report. GHG emissions associated with employee commuting will vary by project. No data were found on average distance that employees traveled to a construction site; therefore, no quantitative estimate of the national GHG impacts from construction employee commuting could be calculated. Opportunities for reducing emissions associated with commuting include establishing carpools or shuttle vans.

2.2 Conserving Electricity

Estimates presented in Section 1 indicate that approximately one-quarter of the construction sector's GHG emissions are associated with generating the electricity that the sector purchases. Electricity is used to power central offices, and on construction sites where grid electricity is available, it is used to power site lighting, trailers, and tools.

Table 6 illustrates how modest electricity conservation efforts can add up to significant GHG emissions reductions, if implemented sector-wide. Using a national average CO_2 emissions factor of 1.36 lbs CO_2 per kWh of electricity, if all U.S. construction firms reduced their electricity use by 10%, the reduction in CO_2 emissions would be an estimated 6.9 billion lbs (3.13 million metric tons). This would represent an almost 2.4% reduction in overall sector emissions.

Table 6: GHG Emissions Reduction Scenarios from Electricity Conservation

Source	Emissions*	Estimate of Sector-Wide Emissions Reductions **	
		Using 3% less electricity	*Using 10% less electricity*
Electricity	1.36 lbs CO_2/ kWh	2.07 billion lbs CO_2 0.93 $MMTCO_2$	6.90 billion lbs CO_2 3.13 $MMTCO_2$
Electricity	1.37 lbs CO_2 equivalents / kWh	2.08 billion lbs CO_2 e 0.95 $MMTCO_2$ e	6.95 billion lbs CO_2 e 3.15 $MMTCO_2$ e

Notes: $MMTCO_2$ = million metric tons of CO_2.
$MMTCO_2e$ = million metric tons of CO_2 equivalents (includes CO_2, CH_4, and N_2O)
*Emissions factor converted from eGRID emissions factor national averages for CO_2, CH_4, and N_2O emitted during electricity generation as of 2004. Note that other GHG emissions (CH_4 and N_2O) account for an additional 0.01 million lbs CO_2 equivalents/million kWh in comparison to CO_2.
** Estimate of possible emissions reductions from using 3% or 10% less electricity from the grid are based on the 2002 electricity consumption estimates and assumptions used in the EPA report, *Quantifying Greenhouse Gas Emissions in Key Industrial Sectors in the U.S.* (May 2008). Numbers presented are for the purpose of illustrating the magnitude of sector-wide reductions only and should not be interpreted as absolute quantities.

While Table 6 applies a national average CO_2 emissions factor for electricity, the emissions factor varies significantly in different regions based on the fuel mix used to generate electricity. Coal-dominant production in East-Central states produces more GHG emissions per kWh of delivered electricity than production using renewable energies such as hydroelectricity in Pacific Northwest states. For example, 2004 CO_2 emissions factors for electricity output in Ohio and Pennsylvania are approximately four times greater than those of Oregon and Washington.[57] Individual construction firms should consider these regional differences when evaluating their opportunities for GHG reductions.

Reducing office electricity use offers additional opportunities to reduce GHG emissions for the sector. EPA estimates that as much as 30% of the energy in a typical office building is wasted. From an analysis of electricity load scenarios for various reduction policies, EPA suggests that 8% electricity reductions are possible simply from switching lighting options, such as replacing incandescent light bulbs with compact fluorescent lights. If operational and maintenance changes are made, such as replacing older heating and cooling equipment with more-energy-efficient systems or shutting down computers at the end of the day, EPA suggests that 12% reductions are possible. EPA reports that a combination of approaches may reduce office electricity consumption by over 30%.[58]

> ***GHG Emissions Impacts for Buildings:*** Given a common electricity consumption of 15.5 kWh per square foot annually, reducing energy use by 30% in a typical office space of 50,000 square feet would avoid 316,000 lbs (143 metric tons) of CO_2 emissions per year. For a mobile office trailer of 750 square feet, approximately 4,800 lbs (2.2 tons) of CO_2 emissions would be avoided (a 30% reduction per year).
>
> ***Cost Impacts for Buildings:*** Reducing the amount of electricity purchased will lead to lower operating costs as well as reductions in GHG emissions. EPA's EnergySTAR program estimates that reducing energy use by 30% in a 50,000 square foot office space can save $25,000 per year.[59]

Renewable energy-based electricity purchases may further reduce emissions, although the magnitude of emissions reductions possible will depend on the percentage of renewable electricity available.

2.3 Reducing Impacts of Construction Materials

Standard methods for estimating GHG emissions, such as those presented in Section 1, typically include only traditionally quantified emissions sources, such as fossil fuel combustion and purchased electricity. Some researchers take a more comprehensive approach by including the full lifecycle emissions associated with an activity's supply chain and waste management. For the construction sector, a lifecycle approach could include the GHGs emitted from all construction materials used and disposed as well as the fuel and electricity used for the materials' production, use, and disposal. Although a comprehensive construction-related lifecycle emissions inventory has not been conducted, there clearly are opportunities to reduce emissions by recycling and/or reusing materials, improving shipping methods, and/or selecting different materials.

Recycling and Reuse

Wastes from new construction, renovation, and demolition projects generate about 25% of the total U.S. solid waste volume.[60] Energy is expended and GHGs are released during the manufacturing and transportation of construction materials. When materials are reused or recycled, the associated emissions that would have occurred during virgin material manufacturing are avoided. Recycling is the process of reprocessing or reforming used materials into new products, while reuse is the process of using a recovered, previously used product instead of a new product. As shown in Table 7, opportunities for materials recycling or reuse exist across construction supplies. For example, two-thirds of recovered asphalt is used for new asphalt hot mixes, and one-third is used as sub-base material for paved roads. In practice, only asphalt, steel, metals, and concrete have been recycled or reused in significant volumes in the United States, because there are established secondary markets for these used materials.

Table 7: Secondary Use Markets for Various Construction and Demolition Materials				
Material	**Generating Activity**	**Recycling Markets**	**Percent**	**Substitutes for:**
CONCRETE	Building construction Building demolition, Infrastructure demolition	Road base	68%	Virgin aggregate
		Aggregate for new asphalt hot-mixes	9%	Virgin aggregate
		General fill	7%	Virgin aggregate
		Other	7%	Virgin aggregate
		Aggregate for concrete mix	6%	Virgin aggregate
		Rip-rap	3%	Virgin aggregate
		TOTAL	100%	
ASPHALT PAVEMENT	Road, parking lot, and driveway maintenance and reconstruction	Aggregate for new asphalt hotmixes	66%	Virgin aggregate
		Sub-base for paved roads	33%	Virgin aggregate
		TOTAL	100%	
WOOD	Building deconstruction	Recovered lumber remilled into flooring	Not available	Virgin lumber
	Building construction Building demolition Land clearing	Mulch and compost		Scrap wood from sawmills, logging debris
		Animal bedding		
		Feed stock for particle board		
		Biomass fuel for boilers		
GYPSUM WALLBOARD	Building construction Building demolition	Gypsum wallboard	Not available	Virgin gypsum
		Portland cement		Virgin gypsum
		Land application in agriculture		Virgin gypsum
ASPHALT SHINGLES	Building construction Building demolition Building renovation	Asphalt mixes Road base	Not available	Virgin aggregate; virgin bitumen
		Cement kilns		Virgin aggregate

Note: With the exception of concrete and asphalt debris, which have well-established recycling markets, data are not well documented concerning the quantities of wood, wallboard, and asphalt shingles used in various applications.
Source: U.S. EPA, *Waste and Materials-Flow Benchmark Sector Report: Beneficial Use of Secondary Materials - Construction & Demolition Debris*, draft in progress.[61]

EPA's preliminary estimates indicate that 170 million tons of building-related construction and demolition (C&D) materials were generated in the United States in 2003.[62] Of that quantity, as much as 48% was recovered, and the remainder was disposed in a landfill.[63] Recovering these materials rather than disposing of them may prove to be a significant opportunity to reduce GHG emissions, considering that between 2000 and 2030, an estimated 27% of existing buildings will be replaced and 50% of the total future building stock has yet to be constructed.[64] Considerable uncertainty is associated with EPA's C&D materials estimates. For instance, the method used to estimate building-related materials relied on data from a limited number of waste assessments, some of which were outdated. However, as there is no centralized, national source for information on quantities of C&D materials generated or recycled, the estimates in these reports are considered to be the best available data.

Table 8 presents the GHG emissions that currently are avoided through recycling various construction materials. Most of the emissions factors in this table are from EPA's WARM model, which includes estimates of the emissions avoided during the extracting and processing of raw materials (e.g., the emissions produced by bauxite mining for aluminum) as well as the emissions from the manufacturing of the material.[65,] WARM offers an emissions factor for concrete recycling under the category "aggregates," which refers to the replacement of virgin crushed aggregate material with the concrete being recycled.[66]

In addition, WARM offers the option to calculate emissions related to the transportation of these materials to waste management facilities.

The recycling estimates in Table 8 are from multiple sources. For some of the materials, national estimates could not be identified, especially for the less commonly recovered construction materials such as plastics. For materials where recycling data are available, the CO_2e emissions avoided are estimated. For example, the table shows that for every ton of asphalt recycled from construction, 0.03 tons of CO_2e emissions are avoided. An estimated 139 million tons/year of asphalt are recycled in the United States, resulting in 4.2 million tons of CO_2e emissions avoided.[67]

Table 8: GHG Emissions Avoided through Recycling or Reuse of Construction and Demolition Materials

Material	Emissions Factor for Recycled Material (metric ton CO_2e/ short ton material)	Recovery Rate **	Quantity of Material Recycled Annually in U.S.**	CO_2e Emissions Avoided Through Recycling (metric tons CO_2e)
Steel	1.79	97.5% (structural) 65% (reinforcement)	40 million tons	71,600,000
Carpet	7.18	4.6%	120,000 tons	862,000
Wood/Lumber	2.46	*	*	*
Plastics (mixed)	1.49	*	*	*
Aluminum	13.57	15%	*	*
Asphalt	0.03	80%	139 million tons	4,170,000
Concrete	0.01	*	140 million tons	1,400,000

Notes:
* Unknown.
****** For construction-related quantities of the material, (e.g., 97.5% of structural steel used in construction, or 40 million tons/year, is recycled).

Sources: Emissions factors for steel, carpet, wood, plastics, concrete (aggregate) and aluminum are from EPA's *Waste Reduction Model*—Results. Model estimate methodology from: *Solid Waste Management and Greenhouse Gases: A Life-Cycle Assessment of Emissions and Sinks* (EPA530-R-02-006); available at: http://www.epa.gov/mswclimate/greengas.pdf.
Emissions factor for asphalt is from EPA's *Waste and Materials-Flow Benchmark Sector Report: Beneficial Use of Secondary Materials - Construction & Demolition Debris*, draft in progress.
Emissions factor for concrete is from Arpad Horvath, "Construction Materials and the Environment," *Annual Review of Environment and Resources*, 2004, p. 189.
Annual concrete recycled quantity is from CMRA, www.concreterecycling.org.
Steel recycling rates and quantity are from personal communication with Bill Heenan, President of the Steel Recycling Institute, and "Fact sheet: 2006 rates," http://www.recycle-steel.org/PDFs/2006Graphs.pdf. Of the 40 million tons recycled, approximately 28 tons are structural and 12 tons are reinforcement steel.
Carpet recycling rate is from http://www.carpetrecovery.org/pdf/annual_report/06_CARE-annual-rpt.pdf.
Asphalt recycled quantity is provided from personal communication of EPA estimates.

In addition to reducing GHG emissions, recycling may be more cost-effective than disposal. Tipping fees at recycling centers are typically less than at landfills regardless of waste type; for example, in San Diego, California, tipping fees for a ton of mixed construction waste could be $65 at a recycling center, but may be $85 to dispose of the same ton at a landfill.[68] Even if a contractor must be hired to haul the materials to recycling centers, recycling can provide enough of an incremental benefit to be economical.[69] Costs or savings associated with recycling C&D materials vary regionally, however. Since C&D materials are primarily regulated at the state level, national information on the average costs, or even ranges of costs, is not currently available. Even when recycling of C&D materials is cost-effective, other challenges remain, including the lack of recycling information and a tendency to continue with familiar disposal practices.[70]

In recent years, some states have established regulations that limit disposal of certain C&D materials in landfills.[71] For example, Massachusetts requires a solid waste facility management plan that includes recycling and composting, and limits disposal of asphalt, concrete, corrugated cardboard, brick, wood, and scrap metal in landfills. In California, specific facilities handle inert C&D materials recycling and C&D wood materials for chipping. While other factors (e.g., landfill space, fuel costs, green building efforts) may be influential in determining the overall market for recycled material, markets would be expected to expand if more states were to encourage recycling by limiting C&D disposal.

Materials Selection, Procurement, and Shipment Methods

The selection of materials with lower environmental impact provides a range of opportunities to reduce GHG emissions, although emissions reductions vary considerably depending on the material. Increasingly, the use of building materials with recycled content is supported as an acceptable measure for GHG reductions.[72] EPA's ReCon tool, designed to compare the GHG impacts of material purchasing and manufacturing, offers an option to evaluate the benefits of using common materials with various recycled contents.[73] Although useful for items such as lumber, copper, aluminum, or steel, ReCon does not provide a listing of all items commonly used in the construction industry, nor does it provide estimates of the monetary costs associated with using recycled materials. EPA's Waste Reduction Model (WaRM), designed to calculate emissions related to alternative waste management practices, offers a wide range of materials and practices, and also estimates emissions related to the waste transportation.[74] The BEES tool is a comparative system designed to balance cost and environmental performance when selecting building products, which may be useful in the decision-making process as it offers options to enter product-specific detail or compare generic categories.[75] All three above tools attempt to provide full lifecycle estimates of the material, such as emissions resulting from raw material acquisition, manufacture, transportation, installation, use, and waste management. This life-cycle approach is not appropriate for use in inventories because of the diffuse nature of the emissions and emission reductions within a single emission factor.[76]

Delivery of materials to a construction site also results in GHG emissions. Reducing delivery-vehicle trips to the construction site results in lower fuel consumption, which will contribute to reduced GHG emissions. For large projects or group of projects in close proximity, creating a consolidated location for materials delivery may reduce transport emissions by allowing contractors to request materials and quantities closer to the time of use. For example, Transport for London in the UK established the London Construction Consolidation Centre as a pilot project for centralizing construction deliveries. Construction sites participating in the pilot project report that use of the Centre reduced road transportation to their sites by 70%, and reduced waste by damage or other losses by 15%.[77] Damage was reduced because materials did not sit unprotected at the construction site. No similar facilities are known to operate in the United States.

For shipments over a significant distance, switching transportation methods may also enable emissions reductions. While originally designed for shipping, trucking, and logistics companies, EPA's Freight Logistics Environmental and Energy Tracking (FLEET) Performance Model can help quantify the current fuel use and emissions of shipments, as well as help evaluate the costs and effectiveness of future emission reduction strategies.[78]

Buying locally produced lumber and other materials can reduce the emissions impacts of transporting materials. The magnitude of these savings varies widely by the construction site location and the source of the materials. Reducing transportation distances may also reduce the cost of hauling materials.

3 Calculating Company-Specific Greenhouse Gas Emissions

Emissions inventories are an accounting of a company's greenhouse gas emissions and sources. In order to construct an accurate inventory, a consistent and unambiguous method is essential. An accurate inventory is a powerful resource for tracking annual emissions, identifying areas to reduce emissions, and even for comparing emissions across companies. An inventory can provide additional value to a construction company when used to inform clients about the firm's environmental stewardship efforts. Construction companies interviewed indicate the motivation for constructing an inventory is threefold: the possible economic benefits from reduced fuel and electricity purchases, the intrinsic environmental benefit from reduced emissions, and the marketing and public image benefits of being a proactive and environmentally responsible community member.[79]

3.1 Existing Calculation Guidance

To ensure that emissions are comparably calculated, various groups have developed spreadsheet or software tools along with complementary protocols on classifying emissions. Most groups provide generalized formats so the protocol can apply to the widest range of industries possible. Although standardized spreadsheet calculators allow for comparisons of emissions across companies, the generalization of sector-specific activities may result in over- or under-estimating emissions. To account for this issue, some protocols include additional toolsets and guidance to calculate sector-specific activities. Two of the best-known GHG inventory methods in the United States are:

- ***GHG Protocol Corporate Standard*—**Currently, the most commonly accepted protocol used to identify emissions sources is the *Corporate Standard* guidance developed by the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD).[80] This guidance document provides standards by which to measure CO_2 and the five other GHGs included in the Kyoto Protocol.[81] The WRI/WBCSD Corporate Standard is consistent with measures proposed by the Intergovernmental Panel on Climate Change (IPCC), and now serves as the basis of the international reporting standard, the International Organization for Standardization (ISO) guidance *ISO14064-I*.[82] These standards are not policy-based, meaning the methods by which emissions are calculated are not determined or influenced by government or state environmental policies. In the Corporate Standard, emissions are assigned to one of three "scopes," where Scope 1 includes emissions that directly result from company operations, such as emissions from industrial operations. Scope 2 includes emissions resulting from energy purchases, such as electricity generated off-site. Scope 3 includes all other associated emissions from company operations, such as employee commuting, business travel, or subcontracted work. Scope 3 may also include any measures of "upstream" emissions embedded in products purchased by the firm and/or "downstream" emissions associated with transporting and disposing of products sold by the firm, such as recycling.[83] Companies are encouraged to report on all possible direct and indirect emissions sources at all levels, although WRI considers only Scope 1 and 2 emissions reporting as a requirement of a corporate inventory.
- ***Climate Leaders Inventory Guidance*—**EPA's Climate Leaders program is an industry-government partnership that works with companies to develop climate strategies. Partner

companies commit to reducing their impact on the global environment by completing a corporate-wide inventory of their GHG emissions, setting aggressive reduction goals, and annually reporting their progress to EPA. EPA's Climate Leaders Inventory Guidance is based on the WRI/WBCSD Corporate Standard, and includes guidelines for setting GHG reduction goals in addition to measuring current emissions. The Climate Leaders program requires the measurement of indirect emissions from purchased electricity in addition to the direct emissions from fuel use, industry processes, or refrigeration and air conditioning equipment.[84] Goals are set based on the companies' Scope 1 and 2 emissions.

The WRI/WBCSD and Climate Leaders guidances are both accompanied by spreadsheet-based tools that companies can use to create an annual inventory of their GHG emissions. The tools include emissions factors for fuel combustion and purchased electricity, but neither protocol clearly addresses the challenges specific to the construction industry. First, while companies in all sectors must consider how to assign responsibility for emissions, this challenge is magnified in construction, where activities are so heavily dependent on subcontractors. Using the WRI/WBCSD and Climate Leaders protocols, most emissions from a general contractor that does not own heavy equipment would be related to the contractor's office operations. All emissions from subcontractors, and thus possibly all site emissions, would not be included in the contractor's Scope 1 or 2 emissions. Second, frequent use of heavy non-road equipment may require modified approaches to emissions calculations, since emissions are affected by both the equipment's load and horsepower.[85] Differences in highway and heavy equipment are not reflected in standard emissions factors for calculations of CH_4 and N_2O emissions, which, although a small component of total emissions, should be included in a complete inventory.[86]

3.2 Current Approaches in Construction Industry Inventories

As of October 2008, five companies with operations in the construction industry are members of EPA's Climate Leaders program. For this report, we asked these companies for their insight on the process and challenges involved in completing an emissions inventory for construction activities. While the Climate Leaders program requires a standardized emissions inventory for its application, none of the companies rely solely on this guidance to inventory their activities. The level of detail in the firms' calculations varies significantly, although most firms follow or expand upon the WRI/WBCSD protocol. Some companies attempt to include job-specific emissions, primarily to better inform clients of a project's likely environmental impact. Examples of construction firms' approaches to calculating their GHG emissions include:[87]

- Turner Construction's inventory closely follows the WRI guidance and toolset, recording corporate-owned activities such as corporate office emissions, corporate fleet vehicle emissions, and emissions from any fuel use by corporate-owned equipment.[88]
- DPR Construction Inc. uses the WRI guidance as a starting point, and has added construction-specific activities by developing its own database of activities to account for employee commuting, corporate fleet vehicle use, and vehicle trips needed for the procurement of materials. Their calculations factor in job site commuting by accounting for differences in workers' vehicles and days worked, and record variations in electricity emissions by using regionally specific emissions factors available in EPA's eGRID.[89]

- Conestoga Rovers & Associates calculates emissions from purchased electricity for its corporate offices, but considers emissions from electricity at the job site the client's responsibility.[90]
- Aggregate Industries calculates office and job site emissions, but does not include electricity used at its corporate headquarters.[91]

While these companies record the types and quantities of waste generated and recycled, none are currently calculating emissions avoided through materials recycling. The lack of information on emissions factors for various recycled materials, and the lack of guidance encouraging responsibility for these emissions, has hindered such calculations.

In summary, even though standardized guidance is available, most companies are still grappling to define the scope of calculations that best reflects the company's operations. These companies' experiences emphasize the need for a calculator to document emissions from construction-specific activities, as well as clearer protocols for defining the boundaries of an emissions inventory (e.g., client versus contractor or subcontractor responsibilities).

3.3 Construction-Specific Calculation Tool

As a complement to this report, EPA's Sector Strategies Division is considering developing an easy-to-use, spreadsheet-based tool for calculating a GHG emissions inventory, designed for construction companies. Construction-specific detail is required in order to identify specific areas for emissions reductions. While this tool has not yet been developed, the intention would be to add construction-related information to the internationally recognized generic protocols.

4 SUMMARY

Greenhouse gas emissions from the construction industry result from a wide range of activities by hundreds of thousands of companies and sites across the country, producing 6% of all U.S. industrial GHG emissions in 2002. Although aggregate emissions from this large sector are high, no single construction site or company is a significant contributor. This document describes opportunities to make modest company-level reductions, which, if put into practice throughout the industry, could reduce emissions by millions of tons per year. Table 9 shows the estimated magnitude of reductions that could be achieved if one combination of reduction scenarios were implemented sector-wide. The 5.5 million metric ton decrease represents an approximately 4% cut in the sector's emissions from fossil fuel and electricity use. Further reductions could be achieved by increasing recycling.

Table 9: Scenario of Construction Sector-wide GHG Emissions Reductions

Activity	Assumption	Metric tons CO_2e
Reduce Equipment Idling	10% reduction from all off-road diesel heavy equipment	830,000
Improve Maintenance & Driver Training	Combined practices to increase fuel economy by 3% for heavy equipment	130,000
Increase Fuel Switching to Biodiesel (B20)	Replace 10% of diesel use with B20	1,400,000
Improve Electricity Conservation	Combined practices to reduce total electricity use by 10%	3,100,000
Additional lifecycle emissions: Increase Materials Recycling *		
Steel	Recycle an additional 3%	2,150,000
Asphalt	Recycle an additional 5%	210,000
Concrete	Recycle an additional 10%	140,000
Total Scenario Emissions Reductions with recycling		**7,960,000**
Total Scenario Emission Reductions without recycling		**5,460,000**

Notes: Source data compiled from various government, academic, and industry documents; see endnotes for further details.[92]
* For construction-related quantities of the material.

To develop Table 9, many assumptions and estimates had to be made when data were unavailable, resulting in significant uncertainty. More research and data specific to construction are needed to provide more-refined estimates of the potential for sector-wide GHG reductions. In particular, data are lacking on the number of pieces of construction equipment by type, their annual operating hours, their current fuel efficiency, and their emissions while idling. Data on construction and demolition materials recycling is not tracked nationally, and extrapolating the data that are available to the national level also results in uncertainty. As future research fills in the missing pieces of data, the construction sector will be able to better target emission reduction opportunities and quantify results.

Meanwhile, the construction industry can demonstrate the importance of individual firms' decisions in affecting GHG emissions. Based on currently available information, it appears construction firms will need to make changes in multiple areas – fossil fuel consumption, electricity use, and materials recycling – to realize meaningful sector-wide reductions. With the increased awareness of and demand for green construction in recent years, the construction industry has demonstrated its ability to play a leadership role in promoting environmental stewardship. In addressing the global environmental challenge of climate change, many construction firms have already taken the initiative to track and reduce the climate impacts of their operations. A better understanding of the sources and magnitude of each firm's impacts will enable many more construction firms to contribute to the climate change solution in the years ahead.

2002 NAICS	NAICS Subsector description	Number of Establishments	Estimated Subsector Emissions by Source					
			($MMTCO_2e$)	($MMTCO_2e$)	(million metric tons CO_2)			
			Total All Sources	Purchased electricity	Natural Gas	Vehicle fuel use		
						on-highway	off-highway	subtotal
Absolute values								
236	Construction of Buildings							
23611	Residential building construction	171,662	24.28	8.13	3.42	10.35	2.37	12.73
23621	Industrial building construction	2,777	1.68	0.48	0.13	0.75	0.32	1.07
23622	Commercial and institutional building construction	37,208	16.21	5.99	1.55	6.79	1.87	8.67
237	Heavy & Civil Engineering Construction							
23711	Water and sewer line and related structures construction	12,357	5.98	0.07	0.24	2.43	3.24	5.67
23712	Oil and gas pipeline and related structures construction	1,403	0.92	0.19		0.73		0.73
23713	Power & communication line & related structures	6,034	3.29	0.58	0.19	2.40	0.12	2.52
23721	Land subdivision	8,403	1.61	1.16		0.45		0.45
23731	Highway, street, and bridge construction	11,239	17.64	2.04	1.62	5.82	8.16	13.98
23799	Other heavy and civil engineering construction	10,502	4.48	0.86	0.29	0.17	3.16	3.33
238	Specialty Trade Contractors							
23811	Poured concrete foundation and structure contractors	27,151	4.33	0.07	0.27	3.01	0.98	3.99
23812	Structural steel, precast concrete erection contractors	4,321	1.41	0.31	0.17	0.66	0.27	0.93
23813	Framing contractors: Carpentry	14,455	1.09	0.20	0.06	0.81	0.02	0.83
23814	Masonry contractors	25,720	2.47	0.35	0.16	1.53	0.42	1.95
23815	Glass and glazing contractors	5,294	0.62	0.02	0.07	0.46	0.06	0.52
23816	Roofing contractors	23,192	3.69	0.61	0.50	2.25	0.33	2.58
23817	Siding contractors	6,632	0.58	0.09	0.04	0.41	0.04	0.45
23819	Other foundation, structure, bldg exterior contractors	2,786	0.43	0.10	0.03	0.25	0.05	0.30
23821	Electrical Contractors	62,586	9.23	2.14	0.05	6.27	0.77	7.04

2002 NAICS	NAICS Subsector description	Number of Establishments	Estimated Subsector Emissions by Source (MMTCO$_2$e) Total All Sources	(MMTCO$_2$e) Purchased electricity	(million metric tons CO_2) Natural Gas	Vehicle fuel use on-highway	off-highway	subtotal
23822	Plumbing, heating, and air conditioning contractors	87,501	6.67	3.57	1.30	1.70	0.09	1.80
23829	Other building equipment contractors	6,087	1.68	0.37	0.01	1.05	0.25	1.30
23831	Drywall and insulation contractors	19,598	0.57	0.06	0.23	0.24	0.03	0.27
23832	Painting and wall covering contractors	38,943	2.68	0.57	0.15	1.60	0.36	1.96
23833	Flooring contractors	12,865	1.42	0.42	0.14	0.84	0.03	0.86
23834	Tile and terrazzo contractors	8,950	0.71	0.17	0.06	0.43	0.05	0.48
23835	Finish carpentry contractors	35,087	2.81	0.68	0.24	1.62	0.27	1.89
23839	Other building finishing contractors	3,729	0.67	0.14	0.07	0.39	0.07	0.46
23891	Site preparation contractors	30,496	8.21	0.91	0.45	0.44	6.41	6.85
23899	All other specialty trade contractors	33,452	6.28	1.21	0.43	3.37	1.27	4.65
Percent of all construction subsectors								
236	Construction of Buildings							
23611	Residential building construction	24.16%	18.43%	25.82%	28.79%	18.09%	7.66%	14.42%
23621	Industrial building construction	0.39%	1.28%	1.52%	1.09%	1.32%	1.02%	1.21%
23622	Commercial and institutional building construction	5.24%	12.29%	19.02%	13.05%	11.87%	6.03%	9.82%
237	Heavy & Civil Engineering Construction							
23711	Water and sewer line and related structures construction	1.74%	4.53%	0.21%	2.02%	4.25%	10.46%	6.43%
23712	Oil and gas pipeline and related structures construction	0.20%	0.73%	0.60%		1.28%		0.83%
23713	Power & communication line & related structures	0.85%	2.59%	1.83%	1.59%	4.20%	0.38%	2.86%
23721	Land subdivision	1.18%	1.20%	3.68%		0.79%		0.51%
23731	Highway, street, and bridge construction	1.58%	13.22%	6.49%	13.63%	10.17%	26.30%	15.84%
23799	Other heavy and civil engineering construction	1.48%	3.23%	2.74%	2.43%	0.30%	10.19%	3.78%
238	Specialty Trade Contractors							
23811	Poured concrete foundation and structure contractors	3.82%	3.40%	0.21%	2.30%	5.26%	3.16%	4.52%
23812	Structural steel, precast concrete erection contractors	0.61%	1.08%	1.00%	1.40%	1.15%	0.89%	1.05%
23813	Framing contractors: Carpentry	2.03%	0.86%	0.64%	0.47%	1.41%	0.07%	0.94%
23814	Masonry contractors	3.62%	1.92%	1.13%	1.38%	2.67%	1.37%	2.21%

2002 NAICS	NAICS Subsector description	Number of Establishments	Estimated Subsector Emissions by Source					
			($MMTCO_2e$)	($MMTCO_2e$)	(million metric tons CO_2)			
			Total	Purchased electricity	Natural Gas	Vehicle fuel use		
			All Sources			on-highway	off-highway	subtotal
23815	Glass and glazing contractors	0.75%	0.49%	0.08%	0.63%	0.81%	0.18%	0.59%
23816	Roofing contractors	3.26%	2.87%	1.93%	4.25%	3.93%	1.06%	2.92%
23817	Siding contractors	0.93%	0.45%	0.29%	0.35%	0.71%	0.13%	0.51%
23819	Other foundation, structure, bldg exterior contractors	0.39%	0.34%	0.32%	0.29%	0.43%	0.16%	0.34%
23821	Electrical contractors	8.81%	7.23%	6.78%	0.44%	10.95%	2.49%	7.98%
23822	Plumbing, heating, and air conditioning contractors	12.32%	4.95%	11.33%	10.93%	2.98%	0.30%	2.04%
23829	Other building equipment contractors	0.86%	1.31%	1.17%	0.12%	1.84%	0.80%	1.47%
23831	Drywall and insulation contractors	2.76%	0.43%	0.21%	1.96%	0.42%	0.10%	0.31%
23832	Painting and wall covering contractors	5.48%	2.08%	1.80%	1.29%	2.79%	1.17%	2.22%
23833	Flooring contractors	1.81%	1.10%	1.32%	1.14%	1.46%	0.09%	0.98%
23834	Tile and terrazzo contractors	1.26%	0.55%	0.54%	0.50%	0.76%	0.16%	0.55%
23835	Finish carpentry contractors	4.94%	2.17%	2.17%	2.01%	2.82%	0.87%	2.14%
23839	Other building finishing contractors	0.52%	0.52%	0.45%	0.55%	0.68%	0.22%	0.52%
23891	Site preparation contractors	4.29%	5.93%	2.88%	3.81%	0.78%	20.65%	7.76%
23899	All other specialty trade contractors	4.71%	4.83%	3.83%	3.60%	5.89%	4.11%	5.26%

Source: Number of Establishments, fuel, and electricity purchases collected from 2002 U.S. Economic Census *Industry Series* reports for Construction (NAICS 23). Fuel and electricity purchases were converted into emissions using the method provided in the EPA Sector Strategies Division report, *Quantifying Greenhouse Gases in Key Industrial Sectors of the U.S.*, May 2008.

APPENDIX B: DETAILS OF 2002 CONSTRUCTION SUBSECTOR EMISSIONS INTENSITY

2002 NAICS code	NAICS Subsector description	Emissions (million metric tons of CO_2e)	Value Added 2002 (thousand dollars)	Intensity ($MTCO_2e$/ 2002k$)
236	Construction of Buildings			
23611	Residential building construction	24.28	93,736,269	0.26
23621	Industrial building construction	1.68	6,252,044	0.27
23622	Commercial and institutional building construction	16.21	71,881,873	0.23
237	Heavy & Civil Engineering Construction			
23711	Water and sewer line and related structures construction	5.98	16,021,682	0.37
23712	Oil and gas pipeline and related structures construction	0.92	7,662,710	0.12
23713	Power and communication line and related structures construction	3.29	23,045,082	0.14
23721	Land subdivision	1.61	14,374,486	0.11
23731	Highway, street, and bridge construction	17.64	36,210,630	0.49
23799	Other heavy and civil engineering construction	4.48	12,042,082	0.37
238	Specialty Trade Contractors			
23811	Poured concrete foundation and structure contractors	4.33	18,211,099	0.24
23812	Structural steel and precast concrete/ Structural steel erection contractors	1.41	5,823,411	0.24
23813	Framing contractors: Carpentry	1.09	8,587,264	0.13
23814	Masonry contractors	2.47	13,174,159	0.19
23815	Glass and glazing contractors	0.62	3,513,111	0.18
23816	Roofing contractors	3.69	12,800,818	0.29
23817	Siding contractors	0.58	2,262,269	0.26
23819	Other foundation, structure, and building exterior contractors	0.43	2,045,722	0.21
23821	Electrical contractors	9.23	51,676,783	0.18
23822	Plumbing, heating, and air conditioning contractors	6.67	66,878,082	0.10
23829	Other building equipment contractors	1.68	10,092,652	0.17
23831	Drywall and insulation contractors	0.57	18,042,291	0.03
23832	Painting and wall covering contractors	2.68	11,516,137	0.23
23833	Flooring contractors	1.42	4,868,960	0.29
23834	Tile and terrazzo contractors	0.71	3,753,983	0.19
23835	Finish carpentry contractors	2.81	9,762,425	0.29

2002 NAICS code	NAICS Subsector description	Emissions (million metric tons of CO_2e)	Value Added 2002 (thousand dollars)	Intensity ($MTCO_2$e/ 2002k$)
23839	Other building finishing contractors	0.67	3,403,706	0.20
23891	Site preparation contractors	8.21	23,114,914	0.36
23899	All other specialty trade contractors	6.28	15,339,069	0.41

Source: Emissions were calculated by subsector for fuel and electricity purchases collected from 2002 U.S. Economic Census *Industry Series* reports for Construction (NAICS 23). Fuel and electricity purchases were converted into emissions using the method provided in the EPA Sector Strategies Division report, *Quantifying Greenhouse Gases in Key Industrial Sectors of the U.S.*, May 2008. Value added collected for each subsector from 2002 U.S. Economic Census *Industry Series* reports for Construction (NAICS Sector 23). Selected Statistics for Establishments by Specialization. Released November 21, 2005.

Appendix C: Construction Subsector Descriptions of 2002 NAICS Codes

Code	Title	Description
23611	Residential building construction	Establishments primarily responsible for the construction or remodeling and renovation of single-family and multifamily residential buildings. Included in this industry are residential housing general contractors (i.e., new construction, remodeling or renovating existing residential structures), operative builders and remodelers of residential structures, residential project construction management firms, and residential design-build firms.
23621	Industrial building construction	Establishments primarily responsible for the construction (including new work, additions, alterations, maintenance, and repairs) of industrial buildings (except warehouses). The construction of selected additional structures, whose production processes are similar to those for industrial buildings (e.g., incinerators, cement plants, blast furnaces, and similar nonbuilding structures), is included in this industry. Included in this industry are industrial building general contractors, industrial building operative builders, industrial building design-build firms, and industrial building construction management firms.
23622	Commercial and institutional building construction	Establishments primarily responsible for the construction (including new work, additions, alterations, maintenance, and repairs) of commercial and institutional buildings and related structures, such as stadiums, grain elevators, and indoor swimming pools. This industry includes establishments responsible for the on-site assembly of modular or prefabricated commercial and institutional buildings. Included in this industry are commercial and institutional building general contractors, commercial and institutional building operative builders, commercial and institutional building design-build firms, and commercial and institutional building project construction management firms.
23711	Water and sewer line and related structures construction	Establishments primarily engaged in the construction of water and sewer lines, mains, pumping stations, treatment plants and storage tanks. The work performed may include new work, reconstruction, rehabilitation, and repairs. Specialty trade contractors are included in this group if they are engaged in activities primarily related to water and sewer line and related structures construction. All structures (including buildings) that are integral parts of water and sewer networks (e.g., storage tanks, pumping stations, water treatment plants, and sewage treatment plants) are included in this industry.
23712	Oil and gas pipeline and related structures construction	Establishments primarily engaged in the construction of oil and gas lines, mains, refineries, and storage tanks. The work performed may include new work, reconstruction, rehabilitation, and repairs. Specialty trade contractors are included in this group if they are engaged in activities primarily related to oil and gas pipeline and related structures construction. All structures (including buildings) that are integral parts of oil and gas networks (e.g., storage tanks, pumping stations, and refineries) are included in this industry.
23713	Power and communication line and related structures construction	Establishments primarily engaged in the construction of power lines and towers, power plants, and radio, television, and telecommunications transmitting/receiving towers. The work performed may include new work, reconstruction, rehabilitation, and repairs. Specialty trade contractors are included in this group if they are engaged in activities primarily related to power and communication line and related structures construction. All structures (including buildings) that are integral parts of power and communication networks (e.g., transmitting towers, substations, and power plants) are included.

Code	Title	Description
23721	Land subdivision	Establishments primarily engaged in servicing land and subdividing real property into lots, for subsequent sale to builders. Servicing of land may include excavation work for the installation of roads and utility lines. The extent of work may vary from project to project. Land subdivision precedes building activity and the subsequent building is often residential, but may also be commercial tracts and industrial parks. These establishments may do all the work themselves or subcontract the work to others. Establishments that perform only the legal subdivision of land are not included in this industry.
23731	Highway, street, and bridge construction	Establishments primarily engaged in the construction of highways (including elevated), streets, roads, airport runways, public sidewalks, or bridges. The work performed may include new work, reconstruction, rehabilitation, and repairs. Specialty trade contractors are included in this group if they are engaged in activities primarily related to highway, street, and bridge construction (e.g., installing guardrails on highways).
23799	Other heavy and civil engineering construction	Establishments primarily engaged in heavy and engineering construction projects (excluding highway, street, bridge, and distribution line construction). The work performed may include new work, reconstruction, rehabilitation, and repairs. Specialty trade contractors are included in this group if they are engaged in activities primarily related to engineering construction projects (excluding highway, street, bridge, distribution line, oil and gas structure, and utilities building and structure construction). Construction projects involving water resources (e.g., dredging and land drainage), development of marine facilities, and projects involving open space improvement (e.g., parks and trails) are included in this industry.
23811	Poured concrete foundation and structure contractors	Establishments primarily engaged in pouring and finishing concrete foundations and structural elements. This industry also includes establishments performing grout and shotcrete work. The work performed may include new work, additions, alterations, maintenance, and repairs.
23812	Structural steel and precast concrete/ Structural steel erection contractors	Establishments primarily engaged in: (1) erecting and assembling structural parts made from steel or precast concrete (e.g., steel beams, structural steel components, and similar products of precast concrete); and/or (2) assembling and installing other steel construction products (e.g., steel rods, bars, rebar, mesh, and cages) to reinforce poured-in-place concrete. The work performed may include new work, additions, alterations, maintenance, and repairs.
23813	Framing contractors: Carpentry	Establishments primarily engaged in structural framing and sheathing using materials other than structural steel or concrete. The work performed may include new work, additions, alterations, maintenance, and repairs.
23814	Masonry contractors	Establishments primarily engaged in masonry work, stone setting, bricklaying, and other stone work. The work performed may include new work, additions, alterations, maintenance, and repairs.
23815	Glass and glazing contractors	Establishments primarily engaged in installing glass panes in prepared openings (i.e., glazing work) and other glass work for buildings. The work performed may include new work, additions, alterations, maintenance, and repairs.
23816	Roofing contractors	Establishments primarily engaged in roofing. This industry also includes establishments treating roofs (i.e., spraying, painting, or coating) and installing skylights. The work performed may include new work, additions, alterations, maintenance, and repairs.
23817	Siding contractors	Establishments primarily engaged in installing siding of wood, aluminum, vinyl or other exterior finish material (except brick, stone, stucco, or curtain wall). This industry also includes establishments installing gutters and downspouts. The work performed may include new work, additions, alterations, maintenance, and repairs.
23819	Other foundation, structure, and building exterior contractors	Establishments primarily engaged in building foundation and structure trades work (except poured concrete, structural steel, precast concrete, framing, masonry, glass and glazing, roofing, and siding). The work performed may include new work, additions, alterations, maintenance, and repairs.

Code	Title	Description
23821	Electrical contractors	Establishments primarily engaged in installing and servicing electrical wiring and equipment. Electrical contractors included in this industry may include both the parts and labor when performing work. Electrical contractors may perform new work, additions, alterations, maintenance, and repairs.
23822	Plumbing, heating, and air conditioning contractors	Establishments primarily engaged in installing and servicing plumbing, heating, and air-conditioning equipment. Contractors in this industry may provide both parts and labor when performing work. The work performed may include new work, additions, alterations, maintenance, and repairs.
23829	Other building equipment contractors	Establishments primarily engaged in installing or servicing building equipment (except electrical; plumbing; heating, cooling, or ventilation equipment). The repair and maintenance of miscellaneous building equipment is included in this industry. The work performed may include new work, additions, alterations, maintenance, and repairs.
23831	Drywall and insulation contractors	Establishments primarily engaged in drywall, plaster work, and building insulation work. Plaster work includes applying plain or ornamental plaster, and installation of lath to receive plaster. The work performed may include new work, additions, alterations, maintenance, and repairs.
23832	Painting and wall covering contractors	Establishments primarily engaged in interior or exterior painting or interior wall covering. The work performed may include new work, additions, alterations, maintenance, and repairs.
23833	Flooring contractors	Establishments primarily engaged in the installation of resilient floor tile, carpeting, linoleum, and hard wood flooring. The work performed may include new work, additions, alterations, maintenance, and repairs.
23834	Tile and terrazzo contractors	Establishments primarily engaged in setting and installing ceramic tile, stone (interior only), and mosaic and/or mixing marble particles and cement to make terrazzo at the job site. The work performed may include new work, additions, alterations, maintenance, and repairs.
23835	Finish carpentry contractors	Establishments primarily engaged in finish carpentry work. The work performed may include new work, additions, alterations, maintenance, and repairs.
23839	Other building finishing contractors	Establishments primarily engaged in building finishing trade work (except drywall, plaster and insulation work; painting and wall covering work; flooring work; tile and terrazzo work; and finish carpentry work). The work performed may include new work, additions, alterations, or maintenance and repairs.
23891	Site preparation contractors	Establishments primarily engaged in site preparation activities, such as excavating and grading, demolition of buildings and other structures, septic system installation, and house moving. Earth moving and land clearing for all types of sites (e.g., building, nonbuilding, mining) is included in this industry. Establishments primarily engaged in construction equipment rental with operator (except cranes) are also included.
23899	All other specialty trade contractors	Establishments primarily engaged in specialized trades (except foundation, structure, and building exterior contractors; building equipment contractors; building finishing contractors; and site preparation contractors). The specialty trade work performed includes new work, additions, alterations, maintenance, and repairs.

Source: All descriptions reproduced from subsector definitions according to the U.S. Census Bureau for NAICS code 23 (Construction).U.S. Census Bureau, *2002 NAICS Codes and Titles, Construction,* March 23, 2004, http://www.census.gov/epcd/naics02/naicod02.htm, accessed October 6, 2008 Available at: http://www.census.gov/econ/census02/data/us/US000_23.HTM.

ENDNOTES

[1] U.S. EPA, "Basic Information," *Climate Change*. Accessed January 22, 2009. http://www.epa.gov/climatechange/basicinfo.html

[2] Ibid.

[3] U.S. Census Bureau,"23 Construction," *2002 NAICS Definitions*. May 6, 2003. Available at: http://www.census.gov/epcd/naics02/def/NDEF23.HTM

BusinessDictionary.com, "construction industry." Definition, 2009 Available at: http://www.businessdictionary.com/definition/construction-industry.html

[4] U.S. Census Bureau, County Business Patterns (CBP), 2006, available at: http://www.census.gov/epcd/cbp/view/cbpview.html.

[5] U.S. Environmental Protection Agency (U.S. EPA), *Quantifying Greenhouse Gas Emissions in Key Industrial Sectors*, Sector Strategies Division, May 2008.

[6] Emissions calculated for Sector Strategies, based on the U.S. Department of Energy (DOE) 2002 *Manufacturing Energy Consumption Survey* and EPA's *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2006*. U.S. Department of Energy, Energy Information Administration (EIA), 2002 *Manufacturing Energy Consumption Survey*, 2005. U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2006*, 2008.

[7] Methane (CH_4) emissions from uncontrolled heavy-duty gasoline vehicles are estimated by the U.S. EPA's NONROAD model to be 20 times the emissions from equipment with low-emissions vehicle technology. IPCC, 2006 National Guidelines for Greenhouse Gas Inventories, 2006, Table 3.2.3. Available online at: http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2_Volume2/V2_3_Ch3_Mobile_Combustion.pdf

[8] 2004 state electricity emissions factors for CO_2, CH_4, and N_2O. EPA, eGRID, available at: http://www.epa.gov/cleanenergy/energy-resources/egrid/index.html.

[9] The *AEO 2008* produces estimates as model output of the EIA National Energy Modeling System's Industrial Sector Demand module, based on the following sources: DOE's 2002 *Manufacturing Energy Consumption Survey*; aggregated construction sector data of the U.S. Department of Commerce, Census Bureau, *Economic Census* 2002: Construction Industry Series; the EIA's *Fuel Oil and Kerosene Sales 2002*; and EIA's 2006 release of *State Energy Data System 2003*. In order to calculate energy consumption, these estimates delineate fuel usage per value output as Unit Energy Consumption (UEC) ratios, since the source data relate to total energy consumption and provide no information on the processes or end-uses. For diesel, gasoline, and purchased electricity, CO2 emissions are calculated as the product of an EIA emissions factor and the modeled energy consumption.

[10] U.S. Census Bureau, *2002 Economic Census: Industry Series Reports*, Construction. November 22, 2005. Available online at: http://www.census.gov/econ/census02/guide/INDRPT23.HTM.

[11] For example, EIA calculates that about 97% (1902.5 MMT CO_2e) of total fossil fuel combustion from mobile sources in 2007 is CO_2; the remaining 3% of emissions are CH_4 and N_2O (respectively 5.1 and 56.2 MMT CO_2e). This report does not attempt to correct the fossil fuel consumption estimates of the source document to account for these additional gases. In order to provide the analyses of total sector and subsector emissions in this report, CO_2 and CO_2e emissions are summed for simplification.

EIA,"Greenhouse Gas Emissions in the U.S. Economy, *Emissions of Greenhouse Gases Report*. 2008 Available at: http://www.eia.doe.gov/oiaf/1605/ggrpt/index.html#economy

[12] U.S. Department of Energy, Energy Information Administration (EIA), *Annual Energy Outlook 2008*, pp. 55 and 63.

[13] The six other sectors are those that were included in both the *AEO 2008* and the *Quantifying Greenhouse Gas Emissions in Key Industrial Sectors* reports. These are: food, paper, chemical (bulk chemical in AEO and all chemical manufacturing is the EPA report), cement, aluminum, and iron & steel.

[14] Comparable sectors (and average annual emissions rate for 2011-2030) include the food (0.29%/yr), paper (0.01%/yr), bulk chemical (-1.08%/yr), cement (-0.32%/yr), aluminum (-0.72%/yr), and iron and steel industries(-0.07%/yr).

[15] Aurora L. Sharrard, H. Scott Matthews, and Michael Roth, "Environmental Implications of Construction Site Energy Use and Electricity Generation," *Journal of Construction Engineering and Management*, Vol. 133, No. 11, November 1, 2007.

[16] For example, Connecticut limits idling of all motor sources (including off-road engines) to three minutes. For additional information and regulations of other states, see http://www.epa.gov/otaq/smartway/idle-state.htm.

[17] U.S. EPA, *Low Cost Ways to Reduce Air Emissions from Off-Road Diesel Construction Equipment*, 2006.

[18] Estimates are calculated from an idling study of long-haul trucks, as no construction equipment-specific studies are available. Lim, Han. *Study of Exhaust Emissions from Idling Heavy-Duty Diesel Trucks and Commercially Available Idle-Reducing Devices*, U.S. EPA, October 2002. Table 7. http://www.epa.gov/oms/smartway/documents/epaidlingtesting.pdf

[19] Huai et al., "Analysis of heavy-duty diesel truck activity and emissions data," *Atmospheric Environment* 40: 2333-2344, 2006.

[20] Analysis by Christopher Steel, Grace Pacific Corporation. E-mail correspondence with Peter Truitt, U.S. EPA. 1 October 2007.

[21] The 2006 U.S. Census indicates 802,349 total construction establishments. On average, it is assumed each firm of any size can reduce diesel idling by 10 hours per month, with an average emissions factor of 15 lbs CO2 per hour from a 2001 model year Class 8 engine. 802,349 firms x 15 lbs CO2/hour x 120 hours/year = 1.44 billion lbs CO2/year = 0.65 million metric tons CO2/ year

[22] U.S. EPA. "Engine and Vehicle Emissions Reductions," March 2007, available at: http://es.epa.gov/ncer/rfa/2007/2007_sbir_phase1.html, and Lim, Han. *Study of Exhaust Emissions from Idling Heavy-Duty Diesel Trucks and Commercially Available Idle-Reducing Devices*, U.S. EPA, October 2002.

[23] Argonne National Laboratory, http://www.transportation.anl.gov/downloads/idling_worksheet.xls.

[24] Michigan Occupational Safety and Health Administration, "Carbon Monoxide Hazards from Internal Combustion Engines: Properly Maintained Forklifts Cost Significantly Less to Operate," http://www.michigan.gov/documents/cis_wsh_cet5011_115680_7.doc.

[25] This estimate assumes a typical diesel pickup with an average fuel economy of 15 mpg, traveling 15,000 miles per year, to be applicable for construction company transportation fleets or establishments without heavy equipment. Assumptions based on review of average vehicle fuel economy data from weblog responses and EPA fuel economy ratings for used vehicles. U.S. EPA, "Diesel Vehicles," 2008. https://www.fueleconomy.gov/feg/diesel.shtml

[26] 2007 U.S. annual No.2 diesel fuel average cost: EIA, "No. 2 Distillate Prices by Sales Type." Released September 30, 2008. http://tonto.eia.doe.gov/dnav/pet/pet_pri_dist_dcu_nus_a.htm

27 Giles Lambertson, “Manufacturers Begin to Tout Fuel Efficiency,” Construction Equipment Guide.com, July 16, 2008, http://www.constructionequipmentguide.com/story.asp?story=10902.

28 2007 U.S. annual No.2 diesel fuel average cost: EIA, "No. 2 Distillate Prices by Sales Type." Released September 30, 2008. http://tonto.eia.doe.gov/dnav/pet/pet_pri_dist_dcu_nus_a.htm

29 Giles Lambertson, “Manufacturers Begin to Tout Fuel Efficiency,” Construction Equipment Guide.com, July 16, 2008, http://www.constructionequipmentguide.com/story.asp?story=10902.

30 Ibid.

31 Articles.DirectoryM.net, “Maximize Fuel Economy: Truck manufacturers offer advice to cut fuel consumption,” July 28, 2008, http://articles.directorym.net/Maximize_Fuel_Economy-a878656.html.

32 Gary Gotting, Machine Design, March 6, 2008.

33 Power Source. John Deere. Vol 4, 2005.

34 Duncan, Andy. “Application compensation.” July 2008. http://www.etrucker.com/apps/news/article.asp?id=70341

35 Example based on similar calculation for repowering engines published in the EPA report *Cleaner Diesel: Low-cost Ways to Reduce Emissions from Construction Equipment*, March 2007.

36 Ibid.

37 Some examples of engine costs are provided in the EPA report *Cleaner Diesel: Low-cost Ways to Reduce Emissions from Construction Equipment*, March 2007.

38 Calculation from biodiesel refinery feedstock listings of the Center for Agricultural Research and Development, current as of May 6, 2008. http://www.card.iastate.edu/research/bio/tools/biodiesel.aspx

39 Specification for ASTM D6751 (B(100)). Available at: http://www.biodiesel.org/pdf_files/fuelfactsheets/BDSpec.pdf.

40 Renewable Fuels Agency, *The Gallagher Review of the Indirect Effects of Biofuels Production*, July 2008, Available at: http://www.dft.gov.uk/rfa/_db/_documents/Report_of_the_Gallagher_review.pdf.

41 E4Tech, *Biofuels Review: GHG Savings Calculations*, June 2008. Available at: http://www.dft.gov.uk/rfa/_db/_documents/E4Tech_GHG_saving_calculations.pdf.

42 Renewable Fuels Agency, *The Gallagher Review of the Indirect Effects of Biofuels Production*, July 2008, Available at: http://www.dft.gov.uk/rfa/_db/_documents/Report_of_the_Gallagher_review.pdf.

43 U.S. DOE, *Lifetime Cycle Inventory of Biodiesel and Petroleum Diesel for Use on an Urban Transit Bus*, May 1998. Available at: http://www.nrel.gov/docs/legosti/fy98/24089.pdf. Graphic with ethanol comparison from Kansas Energy Book, 2007. Available at: http://kec.kansas.gov/chart_book/Chapter5/03_LifeCycleGHGEmissions.pdf.

44 “Case Approves Use of B20 Biodiesel Blends for Construction Equipment,” Reuters, June 17, 2008. http://www.reuters.com/article/pressRelease/idUS134674+17-Jun-2008+MW20080617.

45 Mike Stinson and Josh Canner, “Technology, Green Construction at Destiny USA,” Associated Construction Publications, October 6, 2008. http://www.acppubs.com/article/CA6598346.html.

46 Anthony Radich, *Biodiesel Performance, Costs and Use,* EIA. Available at: http://www.eia.doe.gov/oiaf/analysispaper/biodiesel/.

[47] Ibid.

[48] National Biodiesel Board, http://www.biodiesel.org/buyingBioDiesel/retailfuelingsites/; BioTrucker.com, Available at: http://www.biotrucker.com/sites/.

[49] Marianne Lavelle, "Going Biodiesel is No Cheap Alternative," *U.S. News and World Reports*, March 25, 2008.

[50] Emissions calculation based on AP-42 emissions standard for diesel stationary combustion sources and EIA calculation of diesel BTU content, resulting in a factor of 22.88 lbs CO2 emitted per gallon of diesel. Average diesel cost from EIA prices. http://www.epa.gov/ttn/chief/ap42/ch03/final/c03s04.pdf.

[51] Emissions calculation based on AP-42 emissions standard for duel-fuel stationary combustion sources and EIA calculation of diesel and natural gas BTU content. Available at: http://www.epa.gov/ttn/chief/ap42/ch03/final/c03s04.pdf.

[52] Percent comparison of national electricity emissions factor of 1.36 lbs CO2/kWh from EPA's eGRID, as of 2004, and the EPA emissions factor for uncontrolled diesel stationary combustion. U.S. EPA, *AP 42*, Fifth Edition, Volume I, Chapter 3: Stationary Internal Combustion Sources, Table 3.31, Emissions factors for uncontrolled gasoline and diesel industrial engines, June 2007. Available at: http://www.epa.gov/ttn/chief/ap42/ch03/final/c03s03.pdf

[53] Emma Ritch, "Sprig Electric Plugs into Mobile? Solar Trailers," *San Jose Business Journal*, July 4, 2008.

[54] Canadice Construction Company, "Alternative Energy Products," http://canadiceconstruction.com/alternativeenergyproducts.nxg.

[55] U.S. Census Bureau, *County Business Patterns (CBP)*, 2006. Available at: http://www.census.gov/epcd/cbp/view/cbpview.html.

[56] Raymond J. Cole, "Energy and Greenhouse Gas Emissions Associated with the Construction of Alternative Structural Systems," *Building and Environment* 34 (1999), pages 335 - 348.

[57] U.S. EPA, *Emissions & Generation Resource Integrated Database (eGRID)* version 2.1. Available at: http://www.epa.gov/cleanenergy/energy-resources/egrid/index.html

[58] U.S. EPA, "Office Building Energy Use Profile," *National Action Plan for Energy Efficiency*, *Sector Collaborative on Energy Efficiency*, June 2007. Available at: http://www.epa.gov/solar/documents/sector-meeting/4bi_officebuilding.pdf.

[59] U.S. EPA, "Corporate Real Estate Fact Sheet," *Energy STAR*, http://www.energystar.gov/ia/business/corp_real_estate/factsheet_0804.pdf.

[60] "C&D Debris State Resources." *Construction Industry Compliance Assistance Center*. http://www.cicacenter.org/solidregs.html.

[61] Sources cited in the source document include: Federal Highway Administration, "Transportation Application of Recycled Concrete Aggregate," 2004; David R. Wilburn and Thomas G. Goonan, "Aggregates from Natural And Recycled Sources, Economic Assessments for Construction Applications–A Materials Flow Analysis," *U.S. Geological Survey Circular 1176*, 1998; Robert H. Falk and G. Bradley Guy, "Directory of Wood-Framed Building Deconstruction and Reused Building Materials Companies," U.S. Forest Service, 2004; and Robert Falk, "Wood-Framed Building Deconstruction, A Source of Lumber for Construction?" *Forest Products Journal*, Vol. 52, No. 3, 2002.

[62] U.S. EPA, *Characterization of Building-Related Construction and Demolition Debris Materials in the United States (DRAFT)*, Municipal and Industrial Solid Waste Division, Office of Solid Waste. Draft in progress.

[63] The 48% includes managing materials beyond recycling, including reuse and waste-to-energy. Kim Cochran, U.S. EPA Office of Solid Waste, January 12, 2007, personal communication.

[64] Statement within EPA press release: "EPA and Partners Kick Off Green Building Design Challenge; Contest to reward reuse designs that save resources, costs," May 13, 2008.

[65] U.S. EPA. "Greenhouse Gas Emission Factors ($MTCO_2E$ per short ton)" *Waste Reduction Model*. August 2008. Web-based calculator and Excel worksheet available at: http://www.epa.gov/climatechange/wycd/waste/calculators/Warm_home.html.

[66] Ibid.

[67] Quantity of asphalt from personal communication of EPA estimates.

[68] The City of San Diego, "Potential Benefits of C&D Recycling,"available at: http://www.sandiego.gov/environmental-services/recycling/cdbenefits.shtml. See also: King County Solid Waste Division , "Cost-effectiveness of Jobsite Diversion/Recycling.," October 2 2008 .http://www.metrokc.gov/dnrp/swd/greenbuilding/construction-recycling/cost-effectiveness.asp; Recycling Economics worksheet, available at: http://www.metrokc.gov/dnrp/swd/greenbuilding/documents/economics_worksheet.xls.

[69] Ibid.

[70] Arpad Horvath, "Construction Materials and the Environment," *Annual Review of Environment and Resources*, 2004, p. 194.

[71] New Hampshire, Massachusetts, Rhode Island, Connecticut, New York, Florida, Nebraska, Idaho, and California.

[72] Massachusetts EPA, *MEPA Greenhouse Gas Emissions Policy and Protocol*, http://www.mass.gov/envir/mepa/pdffiles/misc/GHG%20Policy%20FINAL.pdf.

[73] EPA's ReCon tool provides basic comparisons of the emissions produced from virgin materials and the same materials with a selected recycled content. U.S. EPA, "Recycled Content (ReCon)Tool," August 25, 2008. Available at: http://www.epa.gov/climatechange/wycd/waste/calculators/ReCon_home.html.

[74] U.S. EPA. "Waste Reduction Model," *Climate Change-Waste*, September 1, 2008. http://www.epa.gov/climatechange/wycd/waste/calculators/Warm_home.html

[75] National Institute of Standards and Technology, *BEES 4.0.* August 20, 2007. Available at: http://www.bfrl.nist.gov/oae/software/bees/

[76] Comment verbatim from note regarding the WARM and ReCon models. U.S. EPA. "Waste Reduction Model," *Climate Change-Waste*, September 1, 2008. http://www.epa.gov/climatechange/wycd/waste/calculators/Warm_home.html

[77] The pilot consolidation center for construction materials as part of the London Freight Plan purports to reduce transportation emissions by 75 percent. London Construction Consolidation Centre interim report, May 2007, http://www.tfl.gov.uk/assets/downloads/businessandpartners/LCCC-interim-report-may-07.pdf; News Article, http://www.tfl.gov.uk/corporate/media/newscentre/archive/3525.aspx.

[78] U.S. EPA, *Shipper/Logistics FLEET Performance Model*, 2008, http://www.epa.gov/smartway/smartway_shippers_software.htm#model.

[79] Summary from interviews with Michael Dean, Turner Construction, Matthew Crandall, DPR Construction, and Joel Nickel, Aggregate Industries.

80 WRI/WBSCD, “Corporate Standard,” *The Greenhouse Gas Protocol Initiative*, http://www.ghgprotocol.org/standards/corporate-standard.

81 The Kyoto Protocol gases are carbon dioxide (CO_2), methane (CH_4); nitrous oxide (N_2O); hydrofluorocarbons (HFCs); perfluorocarbons (PFCs); and sulfur hexafluoride (SF_6).

82 WRI/WBSCD, “About the GHG Protocol,” *The Greenhouse Gas Protocol Initiative*, http://www.ghgprotocol.org/about-ghgp.

83 WRI/WBSCD, *A Corporate Accounting and Reporting Standard*, Revised Edition, 2004. Page 25. Available at: http://www.ghgprotocol.org/files/ghg-protocol-revised.pdf

84 U.S. EPA, “Inventory Guidance,” *Climate Leaders*, August 20, 2008. http://www.epa.gov/stateply/resources/inventory-guidance.html.

85 Urbemis, a model developed to calculate emissions from land use, calculates construction equipment-specific emissions based on the hours operated, average horsepower used, and average load factor during operation. Rimpo and Associates, Inc., *Urbemis 9.2.4*, 2008. Available at: http://www.urbemis.com.

86 According to IPCC emissions factors, CH4 emissions from an uncontrolled gasoline engine are approximately one-third higher in an uncontrolled gasoline offroad vehicle (33 kg/TJ versus 50 kg/TJ). *2006 IPCC National Guidelines for Greenhouse Gas Inventories*, IPCC, 2006. Available at: http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2_Volume2/V2_3_Ch3_Mobile_Combustion.pdf

87 North Bay Construction, another Climate Leader member, was not available for comment.

88 Michael Dean, Turner Construction, June 18, 2008, personal communication.

89 Mathew Crandall, DPR Construction, August 19, 2008, personal communication.

90 Adam Loney and Greg Carli, Conestoga Rovers and Associates, September 10, 2008, personal communication.

91 Joel Nickel, Aggregate Industries, October 3, 2008, personal communication.

92 Idling calculation range from assumptions made in Section 2, reducing 10 hours idling per year for all construction establishments listed by the U.S. Census Bureau, *County Business Patterns (CBP)*, 2006. Additional calculation assumes 2 million pieces diesel construction equipment idle 29.4% of 1,500 operational hours per year, of which 10% is reduced per year. See articles: U.S. EPA. “Engine and Vehicle Emissions Reductions,” March 2007, available at: http://es.epa.gov/ncer/rfa/2007/2007_sbir_phase1.html, and Lim, Han. *Study of Exhaust Emissions from Idling Heavy-Duty Diesel Trucks and Commercially Available Idle-Reducing Devices*, U.S. EPA, October 2002.

Maintenance and driver training assumes efficiency improvements in 2 million pieces of diesel off-road construction equipment, assuming a heavy-heavy duty diesel vehicle with an average 6.6 miles per gallon operating 1,500 miles per year. See Huai et al., “Analysis of heavy-duty diesel truck activity and emissions data,” *Atmospheric Environment 40*: 2333-2344, 2006.

Electricity conservation assumes a reduction of 10% from total sector-wide purchased electricity consumption. See Table 6.

Biodiesel replacement assumes 10% of any diesel fuel consumption (on- or off-highway) is replaced by B20. See Table 5.

Emissions factor for steel is from EPA’s *Waste Reduction Model—Results*. Model estimate methodology from: *Solid Waste Management and Greenhouse Gases: A Life-Cycle Assessment of Emissions and Sinks* (EPA530-R-02-006); available at: http://www.epa.gov/mswclimate/greengas.pdf.

Emissions factor for asphalt is from EPA's *Waste and Materials-Flow Benchmark Sector Report: Beneficial Use of Secondary Materials - Construction & Demolition Debris*, draft in progress.

Emissions factor for concrete is from Arpad Horvath, "Construction Materials and the Environment," *Annual Review of Environment and Resources*, 2004, p. 189.

Annual concrete recycled quantity is from CMRA, www.concreterecycling.org.

Steel recycling rates and quantity are from personal communication with Bill Heenan, President of the Steel Recycling Institute, and "Fact sheet: 2006 rates," http://www.recycle-steel.org/PDFs/2006Graphs.pdf. Of the 40 million tons recycled, approximately 28 million tons are structural and 12 million tons are reinforcement steel.

Asphalt recycled quantity is provided from personal communication of EPA estimates.