# Carbon Neutrality At Purdue

2007

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*Front cover photo by Derrick Hasterok, 2004, of grasses along the Salmon River in Idaho*

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We are also grateful to Dr. Morgan Olsen, Purdue University Executive Vice President and Treasurer, as well as James Almond, John Sautter, Ken Sandel, and Wayne Kjonaas, who took time to meet with us to discuss the implications of our footprint calculation and the possible implementation of some of our management strategies on the Purdue campus.

Finally, a very special thanks to our six Carbon Neutrality instructors (listed on page ii), who, in spite of their already busy schedules, spent copious amounts of time with us and gave invaluable support and guidance throughout this entire project. Thank you!

# Executive Summary and Preface

In the spring semester of 2007, an interdisciplinary class of 29 students and 6 instructors calculated the annual carbon emissions of Purdue University, as well as generated a series of ideas to reduce those emissions over time to the point of "carbon neutrality," or zero net carbon emissions. Decades of climate research have confirmed that human activities are responsible for a large part of the increase in atmospheric levels of carbon dioxide that have occurred since the Industrial Revolution and that this increase atmospheric $CO_2$ concentration is the primary driver of recent, observed climate change (e.g. global warming). As doubts regarding the connection between human activities and climate change have been addressed by researchers, institutions and individuals have become more interested in pursuing solutions to prevent catastrophic climate change and mitigate the effects of changes which have already occurred. To this end, the pursuit of carbon neutrality as an institutional goal has gained popularity among myriad institutions – from Fortune 500 companies and industry leaders to forward-thinking towns and cities.

Carbon neutrality is a simple goal which requires complex strategies if it is to be met in a sustainable and environmentally-meaningful way. Simply stated, carbon neutrality entails reducing individual or institutional net carbon emissions to zero. This can be accomplished through a variety of techniques including reducing dependence on carbon-intensive fossil fuels as a source of energy, implementing more efficient and judicious energy management practices, and carbon offsets.

As a premier research and engineering institution, Purdue University is ideally suited to adopt the goal of carbon neutrality. Purdue is widely known for its cutting edge research in the areas of science, technology, engineering, and agriculture. Already, a number of Purdue affiliated laboratories and research centers are working to develop and improve renewable energy generation and storage methods, including wind, solar, hydrogen, and many more. The Purdue University Discovery Park Energy Center has declared, "Our vision is to significantly contribute to the development of the energy solution society is currently seeking as we prepare for the eventual transition from fossil fuels to other energy sources" ("Energy Center at Discovery Park", 2005). These important research initiatives indicate that Purdue University has already begun to take steps to reduce fossil fuel usage – the primary driver of anthropogenic climate change. The Purdue Climate Change Research Center (PCCRC) and Center for the Environment (C4E) are committed to promoting research and potential solutions regarding all aspects of the climate change challenge. Perhaps most significantly, though, the 2001-2006 Purdue University Strategic Plan, subtitled "Next Level: Preeminence," states, "We are pledged to use our financial, physical, and human resources wisely and prudently to improve our university, our community, and the world" ("Strategic Plan", 2001). The pursuit of carbon neutrality is an ideal undertaking for Purdue that not only utilizes the university's nationally-recognized advantages in science, engineering, and technology, but also meets this pledge and the overarching goals of the university. Acting now to investigate and implement the measures necessary to bring Purdue University toward true carbon neutrality will extend the university to the next level – preeminence in environmental protection. With that mission in mind, we are pleased to offer this initial report.

## Purdue's Footprint

For this study, we defined Purdue's "carbon footprint" as the net amount of carbon (in the form of carbon dioxide) released to the atmosphere as a result of Purdue University activities, which include: energy production and consumption; building construction; land management; and purchasing decisions for the 2005-06 fiscal year. The geographic boundaries for our study encompassed the Purdue University West Lafayette campus and land holdings throughout Tippecanoe County. We did not include any of Purdue's satellite campuses or properties outside of Tippecanoe County, nor did we include properties owned by the independent Purdue Research Foundation. Our analysis then divided Purdue's carbon footprint into six different parts, or sectors. These sectors, along with definitions, are listed below.

- **On-Campus Energy**: Electricity, steam heating, and chilled water cooling provided by Purdue University's Wade Utility Plant.
- **Off-Campus Energy**: Electricity and natural gas purchased by the University, provided by off-campus utility companies.
- **Transportation**: Automobile, air, and bus travel directly related to University business. This includes faculty and students commuting to and from campus, University-owned vehicle travel, local bus travel by Purdue employees and students,

and student and faculty air, bus, and car travel to conferences and other professional meetings.

- **Permanent Materials**: Manufacture and construction of University buildings. Carbon dioxide is released when building materials are manufactured, transported to the construction site, and when the buildings themselves are constructed. All of these activities are included in the "embodied energy" of the building materials, which was used to calculate this part of the footprint.
- **Consumable Materials**: Embodied carbon dioxide emissions from the production and transport of food, plastics, paper, and other non-permanent materials used on the University campus.
- **Land Use**: Carbon dioxide emissions and storage associated with the "green areas" of the main West Lafayette campus and the various landholdings the University owns throughout Tippecanoe County, including the experimental farms and forests owned by the University.

Working groups developed their own methods for retrieving data and calculating carbon footprints for each of these six sectors. Those sector footprints were then summed to give the total Purdue University carbon footprint. To maintain consistency, all of the final carbon footprints are presented in the units of metric tons of carbon (1000 kg) abbreviated as tC for metric tons of carbon.

Figure 1 (next page) presents the breakdown of the overall footprint into its six sectors. We estimate Purdue activities emitted a total of **182,970 tC** to the atmosphere during the fiscal year 2005-2006.

**On-Campus Energy:** For the time period of July, 2005 through June, 2006, the total CO2 emissions of the Wade Utility Plant measured by the Continuous Emissions Monitoring System were 378,270 metric tons of carbon dioxide ($CO_2$). Removing the weight of the oxygen, this means that **103,165 tC** were released into the atmosphere in this sector. This quantity of carbon represents the largest portion, over 56%, of Purdue University's overall carbon footprint. However, while the carbon emissions from Wade are significant, they are far lower than for most comparably-sized coal-fired energy generating facilities, due to the fact that Purdue utilizes an efficient co-generation process by which the "waste" steam used to generate electricity is also used to heat and cool campus buildings.

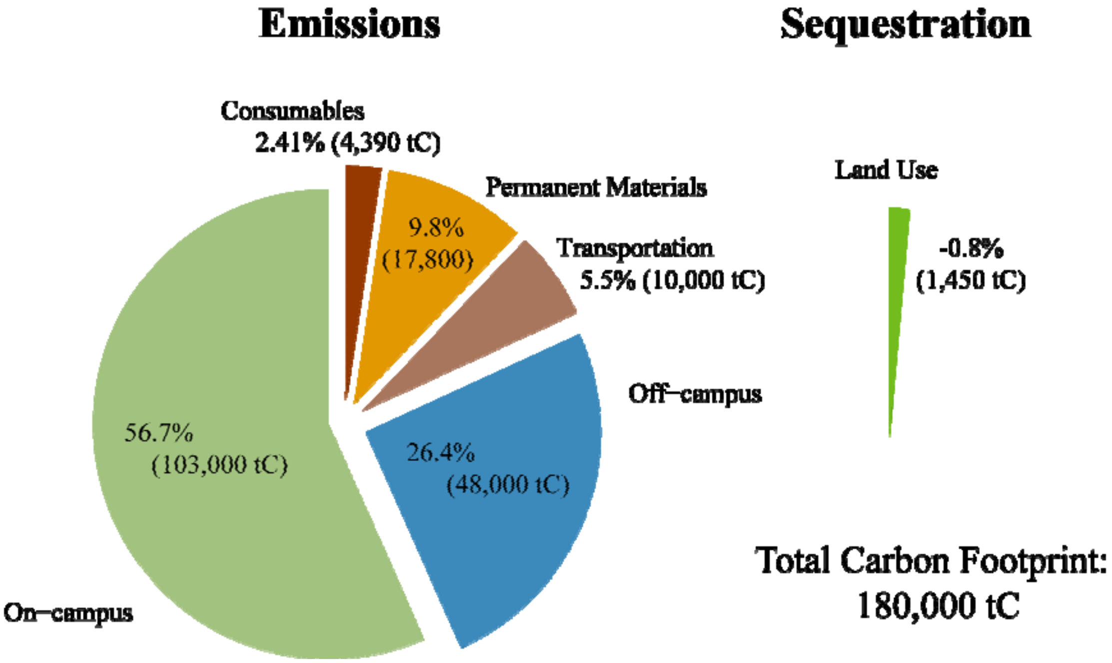

**Figure 1:** Total carbon footprint for Purdue University, divided into six sectors.

**Off-Campus Energy**: In FY 2005-2006 Purdue purchased 153,510,279 kilowatt-hours (kWh) of electricity from off-campus providers to meet energy demand beyond the production capacity of Wade. By assuming that this purchased electricity was produced by Indiana power sources (which are 98% coal fired) and by applying standard assumptions about the efficiency of those plants as well as transmission losses, we arrived at a carbon footprint for purchased electricity of 45,761 tC. Natural gas purchases in fiscal year 2005-2006 contribute an additional 2,247 tC. The total carbon footprint for Purdue University's off-campus electricity and natural gas purchases for the fiscal year 2005-2006 is therefore **48,008 tC**.

**Transportation**: Based on survey data regarding commuting behavior and vehicle choice by Purdue faculty, students, and staff, we estimated the total contribution by commuters to the footprint as 5,233±3,600 tC. The Purdue ground fleet produced an additional 900±75 tC through the combustion of gasoline and diesel fuel. Local bus emissions due to ridership by Purdue students and employees contributed an estimated 800±40 tC. The carbon emissions attributed to the Purdue air fleet were approximately 340±23 tC per year. Carbon emissions from commercial air travel by Purdue faculty and staff on University business, estimated using a survey as well as

University financial data, were 2,774±1,174 tC. Total transporation emissions for 2005 were therefore **10,000±4,912 tC.**

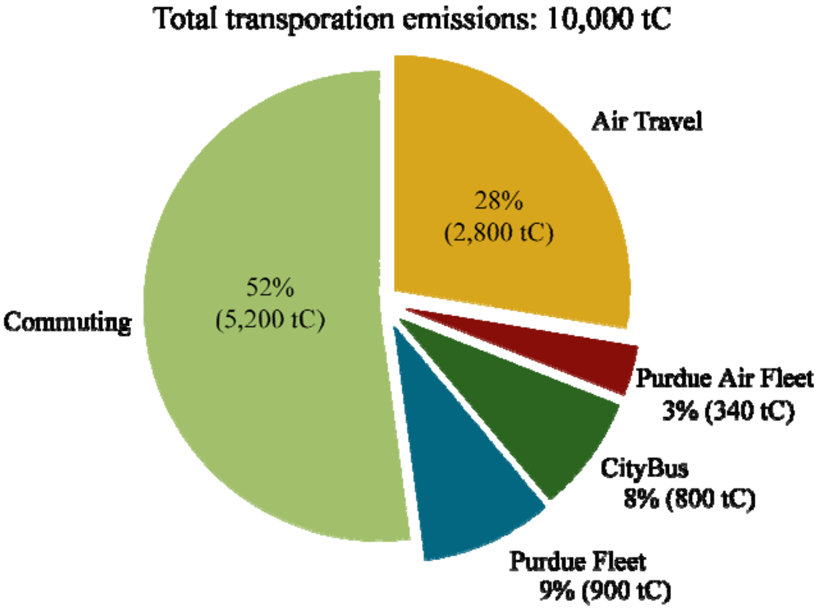

**Figure 2:** Transportation footprint, by transportation type

**Permanent Materials**: From data on the square footage of recent construction on campus as well as from literature values on the embodied energy of many of the materials used, we estimated the embodied carbon in permanent buildings on the Purdue main campus as **17,800 tC** for the 2005 calendar year.

**Consumable Materials**: Data for this sector came from a variety of university purchasing and waste management records. Using standard formulas for embodied energy from the literature combined with these records as well as estimates of carbon emitted during transport of these materials to West Lafayette, we estimated the carbon footprint of paper products used on campus is 3,105 tC. Plastics contribute 229 tC to the footprint; food contributes 936 tC; and waste disposal (primarily waste water treatment) contributes 125 tC. The total contribution of consumable materials to Purdue's carbon footprint is **4,394 tC** (see Figure 3, next page).

**Land Use**: The use of Purdue University's land results in both sequestration and emission of carbon. The annual growth of Purdue's forests results in a **1,500 tC credit**. The use of conservation tillage likely results in a small carbon credit as well; however, this figure is not currently calculable from available data. The use of fertilizers on Purdue's farms contributes

**58.5 tC** to the University's carbon footprint per year. Land use therefore results in a net carbon credit of approximately 1440 tC.

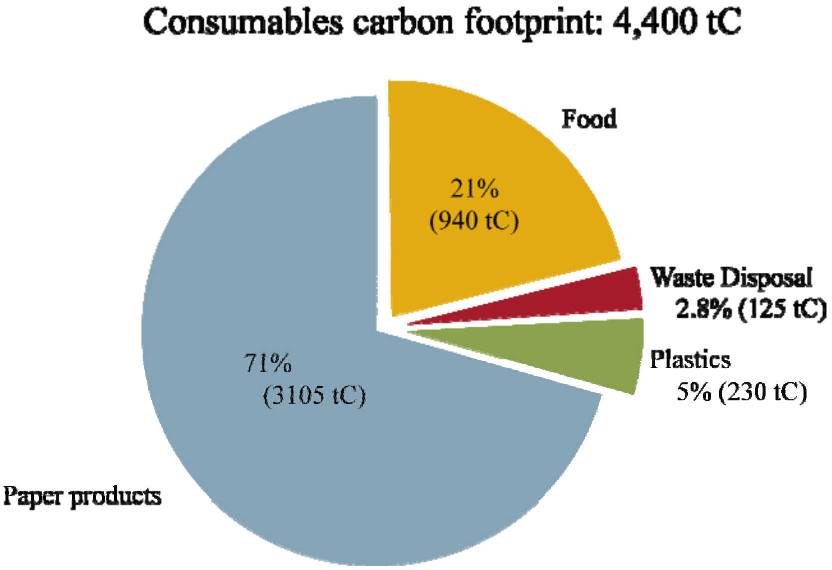

**Figure 3:** Consumables carbon footprint, by material

### Footprint Management

After determining the carbon footprint for our six sectors, we reorganized the class into management groups which developed plans and strategies to reduce the University's net carbon emissions and thereby bring Purdue closer to the goal of true carbon neutrality. The management groups consist of:

- **Energy Supply**: Investigated the choices for a new boiler for Wade Utility Plant, the low-emissions energy generation technologies of wind and solar power, and the possibilities of carbon offsets.
- **Institutional Consumption**: Focused on how the university can reduce carbon emissions by increased energy metering, retrocommissioning buildings, sustainable building designs, green roofs, and geothermal heat pump implementation.
- **Individual Consumption**: Focused on changing individual energy behaviors through education and increasing awareness of energy conservation. Strategies include informational campaigns that encourage turning off and unplugging electronic devices and reducing automobile commuting, and installing meters to increase energy awareness, thereby reducing personal energy consumption and room temperatures.

The management section provides a detailed menu of options that Purdue University could pursue in the future to reduce net carbon emissions. Some of those options are summarized briefly below.

**Energy Supply**: This management plan investigated the choices for a new boiler for Wade Utility Plant, the use of wind and solar power, and the possibilities of carbon offsets. Installation of a new boiler capable of burning biomass could reduce emissions from Wade by 20%, to approximately 82,500 tC/year. Burning natural gas in place of coal would reduce emissions by 33%, to 69,000 tC/year. Carbon capture and sequestration technologies, theoretically capable of capturing 90% of carbon emissions, would reduce carbon emissions to approximately 10,300 tC/year.

**Institutional Consumption**: In this management plan, we focused on how the university can reduce carbon emissions by increased energy metering, retrocommissioning buildings, and adopting more sustainable building design practices, including green roofs and geothermal heat pumps. Without baseline measurements of energy use in individual buildings and by individual users, it is not possible to quantitatively suggest the future benefits of any of the institutional or individual consumption management suggestions. Once meters are installed it will be possible to make targeted suggestions of the most cost effective and high-impact projects Purdue University can undertake.

**Individual Consumption**: This group focused on changing individual behavior related to energy consumption through education and increasing awareness of conservation. Strategies discussed include the implementation of informational campaigns to encourage turning off and unplugging electronic devices when not in use and to promote alternatives to single-occupant automobile commuting. Installing meters to reduce personal energy consumption and provide energy efficient climate-control settings for campus buildings.

Taken as a whole, these management sections outline what we consider to be a diverse array of viable options for the reduction of Purdue University's carbon impact. To realize the goal of complete carbon neutrality at Purdue, management options from all three sectors will clearly be required. Although true carbon neutrality is an ambitious goal, we believe it to be a worthy and attainable one for the University, particularly given its international reputation in the areas of science, engineering, and technology. The ambitious scope of such an objective requires a careful approach, however, and the implementation of a plan with manageable incremental and intermediate goals may be essential for success. The options outlined in this document present an opportunity to reduce Purdue's carbon footprint over a range of timescales and with varying levels of emissions reduction, thereby facilitating movement toward carbon neutrality at a variety of possible speeds and initial costs. Although the options presented herein are certainly not the only solutions open to the University, we believe that they represent an excellent menu of ideas for providing the greatest reduction in carbon emissions for Purdue University as well as a host of additional benefits in the most efficient manner possible.

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# 1. Introduction

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## 1.1 What is Carbon Neutrality?

In recent years, the concept of "carbon neutrality" has been gaining in popularity and notoriety as a potential strategy to address the issue of climate change. Carbon neutrality is the process of reducing individual and/or institutional net carbon emissions substantially, ideally all the way to zero. Carbon neutrality can be achieved through a number of different integrated strategies, including for example, developing and utilizing renewable energy sources, improving energy transmission methods, adopting energy efficient technology, practicing better energy conservation, and creating or purchasing "carbon offsets." Significant individual and organizational reductions of carbon emissions are a vital part of any plan to mitigate future climate change impacts. Many nations, organizations, and individuals across a wide range of political and economic divisions have expressed interest in the concept of carbon neutrality and are pursuing initiatives to make this goal a reality.

In the United States, the goal of institutional carbon neutrality has taken root, among individuals, organizations, and municipalities. Individuals can work to reduce their household carbon emissions through better energy conservation, using alternative fuel sources and vehicles, and switching to green power. If large numbers of individuals follow this path, we may begin to see significant carbon emissions reductions and demands for more environmentally friendly energy generation methods and technology from the ground up.

Admittedly, however, one individual's carbon reduction has a minimal impact on the level of global, national, or even regional carbon emissions. Conversely, large institutions, such as universities, can have a more substantial impact on carbon emissions because of their larger size and population. Additionally, many universities have self-contained, centralized infrastructures which lend themselves to implementing large scale carbon emissions reduction strategies. And lastly, universities are often considered to be centers for cutting-edge technological and scientific research, which suggests that they have the capabilities to develop and execute revolutionary energy-saving measures and plans.

The goal of campus carbon neutrality has many benefits, but it is not without costs—at least in the short term. Universities must make significant changes to their energy infrastructure and behaviors in order to make significant steps toward carbon neutrality. If a university agrees to pursue carbon neutrality at the administrative level, the school must actively promote that goal among students, faculty, and staff. Reaching carbon neutrality involves changing individual attitudes towards the environment and specifically the importance of protecting the environment through carbon emissions reductions. However, if the school is successful, it will reduce overall energy costs in the long run, while reducing the institution's long term effect on the environment as well.

## 1.2 What is a Carbon Footprint?

The first step that any individual or organization must take in order to begin the process of attaining carbon neutrality is to calculate their "carbon footprint." For our initiative, we defined "carbon footprint" as the cumulative total of net carbon emitted annually to meet the material and energy demands of the campus. Carbon is most commonly emitted in the form of carbon dioxide ($CO_2$) from the burning of fossil fuels such as coal, oil, and natural gas. However, carbon is also emitted during the manufacture of materials, which is referred to as the materials' embodied carbon, or embodied energy. The embodied carbon of an object is the total amount of the carbon emitted during production, manufacture, and transportation of the item. A carbon footprint can be calculated on the individual level by determining the carbon utilized by a person's electricity and natural gas usage, their vehicle gasoline usage and mileage, and their food and products consumption, ideally including transportation and packaging of the items. At the institution level, the scale of the carbon footprint increases dramatically given the huge area, population, and consumption that a campus or corporation encompasses. Calculating the "carbon footprint," or conducting an inventory of carbon usage and stocks mentioned above must occur in order for an individual or institution to determine what will be required to reduce their carbon emissions to zero.

## 1.3 Carbon Neutrality and Purdue University: A Perfect Fit

Purdue University is an ideal candidate for accomplishing the goal of carbon neutrality. Purdue is widely known for its cutting edge research in the areas of science, technology, engineering, and agriculture. Currently, a number of Purdue affiliated laboratories and research centers are already working to develop and improve renewable energy generation and storage methods, including wind, solar, hydrogen, and many more. The Purdue University Discovery Park Energy Center has declared, “Our vision is to significantly contribute to the development of the energy solution society is currently seeking as we prepare for the eventual transition from fossil fuels to other energy sources” (“Energy Center at Discovery Park”, 2005). These important research initiatives indicate that Purdue University has already begun to take steps towards addressing the problems of climate that are caused by fossil fuel use. The Purdue Climate Change Research Center (PCCRC) and Center for the Environment (C4E) are committed to promoting research and potential solutions regarding all aspects of the climate change challenge. Perhaps most significantly, though, the 2001-2006 Purdue University Strategic Plan, subtitled “Next Level: Preeminence,” states, “We are pledged to use our financial, physical, and human resources wisely and prudently to improve our university, our community, and the world” (“Strategic Plan”, 2001). Carbon neutrality fits perfectly into this statement of the larger goals of the university.

Several universities throughout the United States have created plans to reduce their school’s net carbon emissions and address the problem of climate change. In 2006, the Bren School of Environmental Science and Management, part of the University of California at Santa Barbara (UCSB), released their plan for “Changing the Campus Climate.” The Bren School conducted an inventory of the greenhouse gas emissions of UCSB and then proposed a series of mitigation strategies to reduce those emissions. The report provided the University of California at Santa Barbara with emissions targets and several stages for implementing greenhouse gas mitigation strategies by the years 2010, 2020, and beyond. The report points out that the UCSB plan will coincide with, and even transcend, many proposed international, national, state, and local climate change policy endeavors. The Bren School report provides an excellent model for determining the scope, guidelines, and goals of a campus carbon reduction initiative, as well as identifying the larger implications of such a course of action.

Some Big Ten Schools, which are closely comparable to Purdue University, have also begun carbon neutrality and awareness initiatives. The University of Michigan School of Natural Resources and Environment (SNRE) has instituted the Center for Sustainable Systems (CSS), which is undertaking, “A set of integrated industrial and ecological processes that equitably meets the biophysical needs of society while maintaining the integrity of life-supporting ecosystems over a long-term time horizon.” As part of CSS initiative, the SNRE hosted the "Carbon-Neutral Visit Day" for incoming students to their program. Incoming students were educated about the carbon intensity of current travel options and encouraged to offset their air travel carbon emissions. The SNRE believes the Carbon-Neutral Visit Day, "reinforces the school's commitment to sustainability...and introduces new students to the Sustainable Systems academic plan" ("Center for Sustainable Systems," 2006). Also, in February 2007, the EPA ranked Penn State University number 3 in the nation for the Top 10 College and University Green Power Partners. Since June 2006, Penn State has worked to improve energy conservation efforts, and now purchases 20% of its campus energy from green power sources, specifically biomass, hydropower, and wind power. In addition, Penn State has opted to conform to Leadership in Energy and Environmental Design (LEED) standards for all new building construction, and recently committed under the President's Climate Pledge to offset all greenhouse gas emissions from Penn State's non-green power usage. The EPA Program Manager commented, "Penn State has made a significant commitment to green power which has only increased over time, and if all the rest of the schools in the Big Ten were doing this, it would be an amazing show of environmental leadership and pollution prevention" (Santiago, 2007). Neither one of these universities have made full-scale plans for carbon neutrality, but they are certainly taking steps in the right direction. Purdue University is well-situated to begin similar initiatives, and transcend the goals set by other universities.

Purdue University's commitment to carbon neutrality could also have a significant positive impact upon the state of Indiana. Currently, the state of Indiana derives only 0.4% of its energy from renewable sources. Conversely, 98% of the state's energy comes from coal, which is an extremely carbon intensive fossil fuel ("Electric Power Sector Consumption Estimates," 2003). However, renewable power sources are available in the state of Indiana. The U.S. Department of Energy National Renewable Energy Laboratory estimates that the state of Indiana has at least 40,000 Megawatts of wind energy potential ("Indiana Wind Power Potential," 2006). Wind farms coexist well with row-crop operations, and farmers can receive additional economic benefits by allowing wind farms to be constructed on their land, which could help augment the agricultural sector of the state. Currently, a wind farm is being constructed in Benton County, Indiana, just north of Purdue University. Purdue could certainly opt to purchase a quantity of the campus electricity from this growing green power source. However, Purdue also owns a number of properties with wind energy generation potential that are in close proximity to main highvoltage power lines, a key factor in keeping wind power costs as low as possible. Thus, Purdue has a unique opportunity to develop their own wind farms on these locations.

Overall, by adopting carbon mitigation and energy conservation policies, Purdue University will reduce a portion of the entire state's carbon footprint. Pursuing carbon neutrality at Purdue represents a great opportunity to learn about and develop methods for carbon emission calculations, and for development of a creative management plan, since the university is a relatively self-contained entity, its energy use is well documented, and the administration is interested in working to improve the campus' energy efficiency and overall environmental sustainability.

## 1.4 The Organization of Our Initiative

This plan was created by students and faculty participating in a new, interdisciplinary course taught in the spring of 2007. The course was team taught by six faculty members from Agronomy, Chemistry, Civil Engineering, Earth and Atmospheric Sciences, Political Science, and the Purdue University Physical Facilities Office. In addition to the above mentioned disciplines, the students in the course hailed from a broad range of majors, including Agronomy, American Studies, Biology, Forestry, Earth and Atmospheric Sciences, Chemistry, Natural Resources and Environmental Science, Political Science, and multiple fields of Engineering. The interdisciplinary nature of the course yielded multiple perspectives and a diverse range of ideas and solutions to the issues presented in our research and policy formulation. The class was an open forum for discussion and education that encouraged collaborative efforts and combined a valuable mix of expertise.

To organize our research, the class first divided into six groups to calculate the carbon footprint of different sectors of Purdue University. We established the six sectors of on-campus energy, off-campus energy, transportation, permanent materials, consumable materials, and land use. In our individual footprint groups, we spent a great deal of time and effort meticulously calculating the carbon footprints of our sectors. The students undertook rigorous research and difficult data collection to obtain accurate information and footprint totals. Once each of the groups obtained accurate estimates of their portion of the university's carbon footprint, we reorganized the class into new groups to develop effective strategies to reduce the university's carbon emissions. We separated into the management groups of energy supply, institutional consumption, and individual consumption. Each of the management groups developed a menu of options to provide Purdue University with a variety of ways to reduce the total carbon footprint. Additionally, we created a synthesis group to combine and edit the individual footprint and management group portions into one comprehensive document.

## 1.5 Footprint Groups

For this study, as a class we defined our "carbon footprint" as the net amount of carbon released to the atmosphere as carbon dioxide from the burning of fossil fuels as a consequence of Purdue University activities, building construction, land management and purchasing decisions for the 2005-06 fiscal year (July 1, 2005 to June 30, 2006). In a small percentage of the footprint (less than 10%), however, data for the fiscal year was not available and groups would use data from calendar year 2005 or 2006 as appropriate. The geographic boundaries for our study encompassed the Purdue University West Lafayette campus and land holdings throughout Tippecanoe County. We did not include any of Purdue's satellite campuses or properties outside of Tippecanoe County. We also chose to exclude Purdue Research Foundation holdings from our calculations. We acknowledge that the Purdue Research Foundation provides important financial and research opportunities to the faculty and students of Purdue University. However, we have chosen to narrow our initial examination to the carbon footprint left directly by the university in order to clarify our management options and make our calculations more manageable and accurate.

Our analysis divides Purdue's carbon footprint into six different parts, or sectors. These sectors, along with definitions, are listed below.

- **On-Campus Energy**: Electricity, steam heating, and condensed air cooling provided by Purdue University's Wade Utility Plant.
- **Off-Campus Energy**: Electricity and natural gas purchased by the University, provided by off-campus utility companies.
- **Transportation**: Automobile, air, and bus travel directly related to University business. This includes faculty and students commuting to and from campus, University-owned vehicle travel, local bus travel by Purdue employees and students, and student and faculty air, bus, and car travel to conferences and other professional meetings.

- **Permanent Materials**: Manufacture and construction of University buildings. Carbon dioxide is released when building materials are manufactured, transported to the construction site, and when the buildings themselves are constructed. All of these activities are included in the "embodied energy" of the building materials, which was used to calculate this part of the footprint.
- **Consumable Materials**: Embodied carbon dioxide emissions from the production and transport of food, plastics, paper, and other non-permanent materials used on the University campus.
- **Land Use**: Carbon dioxide emissions and storage associated with the "green areas" of the main West Lafayette campus and the various landholdings the University owns throughout Tippecanoe County, including the experimental farms and forests owned by the University.

Each of the groups developed creative and unique methods for retrieving their data and calculating their footprints. The footprints calculated by each of the six sectors were then added together to give the total Purdue University carbon footprint. To maintain consistency, all of the final carbon footprints are presented in the units of metric tons of carbon (1000 kg) abbreviated as TC for tonnes of carbon.

## 1.6 Management Groups

After determining the carbon footprint for our six sectors, we reorganized the class into management groups to develop plans and strategies to address the carbon emissions and attempt to reach our goal of carbon neutrality. The management groups consist of:

- **Energy Supply**: Investigated the choices for a new boiler for Wade Utility Plant, the green power options of wind power and solar, and the possibilities of carbon offsets.
- **Institutional Consumption**: Focused on how the university can reduce carbon emissions by increased energy metering, retrocommissioning buildings, sustainable buildings designs, green roofs, and geothermal heat pump implementation.
- **Individual Consumption**: Focused on changing individual energy behaviors through education and increasing awareness of energy conservation. Strategies include informational campaigns that encourage turning off and unplugging electronic devices and reducing automobile commuting, and installing meters to reduce personal

energy consumption and room temperatures.

The management section provides a detailed menu of options that Purdue University could pursue in the future to reduce net carbon emissions.

# 2. Purdue University's Carbon Footprint

## 2.1 On-Campus Energy Carbon Footprint

### 2.1.1 Sector Boundaries

The on-campus energy component of the Purdue University carbon footprint accounts for the carbon which is emitted from the Wade Utility Plant as a result of burning coal, natural gas, and fuel oil. It also includes carbon emissions that result from the use of limestone (in the fluidized-bed boiler) to capture sulfur dioxide ($SO_2$) emissions. These emissions are monitored by an EPA mandated and highly accurate Continuous Emissions Monitoring System (CEMS). The CEMS system is able to capture exhaust gas concentrations of carbon dioxide ($CO_2$) regardless of the fuels being burned (Schuster, 2007).

Wade Utility Plant generates approximately 50 - 60% of the electricity and the majority of the steam and chilled water consumed by campus buildings connected to the Purdue Power Grid. Wade consists of two coal-fired stoker boilers, one coal-fired fluidized bed boiler, and one oil and gas-fired boiler. Together, these four boilers burn over 153,000 metric tons of coal and a limited amount of natural gas and oil each year to generate over 3,000,000 klbs ($1.16 \times 10^{20}$ kBtu) of steam.[1] The university's infrastructure is dependent on the generation of steam to meet the majority of heating and cooling demands on campus (See Figure 2.1.1, next page).

Wade Utility Plant is able to achieve greater than 80% efficiency at converting coal to usable energy in the form of steam for electricity generation, chilled water, and heating for campus buildings and water. However, the efficiency of Wade Utility Plant drops to approximately 76% when the parasitic heat and transmission losses are taken into consideration. The term "parasitic" refers to the portion of energy that Wade consumes between the input and output stages to operate the physical facilities of the plant. To elaborate, efficiency is calculated as the "energy out" divided by the "energy in." The "energy in" is the energy contained in the coal which is released as heat through combustion. The "energy out" is the energy which is supplied to the campus in the form of electricity, steam, and chilled water which heats, cools, and powers the campus. The efficiency of Wade Utility plant is substantially higher than the average

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[1] The natural gas and oil boilers are only put into operation during peak load periods, such as very cold or very hot weather, and therefore burn a much smaller amount of fuel than the coal boilers.

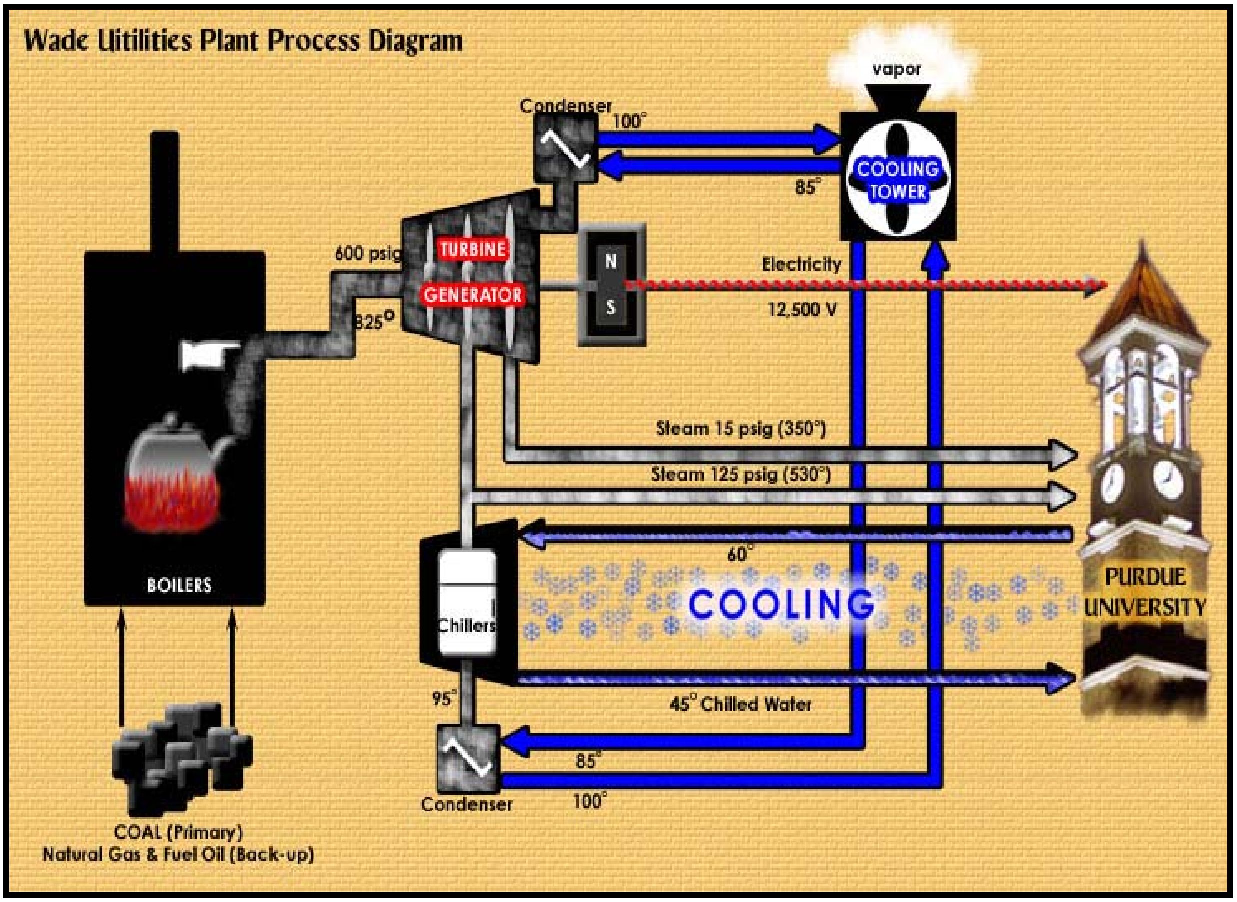

**Figure 2.1.1** Energy co-generation capacity of Wade Utility Plant

coal-burning power plant because of its ability to make use of waste heat and steam created during standard boiler operation to generate additional electricity and to power campus heating and cooling mechanisms. The high-pressure steam generated by the boilers is first used to drive high-speed turbines to generate electricity. Subsequently the steam is used to produce chilled water in centrifugal chiller units as well as distributed via the campus steam distribution system to meet building and water heating demands (see Figure 2.1.2 next page).

### 2.1.2 Methods/Assumptions/Data

We were able to determine very accurately the amount of carbon emitted by the plant through analysis of the CEMS (Continuous Emissions Monitoring System) data, which is certified regularly by the EPA's periodic Relative Accuracy Test Audits (RATA). The CEMS gives us highly accurate totals from direct measurements and alleviates the need to develop estimates of carbon releases from coal, natural gas, fuel oil and biomass individually.[2] We used CEMS data from July, 2005 – June, 2006 (Fiscal Year 05-06) which coincides with the off-campus energy period of examination.

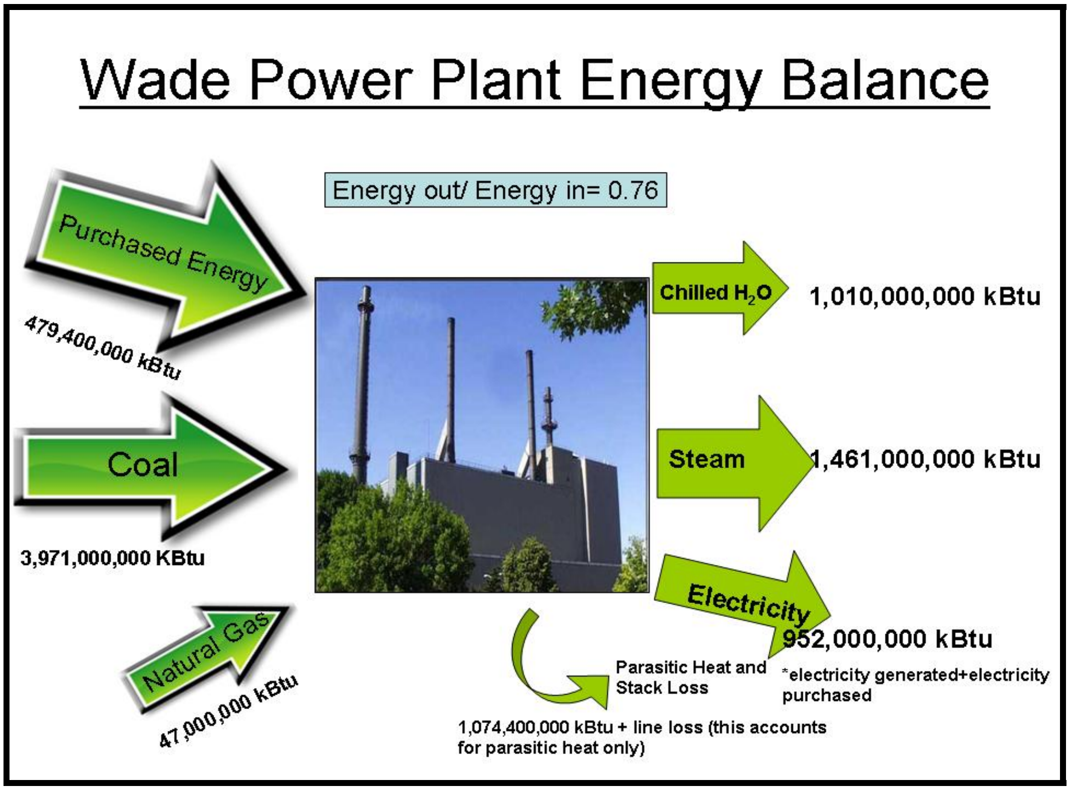

**Figure 2.1.2** Energy balance for Wade Utility Plant (July 1, 2005 to June 31, 2006).

### 2.1.3 Results

For the time period of July, 2005 through June, 2006, the total $CO_2$ emissions of the Wade Utility Plant measured by the CEMS were 378,270 metric tons of $CO_2$. Removing the weight of the oxygen, we found that 103,165 TC (tons of carbon) were released into the atmosphere during our measurement year.[3] This quantity of carbon represents the largest portion, over 58%, of the total carbon footprint for Purdue University.

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[2] The CEMS data represent 99.218% uptime in monitoring and the uncertainty in emissions data is +/- 6.65% (See Appendix X, Figure X). Error was calculated based on sum of quadrature from the RATA verification of the CEMS relative accuracy in each of the four boilers. (personal communication by Dan Schuster with Robin Ridgeway)

[3] Conversions from short tons to metric tones were made using the conversion factor of 1 short ton = 0.90718474 metric tones.

## 2.2 Off-Campus Energy Carbon Footprint

### 2.2.1 Sector Boundaries

The off-campus energy sector includes Purdue University's electricity and natural gas purchases, beyond the natural gas purchased for operating the oil/gas boiler at the Wade Utility Plant. Currently, Purdue purchases approximately half of its electricity from the Duke Energy Corporation and all of its natural gas from the Vectren Corporation (Schuster, 2007).

The outsourced electricity and natural gas is utilized by on-campus buildings, student residence halls, off-campus buildings that host official Purdue activities, and many farm and agricultural research areas owned by Purdue University throughout Tippecanoe County. Residences include various dormitories as well as Purdue Village and Hilltop Apartments, both of which are Purdue-owned apartment-style residences. Tenants of the apartment residences maintain individual natural gas accounts. Off-campus buildings include buildings that sponsor groups, activities, or events that contribute to the academic, athletic, and/or cultural climate of the University. Examples include the Black Cultural Center, Housing and Food Services, and the Athletic Department facilities. Many of these facilities maintain individual natural gas accounts, and some also maintain electrical accounts outside of the Purdue University grid. Our basic rule for including these facilities in the footprint was as follows: if Purdue University pays the bill directly, we included the unit.

### 2.2.2 Methods/Assumptions/Data

#### *2.2.2.1 Electricity Calculations*

To calculate the carbon footprint from electricity production, we first determined the method used to produce the energy brought onto campus. Approximately 98% of Indiana's electricity comes from coal-fired power plants, while about 1% comes from natural gas, and 1% from other sources, like wind, solar, and fuel oil ("State Energy Profiles: Indiana," 2006). Our calculations assume that all Purdue purchased power comes from Indiana sources. Although we acknowledge that some electricity flows freely across state borders within larger regional power grids, we are assuming that the amount of energy flowing into Indiana is about equal to the amount flowing out of the state. We then determined the average efficiency of Indiana's coal-fired power plants for use in our footprint calculations (See Appendix A-1).

The amount of electricity and natural gas purchased by the University from outside sources is documented by Purdue Physical Facilities. According to these records, in 2005 Purdue purchased 153,510,279 kilowatt-hours (kWh) of electricity. Duke Energy Corporation provided the majority of the electricity, but smaller amounts were provided by Tipmont REMC, Warren County REMC, and Boone County REMC (Schuster, 2007).

In addition to the amount of electricity purchased by Purdue University, transmission losses of the purchased electricity must also be taken into account when determining carbon emissions. According to the U.S. Department of Energy Office of Electricity Delivery and Energy Reliability, current transmission losses of electricity from source to end location are about 10% ("Overview of the Electric Grid," 2006). The addition of these transmission losses increases electricity consumption by 10% per year, or 15,351,028 additional kWh in 2005. This raises purchased electricity in 2005 to 168,861,307 kWh.

Average carbon production per unit of electricity generated in Indiana can be calculated based on two figures: the total amount of electricity produced by the state of Indiana in 2005 (122,817,019 MWh) ("Electric Power Annual," 2006) and the total carbon emissions from that electricity production (122,019,966 TC) ("Clean Air Markets," 2005). Using these figures yields the following rate of carbon emission per kWh generated on average from Indiana power plants:

$$1.22\times10^{8}\,\frac{tons\,CO_2}{year}\times\frac{1{,}000\,kg\,CO_2}{1\,ton\,CO_2}\times\frac{12\,g/mol\,C}{44\,g/mol\,CO_2}\times\frac{1}{1.23*10^{8}\,MWh/yr}\times\frac{1\,MWh}{1{,}000\,kWh}=0.271\,\frac{kg\,Carbon}{kWh}$$

**Equation 2.2.1** Average carbon production per unit of electricity generated

Based on this result, the total carbon emissions due to Purdue's purchased electricity can be easily calculated as follows:

$$0.271\,\frac{kg\,C}{kWh}\times\frac{168{,}861{,}307\,kWh}{year}=45{,}761{,}000\,\frac{kg\,C}{year}\times\frac{1\,TC}{1{,}000\,kg\,C}=45{,}761\,\frac{TC}{year}$$

**Equation 2.2.2** Purdue 2005 carbon emissions from purchased electricity

Therefore, the total carbon footprint from Purdue's outsourced electricity acquisitions in 2005 equals 45,761 TC.

#### *2.2.2.2 Natural Gas Calculations*

Natural gas contributes to the overall Purdue carbon footprint in two ways. First, it produces carbon dioxide through direct burning in furnaces, water heaters, and natural gas boilers. Second, the loss of natural gas to the atmosphere during transportation from the source to the university also produces carbon dioxide.

In 2005, Purdue University purchased 145,876 decatherms of natural gas (Schuster, 2007). In order to determine the amount of carbon dioxide released per decatherm of gas, we obtained a "carbon intensity" value for direct combustion (13.8 kg carbon/gigajoule (GJ) energy) and also for transmission losses (0.8 kg C/GJ) of natural gas (MacDonald, 1990). (We also double checked these values by determining the carbon intensities of its constituent gases: methane, ethane, nitrogen, propane, and butane—see Appendix A-2.) Using these values, we determined the carbon emitted due to Purdue's natural gas purchases in 2005:

$$145{,}876\, decatherms \times \frac{1{,}055{,}057{,}000\ J}{1\, decatherm} \times \frac{1\, GJ}{10^9\ J} = 153{,}907\ GJ$$

$$153{,}907\, GJ \times \frac{13.8\, kg\, C + 0.8\, kg\, C}{1 GJ} \times \frac{1 TC}{1{,}000\, kg\, C} = 2{,}247\, TC$$

**Equation 2.2.3** Carbon emissions from natural gas purchases

Thus, the total carbon footprint created by Purdue's off-campus natural gas purchases in 2005 equals 2,247 TC.

### 2.2.3 Results

The total carbon footprint for Purdue University's off-campus electricity and natural gas purchases for the calendar year of 2005 is 48,008 TC.

$$45{,}761 TC + 2{,}247\, TC = 48{,}008\, TC$$

**Equation 2.2.4** Total off-campus carbon footprint

Electricity accounts for approximately 95% of this footprint, while natural gas accounts for 5%. This footprint is equivalent to the amount of energy used by 5480 average US households in one year.[4]

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[4] According to most carbon footprint calculators, the average U.S. household emits about 19 metric tons of $CO_2$ per year.

## 2.3 Transportation Sector Carbon Footprint

### 2.3.1 Sector Boundaries

To estimate the carbon footprint of Purdue's transportation sector we considered car, truck, bus, and air travel that relate directly to University business. We conducted a survey of the commuting and business travel habits of Purdue staff, faculty and students to help estimate the largest portions of the footprint. For all forms of university-associated travel, we did not consider the carbon footprint of manufacturing the utilized vehicles, buses and airplanes. We also did not consider campus deliveries for products such as food and paper unless the deliveries were made in Purdue owned vehicles. In some cases, these transportation-related emissions for such deliveries were included instead in the consumable or permanent materials sectors.

#### *2.3.1.1 Automobiles*

For non-university owned student/faculty vehicles, we were only able to account for private vehicles which use Purdue University parking permits. Many students do not purchase parking permits and park instead in neighborhood streets. However, we determined that, given our time and resource constraints, we would be unable to accurately account for people who use short term parking or general West Lafayette street parking. We therefore excluded those trips from our calculation, and our values thus reflect an underestimation of the actual carbon footprint of this subsector.

We also included emissions from university-owned vehicles. These vehicles fall into the following categories: university vehicles used by students, faculty, and staff for University business; buses that are rented by university organizations and athletics for travel; departmental and special vehicles; maintenance vehicles; and vehicles used and operated by the Purdue Police and Fire department. The Land-Use Transportation category includes the vehicles owned by the agriculture departments such as farm maintenance vehicles and off-road vehicles. These values are considered separately from the "University-owned vehicle" sub-sector because that fuel is purchased by those specific departments and not by the transportation department.

#### *2.3.1.2 Buses*

The cities of West Lafayette and Lafayette are served by the bus company CityBus, which operates primarily diesel buses, although some are diesel-electric hybrids. In 2005, Purdue contributed 68% to CityBus' total annual revenue, thereby allowing Purdue affiliated individuals to ride for free ("CityBus Facts," 2007). However, we were unable to obtain the records differentiating between Purdue-affiliated riders and those riders without a university affiliation. We therefore used the proxy that 68% of all CityBus' carbon footprint can be attributed to Purdue-affiliated individuals.

#### *2.3.1.3 Air travel*

Professors, research groups, athletic teams, and student organizations go on many trips per year by plane, contributing substantially to the transportation sector of the university's carbon footprint. Our calculation for air travel includes university-owned planes as well as commercial flights taken by Purdue students and employees for university business.

### 2.3.2 Methods/Assumptions/Data

#### *2.3.2.1 Student/Faculty/Staff Commuter Emissions*

Students and faculty commuting to and from campus are responsible for a significant proportion of Purdue's carbon emissions. The carbon emissions for this portion of the transportation sector's total are calculated using parking permit data from the Purdue University Visitor Center and results from the faculty, staff, and student survey.

Students mainly purchase C lot and C garage permits (located further from central campus), totaling 5,328 permits per year. The faculty and staff mainly purchase A and B parking permits (generally spaces closer to campus), for a total of 10,002 and 1,357 permits per year respectively. We administered a survey to about 0.5% of the campus population including faculty, staff, and students who drive to campus and who hold parking permits from the university (See Appendix B-1 for survey methodology). From the survey, we calculated the average fuel economy for campus commuters and the average commuting mileage driven per year for each permit category. In each permit category the amount of fuel used in a year was multiplied by the EPA carbon constant for gasoline (2.421 kg C/gal) ("Emission Facts," 2005) to get the emissions value in metric tons of carbon. Less than 1% of survey respondents had automobiles with diesel engines so the conversion for regular gasoline was used. The Q test for outliers was performed on the daily mileage data because there were two respondents who commuted very unusual distances (131 and 140 miles). The next largest value of 100 miles, however, was not considered an outlier so that data point was included in the calculations. Table 2.3.1 below shows the average fuel economies, fuel efficiencies, and intermediate calculations as well as the final totals. The calculation for the A permit category is as follows:

$$\frac{14.02\,mi}{day} * \frac{4.99\,days}{week} * \frac{48.32\,wks}{year} * \frac{gal}{23.31\,mi} * \frac{2.421\,kg\,C}{gallon} * \frac{TC}{1000kg\,C} * 10002\,A\,permits = 3509\ TC$$

**Equation 2.3.1** Carbon emissions from A permit holders (in TC)

The uncertainty for commuter emissions was calculated based on standard deviations for each average value used. Table 5.2.1 in Appendix B-2 summarizes the standard deviations, the relative uncertainty and the absolute uncertainty for each permit type, and Equation 5.2.1 summarizes the calculations used.

The approximate carbon emissions are 3,510±3,300 TC for holders of A permits, 458±220 TC for B permits, and 1,124±1,500 TC for both types of C permits (see Table 2.3.1 below). The total contribution by commuters to the footprint is 5,233±3,600 TC. The large error bars in these calculations are a result of the small survey sample size which was necessitated by the time constraints of this project. Refinement of the commuter contribution to the transportation sector of the carbon footprint is possible through the administration of a follow-up survey with a larger, more representative sample.

| **Permit Type** | **Average Miles/ Day** | **Average Days/ Week** | **Average Weeks/ Year** | **Average Miles/ Gallon** | **Gallons/ Year** | **kg C/ gal** | **kg C/ yr-permit** | **TC/yr-permit** | **Number of permits** | **TC/ year** |
|---|---|---|---|---|---|---|---|---|---|---|
| A | 14.02 | 4.99 | 48.32 | 23.31 | 144.9 | 2.421 | 350.8 | 0.3508 | 10002 | 3509 |
| B | 13.00 | 5.00 | 50.00 | 23.31 | 139.4 | 2.421 | 337.5 | 0.3375 | 1357 | 458 |
| C | 12.45 | 4.97 | 36.94 | 23.31 | 98.0 | 2.421 | 237.3774 | 0.2374 | 5328 | 1265 |
| | | | | | | | | | **Total** | **5232** |

**Table 2.3.1** Calculation of commuter carbon footprint (intermediate and total values)

### *2.3.2.2 University-Owned Vehicles (Purdue Ground Fleet)*

Travel in vehicles owned by Purdue also contributes to the university's carbon footprint; however, the magnitude of this contribution is significantly smaller than that of private commuting traffic. Using an estimate from the Transportation Department Service Manager of the amounts of gasoline and diesel fuel purchased during 2006 (300,000 and 60,000 gal respectively), the amount of carbon emitted was calculated with an uncertainty of 10%. This uncertainty was estimated from the imprecision of the available information. Exact values for fiscal year 2005-06 consumption were unable to be obtained so an estimate from 2006 was used. Again, the values for the carbon content per gallon of fuel set by the EPA (2.421 kg C/gal for gasoline and 2.778 kg C/gal for diesel) were used ("Emission Facts," 2005). See Equation 2.3.3, next page.

$$300{,}000\, gal\ gas \times 2.421 \frac{kg\,C}{gallon} \times \frac{1TC}{1{,}000\,kg\,C} = 726TC\ \ for\ gasoline$$

$$60{,}000\, gal\ diesel \times 2.778 \frac{kg\,C}{gallon} \times \frac{1TC}{1{,}000\,kg\,C} = 167TC\ \ for\ diesel$$

**Equation 2.3.2** University-owned vehicle carbon emissions for gasoline and diesel

The amount of carbon emitted by the burning of gasoline is approximately 730±73 TC, and from diesel it is approximately 170±17 TC, for a total of 900±75 TC. However, this is not a complete estimate of the amount of carbon emitted during off-campus trips, because it only includes the fuel purchased by the University and not the portion purchased off-campus and reimbursed. This calculation therefore underestimates the total amount of fuel consumed by university-owned vehicles.

The Purdue Fire Department uses both gasoline and diesel and contributes 0.481 TC and 1.4 TC respectively (Ply, February 2007).

$$199\, gal\ gasoline \times 2.421 \frac{kg\,C}{gallon} \times \frac{1TC}{1{,}000\,kg\,C} = 0.481TC\ \ for\ gasoline$$

$$504\, gal\ diesel \times 2.778 \frac{kg\,C}{gallon} \times \frac{1TC}{1{,}000\,kg\,C} = 1.4TC\ \ for\ diesel$$

**Equation 2.3.3** Purdue Fire Department carbon emissions for gasoline and diesel

Purdue's Police Department denied our requests for fuel usage data; therefore, its contribution to the carbon footprint is not included.

#### *2.3.2.3 CityBus*

CityBus used 423,494 gallons of diesel fuel in 2005. Purdue contract revenue constitutes 68% of CityBus' annual revenue; consequently, we estimate that Purdue bus riders are responsible for approximately 287,976 gallons of diesel. To calculate an uncertainty, we estimated that on a yearly basis, the student and staff riders are responsible for anywhere between 63 and 73% of the total riders. This would make Purdue's annual contribution to CityBus carbon emissions approximately 800±40 TC.

$$423{,}494\, gal\ diesel \times 0.68 \times 2.778 \frac{kg\,C}{gallon} \times \frac{1TC}{1{,}000\,kg\,C} = 800TC$$

**Equation 2.3.4** CityBus' carbon emissions

#### *2.3.2.4 Purdue Air Fleet*

Purdue maintains a fleet of aircraft to train students in aviation and to transport University staff. This includes propeller-driven aircraft and jets. Propeller-driven aircraft use

100LL, a gasoline with lead additives ("Air BP," 2007). Turbine-driven aircraft (jets) use Jet Fuel A. Purdue's propeller-driven aircraft use about 80,400 gallons of LL100 fuel annually, for which the EIA calculates a carbon density of 2.271 kg C/gal, yielding a total of 184±18 TC ("Voluntary Reporting of Greenhouse Gases," 2006). Purdue's turbine aircraft use about 57,600 gallons of Jet Fuel A for which the EIA calculates a carbon density of 2.61 kg C/gal, yielding a total of 151±15 TC. Due to variation in fuel quality and the completeness of combustions, we estimated an uncertainty of ± 10% of the total carbon emissions for each type of fuel. The total carbon footprint that can be attributed to the fuel used by the Purdue air fleet is thus approximately 340±23 TC per year.

$$80{,}400\,gal\;LL100 \times 2.2271\frac{kg\,C}{gallon} \times \frac{1TC}{1{,}000\,kg\,C} = 184\,TC\;\; for\; propeller-driven\,aircraft$$

$$57{,}600\,gal\;Jet\,Fuel\,A \times 2.61\frac{kg\,C}{gallon} \times \frac{1TC}{1{,}000\,kg\,C} = 151\,TC\;\; for\; turbine\; aircraft$$

**Equation 2.3.5** Carbon emissions from university-owned aircraft

### *2.3.2.5 University Reimbursed Transportation*

Purdue keeps track of the funds that are used to reimburse faculty members who travel on university business. Purdue reimbursement forms were used to determine the amount of money spent on commercial air travel during the 2005 calendar year, approximated by taking the average of the 2004-05 and 2005-06 academic years (Raymond, February 2007). Calculating the carbon footprint of this air travel from a dollar figure requires a number of significant assumptions and estimates. The average domestic flight in the United States in February 2006 was 2,000 miles at a total cost of $258, resulting in an average cost per mile for domestic flights, which gives a fare constant of $0.129/mile (Reed, 2006). The typical domestic flight uses an aircraft like a MD-80 aircraft, which has a fuel efficiency of 0.3 mpg ("MD-80 Airplane Characteristics," 1990). The carbon conversion factor for Jet fuel A is 2.61 kg C/gal. Finally, we estimated an average of 155 people per domestic flight from the carrying capacities of the most common commercial aircraft in order to calculate a personal share of each flight's carbon emissions ("MD-80 Airplane Characteristics," 1990). Taken together, these figures result in a carbon footprint for domestic air travel of 1,063 TC (see Appendix B-3 also) as follows:

$$\frac{\$2{,}442{,}670}{\$0.129/mi} \times \frac{1\,gal}{0.3\,mi} \times \frac{2.61kg\,C}{1\,gal} \times \frac{1TC}{1{,}000kg\,C} \times \frac{1\;flight}{155\;people} = 1{,}063\,TC\,(domestic)$$

**Equation 2.3.6** Carbon emissions from reimbursed domestic air travel (based on spending)

The method used for international flights was the same with the exception of how we determined the initial fare constant. For transatlantic flights, we took an average flight to be from Chicago, IL to Paris, France. According to American Airlines, an adult ticket costs $909 for the 8,294 mile round trip ("CHI to PAR Roundtrip," 2007). This gives a transatlantic average cost of $0.11/mile. For transpacific flights, we assumed that the average flight would be from Chicago, IL to Tokyo, Japan. According to United Airlines, an adult ticket costs $1,111 for the 12,628 mile round trip ("CHI to TYO Roundtrip," 2007). This gives a transpacific average cost of $0.09/mile. Survey data indicated that faculty flew 2.5 times more on transatlantic flights than transpacific flights. With this information, the average international flight cost is $.104/mile. Based on common airplane seating capacities, we assumed that airplanes hold an average of 350 people on both types of international flights. Finally, we calculated the average fuel economy for these flights based on data for a Boeing 747-400, which gets 0.2 mpg.

$$\frac{\$1{,}517{,}663}{\$0.104/mi} \times \frac{1\,gal}{0.2mi} \times \frac{2.61kg\,C}{1\,gal} \times \frac{1TC}{1{,}000kg\,C} \times \frac{1\,flight}{350\,people} = 544\,TC$$

**Equation 2.3.7** Carbon emissions of reimbursed international air travel (based on spending)

The carbon emissions attributed to international flights is 544 TC (See Appendix B-3). In total the emissions for airline travel are 1,607 TC. This number is most likely an underestimate of actual Purdue reimbursed air travel since it does not take into account trips of faculty, staff or students which are paid for by other institutions.

To get another estimate of Purdue's airline footprint, we used the survey previously described in section 2.3.2.1 (See also Appendix B-1 for survey questions). We undertook the calculations with the following data and conservative estimates. There were 38,712 enrolled students as of the 1st of October 2005, 109 deans and department heads, 2,749 faculty and postdoctoral students, 7,647 staff and 4,461 graduate students ("Purdue University Enrollment Summary," 2006). From the surveys we obtained an average number of miles flown in a representative school year for each of those categories, and the number of commercial airline trips taken within 3 categories. Category A contains all domestic flights and those to Canada and Mexico, for which we averaged the number of miles to be 2,000 miles roundtrip (RT) and used 155 passengers based on the average carrying capacity of common commercial passenger jets. Category B includes all transatlantic flights and flights to South America which we estimated to be on average 10,000 miles RT. Transpacific flights and flights to Africa are included in category C and were averaged to be about 18,000 miles RT. For categories B and C, we estimate an average number of 350 passengers.

The following is a sample calculation for faculty regarding their reimbursed domestic airline travel (flights of category A):

$$\frac{106\,cat.A\ flights}{35\ faculty\ surveyed} \times 2858\ faculty \times \frac{2{,}000\,mi}{flight} \times \frac{1\,gal}{0.3\,mi} \times \frac{1\ flight}{155\ people} \times \frac{2.61\,kg\,C}{1\,gal} \times \frac{1\,TC}{1{,}000\,kg} = 970\,TC$$

**Equation 2.3.8** Domestic airline carbon footprint for faculty

Based on the surveys, our basic estimate of Purdue University's carbon footprint related to business travel in 2005 totaled 4,850 TC; 902 TC from reimbursed car travel and 3,948 TC from reimbursed airline travel. See Appendix B-4 for information used in the calculation of these values. The airline travel value calculated from survey results is almost 3 times above the estimate based on the reimbursement forms. There is more uncertainty for our estimates based on the survey because we only polled 0.5% of the Purdue population due to time constraints and thus our error is large. More specifically, only 1.5% of the faculty were polled and they account for most of the airline travel footprint. Since the carbon emissions from the survey were 3,948 TC and from the forms for reimbursed travel were 1,607 TC, we are taking an average and reporting the carbon emissions for air travel as 2,774±1,174 TC.

### *2.3.2.6 Land-Use Transportation*

Land-use related fuel consumption was calculated based on the actual financial records of the amount of gasoline and diesel fuel purchased for use in 2005 on the Agronomy Research Farm (372.3 ha), and then extrapolated based on area to estimate the amount of fuel used for the Animal Research Farm (613.1 ha), and Throckmorton Farm (335.9 ha), where no financial records were available. This accounts for fuel used for both on-road and off-road purposes. Since we did an extrapolation as opposed to having exact fuel amounts for each farm, each of which has different land-use transportation demands, we assumed an approximate 10% uncertainty in our calculations to be consistent with the other university-owned vehicle calculations. The total amount of fuel used was converted into carbon emissions using EPA carbon constants ("Unit Conversions," 2004) in a similar manner to the previous calculations involving vehicle fuel (see Table 5.3.6, Appendix C-5). The total carbon emissions for this sub-sector, assuming a 10% uncertainty, are 103±8 TC (see Equation 2.3.10, next page).

$$Gasoline\ Emissions = 1{,}321.3\ ha \times \frac{3{,}334\ gallons}{372.3\ ha} \times \frac{2.42\ kg\ C}{1\ gallon} \times \frac{1TC}{1{,}000\ kg} = 28.6\ TC$$

$$Diesel\ Emissions = 1{,}321.3\ ha \times \frac{7{,}525\ gallons}{372.3\ ha} \times \frac{2.77\ kg\ C}{1\ gallon} \times \frac{TC}{1{,}000\ kg} = 74.0\ TC$$

**Equation 2.3.9** Carbon emitted by vehicles on Purdue University farms

### 2.3.4 Results

The transportation sector's contribution to Purdue University's carbon emissions is 11,054±4,000 TC (See Table 5.2.7 in Appendix B-6). The total uncertainty was calculated using the square root of the sum of the squares of each sub-sector value. Of all the different forms of transportation that contribute to Purdue University's carbon footprint, the largest is, by far, daily commuting of faculty, students and staff (comprising 48%). Reimbursed air travel was 25% of the footprint. This percent contribution was somewhat lower than expected, given the extensive research-related travel undertaken by faculty and graduate students. A reason for this may be that the number of trips taken by faculty and graduate students is unevenly distributed across campus and our survey may not have been representative in its sampling. Purdue University vehicles and university-related travel with private vehicles contributed 8% each, which is also an underestimate because the fuel amounts for the university-owned vehicles did not include fuel purchased away from campus. CityBus contributed 7% of the total carbon emissions, which is a relatively small number compared to the commuter percentage. Of negligible participation in the carbon emissions were the sub-sectors Land-use transportation, Purdue air fleet and the Purdue fire department.

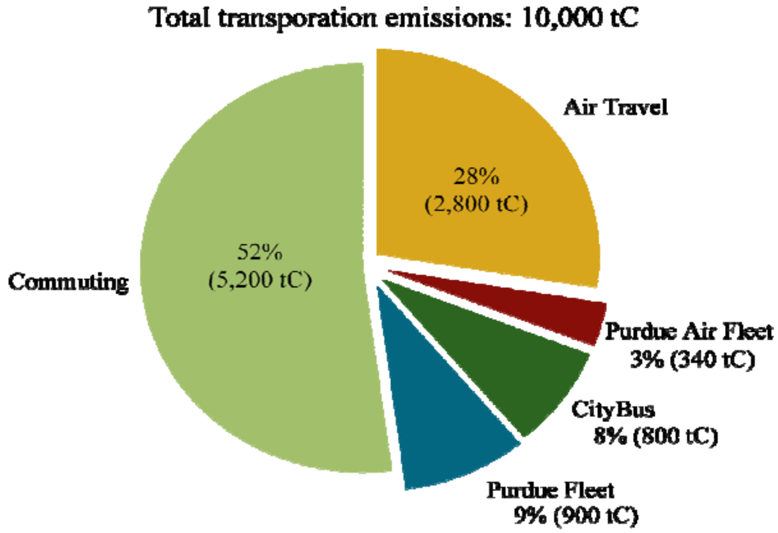

**Figure 2.3.1** Break-down of the carbon emissions by Transportation sub-sector (in % of TC).

## 2.4 Permanent Materials Carbon Footprint

### 2.4.1 Sector Boundaries

Permanent materials refers to Purdue University's built environment and is defined to include all materials used in the construction of new buildings and major renovations (e.g., re-roofing) to existing buildings on the Purdue University West Lafayette main campus. The carbon footprint calculated for these permanent materials includes an accounting of the carbon emissions as $CO_2$ (in metric tons of carbon, TC) associated with the energy that went into the manufacture of all building materials, their transportation to the building site, and related on-site construction activities. The emissions from routine maintenance and minor repair of buildings are not considered.

### 2.4.2 Methods/Assumptions/Data

This carbon footprint statement was based on construction activities in the year 2005. If a project spanned more than one year, then the carbon emissions value for the entire project was calculated and divided by the total years to complete the project. For all major renovations, emissions were based on the embodied energy of the specific materials used (i.e., the embodied energy of the roofing tiles used for the Brown Laboratory of Chemistry roof replacement project) whenever that information was available. In the event that it was not possible to obtain a list of specific materials used for the renovation, the value for the total embodied energy of the project was calculated by making assumptions about the materials used in each specific renovation based on the project description and the square footage of the renovated space. This approximation assumes that the most energy intensive materials usually used in structural components of the building typically were not replaced during renovations.

The carbon footprint of Purdue's permanent materials was derived by first calculating the embodied energy associated with the building materials. Total embodied energy, given in $MJ/kg_{material}$, represents the sum of the energy used to manufacture each material, its transportation to the construction site, and the energy associated with the actual placement of the material during the building process. Purdue does not keep detailed lists of materials used in the construction of its buildings, so representative lists were chosen from the literature based on buildings with similar end-use and square footage (Scheuer, et. al., 2003). Although the building industry is highly localized and access to materials, building practices, and local regulations vary widely, building codes do provide some degree of consistency in material choices and construction practices, making these estimations more robust. A simple calculation (see equation 2.4.1) was then used to convert the total embodied energy calculated for each building into metric tons of carbon.

### *2.4.2.1 Summary of Embodied Energy Models*

There is a wide range of data, often nation-specific, on the embodied energy found in typical construction materials (Hammond and Jones, 2006). We based our analysis on the values for embodied energy presented in Scheuer, et. al. from the University of Michigan's Center for Sustainable Systems (2003), because their model building is a 6 story building on the University of Michigan campus and they use a Midwest region fuel mix to calculate energy consumption for the electricity used in material production. Another embodied energy data set developed by Gumaste (2006), for embodied energy of construction in India, was used for comparison with the Scheuer et al. values.

### *2.4.2.2 Footprint Calculation Method and Algorithm*

The campus building used for the Scheuer, et. al. calculation described above was 7,300 square meters, had a projected lifespan of 75 years (typical of university buildings), and was mixed-use. The bottom three floors and basement were used for classrooms and offices while the upper three stories served as hotel rooms. This paper included a comprehensive list of materials that went into the building, and their respective embodied energies. It is our belief that this building is a good model for Purdue because the majority of buildings included in the Purdue footprint analysis are mixed-use, classrooms, or dormitories.

The following algorithm was used to convert embodied energy obtained from Scheuer et al., which was in units of megajoules (MJ) per m$^2$ of floor area into a form that was suitable for our estimating purposes (metric tons of carbon per m$^2$ of floor area).

$$\frac{MJ}{m^2} \times \frac{1\,kWhr}{3.6\,MJ} \times \frac{1.34\,lb\,CO_2}{1\,kWhr} \times \frac{2.202\,kg}{1\,lb} \times \frac{12\,kg\,C}{44\,kg\,CO_2} \times \frac{1\,TC}{1000\,kg\,CO_2} = \frac{metric\,ton\ C}{floor\ area\,(m^2)}$$

**Equation 2.4.1** Conversion of embodied energy to carbon emissions

The conversion from kilowatt hours of electricity to pounds of $CO_2$ emitted was obtained from Energy Information Administration records ("Carbon Dioxide Emissions," 2000). This data takes into account the primary sources of fuel for energy production and the amount of carbon dioxide emissions from each of those fuel sources. Using the percentage of usage for each different type of fuel, a weighted average can be obtained that indicates the average carbon dioxide emissions per unit of energy for energy usage in the United States (See Appendix C-1).

The building material embodied energy term has units of mega Joules of energy per kilogram of building material. Scheuer et al. (2003) also included a list of the masses used in the building for each individual material. Using this data, we simply multiplied the embodied energy of a material by the mass used in the building to get total energy, and then divided by the gross floor area of the building to get MJ/m$^2$. This number can be used to estimate the amount of embodied energy per square meter of any similarly constructed buildings within a reasonable error margin.

Both new construction and renovation of buildings were considered in our footprint analysis (See Appendices C-2 and C-3). Using the start and completion dates, we were able to find the fraction of the overall building that was built in 2005 using a time factor (construction months in 2005/overall construction months). While this may not exactly estimate the carbon footprint for building in 2005 (since the footprint is probably larger or smaller at different stages of construction), this provides an average value that can be applied to an entire construction project. Multiplying this fraction by the buildings' floor areas gave us a corrected gross floor area (GFA). This time factor and corrected GFA allowed us to create a much more accurate footprint. The new building and renovation construction projects that were factored into our calculations for the 2005 calendar year are listed in Appendices C-2 and C-3.

### 2.4.3 Results

The algorithm described in this report was applied to all building construction and renovations mentioned previously. We factored in the building materials, metric tons of each material used in the university building from the Scheuer et al. estimate, and MJ of embodied energy per kg of building material (See Appendix C-4). From this data, values for the embodied carbon as kg carbon dioxide per meter squared of gross floor area were calculated. Once the embodied carbon per square meter of floor area was calculated, this could be applied to the square meter floor areas of the Purdue building and renovation projects for 2005 (See Appendix C-5). For renovations, we only included the calculations for the embodied energy of the building materials that we assume were used during the specific projects. The final result for embodied carbon in permanent buildings on the Purdue main campus was estimated to be 17,800 TC for the 2005 calendar year (see Table 2.4.1, next page).

| **Building** | **Embodied Carbon (TC)** |
|---|---|
| Biomedical Engineering | 3,930 |
| Schwartz Tennis Center | 1,710 |
| Lawson CS Building | 3,570 |
| Lynn Hall Radiation Therapy Facility | 304 |
| Forney Hall of Chemical Engineering addition | 1,030 |
| Aquaculture Building reconstruction | 520 |
| Pao Hall of VPA landscaping | 245 |
| Brown Laboratory roof | 137 |
| Wetherill Laboratory roof | 158 |
| Cary Quad renovation | 5,410 |
| Entomology Lab Infrastructure upgrade | 163 |
| Forney Hall of Chemical Engineering renovation | 285 |
| Hovde Hall third floor renovation | 149 |
| Smith Hall rooms 174/178 renovation | 172 |
| Total of all buildings | 17,800 (TC) |

**Table 2.4.1** Total embodied carbon for 2005 new construction and renovation at Purdue

The Gumaste model (2006) discussed previously was used to compare our estimates obtained from the Scheuer et. al. model (2003). The same calculation method was used for this model as for the Scheuer et al. model, and so intermediate calculations are not reported. Out of the given structure choices for this model, we have chosen to use a G+2 structure (ground floor plus two more floors, so three stories in all) (Gumaste, 2006). We believe this structure type to be the most representative of Purdue University's construction. The results from the two models are summarized in Table 2.4.2 below, along with an average embodied carbon.

| **Model** | **Embodied Carbon** |
|---|---|
| Scheuer (2003) | 17,800 |
| Gunmaste (2006) | 13,500 |
| Average | 15,600 |

**Table 2.4.2** Summary of embodied carbon values (TC emitted as $CO_2$ for 2005).

Errors in our estimate of embodied carbon are difficult to quantify realistically because of the disagreement between models and, most significantly, because without materials lists for the buildings on Purdue's Campus it is unclear which model is the best fit for a Purdue building. For these reasons, we chose to use the estimate from the Scheuer model, which seems to make more appropriate assumptions for Purdue based on similar geography and building use demands.

## 2.5 Consumables

### 2.5.1 Sector Boundaries

The purpose of the consumables group is to classify the disposable materials that Purdue University students, faculty, and staff use which affect Purdue's carbon footprint. Our top four categories for classification of the consumable boundaries are paper products, plastic products, food, and lab supplies. We chose these four categories of consumables based on two criteria: high consumption volume and high turnover rate. After obtaining data on the physical quantities of products used on campus (*i.e.* pounds of food and number of reams of paper), we calculated the carbon emission by examining energy used in transportation, manufacture, and waste disposal of those products.

### 2.5.2 General Methods for Calculating Carbon Emissions

Under typical industrial processes in Indiana coal is the main source of energy, which allowed us to convert coal energy into emission loads. Coal processing has emissions of 205.99 lb $CO_2$/MBtu ("Unit Conversions," 2004). Using the following calculation we estimated carbon emissions, therefore, for industrial processes:

$$\frac{energy(kWh)}{year}\times\frac{10107\,Btu}{1\,kWh}\times\frac{1\,MBtu}{10^6\,Btu}\times\frac{205.99\,lb\,CO_2}{1\,MBtu}\times\frac{1\,metric\,ton}{2204.62\,lb}\times\frac{12\,TC}{44\,TCO_2}=\frac{TC}{year}$$

**Equation 2.5.1** Carbon emitted for energy used in typical Indiana industrial processes.

Conversions for transportation are relatively straightforward, and use diesel-burning emissions factors and an average fuel economy for a tractor-trailer, which is the primary conveyance for consumables. This conversion is shown below.

$$Miles\times\frac{22.23\,lb\,CO_2}{gallon\,gas}\times\frac{1\,gallon\,gas}{6.2\,miles}\times\frac{1\,metric\,ton\,(T)}{2{,}204.62\,lb\,CO_2}\times\frac{12\,TC}{44\,TCO_2}=TC$$

**Equation 2.5.2** Conversion from semi-truck miles traveled to carbon emitted.

This generalized equation uses a tractor-trailer fuel economy of 6.2 mpg (Langer, 2004). Additionally, we found that tractor-trailers use mainly diesel fuel with 22.23 lb $CO_2$ emissions/gal ("Unit Conversions," 2004). Specific estimations vary by category and more detailed explanations of assumptions and methods are given later in this report.

*2.5.2.1 Paper Products*

One difficult aspect of carbon emissions estimation from consumable materials is the wide variation of paper products used at the Purdue campus. Appendix D-1 details the major types of paper products that were investigated. However, the only complete data that could be found was for purchased volumes of books and journals. It was therefore necessary to make certain assumptions to estimate the quantity of paper products such as paper towels used in restrooms and napkins used in dining courts. Products such as books and journals were converted into reams of paper using page numbers to estimate the total weight. For other products we used waste analysis techniques, in which waste production data was analyzed to estimate the original weight of paper purchased and used.

***Books and Journals*** Different books and journals use very different printing paper and vary greatly in length. In order to estimate the total weight of books and journals, we used the data obtained from Information Technology at Purdue (ITaP) and Purdue Libraries and assumed that the average library volume is equivalent to 300 letter sized pieces of paper (see Table 2.5.1). We then converted the total page numbers into equivalent reams to calculate their weight ("Additional Data and Facts," 2005).

| Paper Products Consumed (2005) | |
|---|---|
| Books (purchased volumes) | 49,636 |
| Journals (subscribed volumes) | 35,728 |
| Printing/Copy Paper (ITaP printing system, pages) | 58,464,000 |

**Table 2.5.1** Campus-based paper consumption data (2005)

$$85{,}324\,volumes \times \frac{300\ pages}{volume} \times \frac{1\,ream}{500\ pages} = 51{,}194\,reams\,of\ books\,and\ journals$$

$$51{,}194\,reams \times \frac{20\,lbs}{1\,ream} = 1{,}023{,}890\,lbs = 465\,T$$

**Equation 2.5.3** Conversion from books and journals to equivalent weight of paper

***ITaP Printing*** Similar to the book products, we assume that all printing labs use the same paper products. The same conversion applies:

$$\frac{160{,}000\ pages}{1\,day} \times \frac{365\,days}{1\,year} \times \frac{1\,ream}{500\ pages} = 116{,}800\,reams\,of\ ITaP\ system\ paper$$

$$116{,}800\,reams \times \frac{20\,lbs}{1\,ream} = 2{,}236{,}000\,lbs = 1{,}059.5\,T$$

**Equation 2.5.4** Conversion from Itap printing to equivalent weight of paper

***Input-Output Analysis of Paper Waste*** Consumption of paper products varies widely among Purdue's many academic departments, business and administrative offices, computer labs, and residence halls. Therefore, we used waste stream analysis to make an estimation of paper consumption. In general, consumption of each type of paper product will generate a certain amount of solid waste with a constant "input-output" ratio (Nakamura and Konbo, 2002). We used waste stream data from 1995 to estimate the total amount of mixed paper (beyond books, journals, and printers) consumed annually at Purdue. Appendix D-2 shows that the total amount of mixed paper used is 3,961.67 T. Therefore, the total for the estimation by weight of paper products consumed on the Purdue campus is given by:

$$3{,}961.67 + 465 + 1{,}059.5 = 5{,}486.17 \text{ T paper}$$

**Equation 2.5.5** Total weight of all campus paper products

The carbon emissions production calculation uses an average industrial process to estimate emissions for different types of paper products. Emissions are calculated with the general methods discussed earlier. Energy demand by paper type is given in Table 2.5.2. Each process has a known amount of energy consumption per unit weight, so energy consumption for the total amount of paper used by Purdue can easily be found. With the amount of energy used to create all of Purdue's paper products and equation 2.4.1, the total carbon emissions from paper production can be found.

| Total Weight Consumed (T) | Energy Intensity | | Energy Consumption (GJ) |
|---|---|---|---|
| | Heating Process | Specific Electricity Consumption | |
| Office Paper: 1,214.1 | 2.75 GJ/T | 2.2 GJ/T | 6,009.8 |
| Newspaper: 673.7 | 7.71 GJ/T | 1.54 GJ/T | 6,231.7 |
| Mixed Paper: 550.8 | 6.61 GJ/T | 1.98 GJ/T | 4,731.4 |
| Cardboard: 1,255.2 | 5.51 GJ/T | 1.65 GJ/T | 8,987.23 |
| Restroom: 1,791.2 | 5.51 GJ/T | 2.64 GJ/T | 14,598.3 |
| ∑ =5,486.17 T paper | | | **Total (GJ): 40,558.4 GJ = 11,126,620 kWh**[5] |

**Table 2.5.2** Energy consumption from production of various paper products.

From the electricity output of 11.13 million kWh (above), the total carbon emission from production of paper products obtained from equation 2.5.1 is 2,901.63 TC.

***Transportation Distance and Shipping Rates*** To calculate the carbon emissions created by the transportation and shipping of paper products, we assume a certain transportation rate and shipping distance. We use 2,000 miles as an estimate of transportation distance, which is

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[5] Jacco Farla, et. al, 1997. "Energy Efficiency Development in Pulp and Paper Industry." *Energy Policy* 25(7): 745-758.Average industrial energy efficiency data from 1980-2000 in OECD countries was used

roughly half the distance across the United States. We also assumed that all paper products are shipped using standard 40-foot semi trucks with 55,000 lbs (24.95 T) freight capacity per shipment.[6]

Average Shipping Distance: 2,000 miles

Total Transportation Distance: 228 shipments · 2,000 miles = 456,727 miles

$$456{,}727\,miles \times \frac{3.585\,lb\,CO_2}{1\,mile} = 1{,}637{,}367\,lb\,CO_2 = 743.6\,T\,CO_2 = 203\,TC$$

**Equation 2.5.6** Conversion from shipping distance to carbon emitted

Therefore, the total carbon emissions for paper products used on Purdue's campus, including transportation and production, is:

$$203 + 2{,}901.63 = 3{,}104.63 \text{ TC}$$

**Equation 2.5.7** Total carbon emissions from production and transportation of paper.

### *2.5.2.2 Plastic Products*

Plastics emissions were calculated using analysis of the solid waste sector. The calculations use the assumption that 11% of the total waste stream consists of plastics ("After it's Been Binned," 2006). Using this assumption, the plastics contribution to campus waste was approximately 617.8 T. According to the Purdue Recycling and Refuse Coordinator, the plastic containers used for vending machine drink containers make up a large portion of the waste plastic, so we used their properties for calculations in this subsector. According to manufacturing data, plastics bottles consume approximately 5 GJ of useable power per ton during production ("Industrial Energy Intensity," 2004). Assuming that half of the total plastic is transported in food packaging and the other half is transported in bulk, half of campus plastics emissions will be calculated in the food supplies section later. Emission calculations for the other half of plastics were based on a value of 309 T (618/2) of plastic, and follow the same methods used for calculating process energy of paper. Total emissions are given in Table 2.5.3 using equations 2.5.2 and 2.5.1.

| | |
|---|---|
| Transportation Carbon | 7.5 TC |
| Production Carbon | 221 TC |
| **Total** | **228.5 TC** |

**Table 2.5.3** Total carbon emissions from plastics

---

[6] "Summary of State Motor Vehicle Registration Fee Schedule," *U.S. Department of Transportation Federal Highway Administration*. 2001. <www.fhwa.dot.gov/ohim/hwytaxes/2001/pdf/pt11.pdf> (8 April 2007). The average maximum allowable weight for an entire tractor trailer, including truck and loaded boxcar, in the United States is 80,000 lbs. However, the truck/hauling portion of a tractor trailer weighs 25,000 lbs on average, leaving only 55,000 lbs available for the shipment.

### *2.5.2.3 Food Products*

In determining the $CO_2$ emissions from campus food consumption, this sector was initially divided into human and animal foods. From extensive searching around campus, it was determined that animal feed was an insignificant contribution to carbon emissions, and was therefore excluded. Fortunately, detailed data is available on the amount, type, and transportation distance of each food used on campus. This data is detailed in Appendices D-4 and D-5. The food sector calculations consider both the energy required for transportation of the food from the manufacturer to the Purdue University campus and the energy required to convert raw materials to an edible food product. The energy used to cook the food once it reaches Purdue is covered by the on-campus energy sector.

Campus food includes only food consumed in residence halls and from vending machines and restaurant/catering services. Energy of production is calculated by assigning a factor (from 0 to 1) scaled to the intensity of processing required to transform raw food to edible product. Fresh foods, like apples and bananas, represent a zero (0) on the scale. A 0.3 is representative of foods that have a small amount of processing involved, such as canned vegetables or fruit. A 0.5 food has a moderate amount of processing requirement, for example, potato chips. A 0.7 food has considerable processing needs, like chicken nuggets or hot dogs. Finally, a 1 food requires an intense industrial process, not typical of food processing, and not used in this analysis. Using the assigned value, each food process was scaled by comparing it to the value of a typical process. The overall energy intensity of the sample process was estimated at 4,005 MJ/T and scaled to the 0.7 level (“Industrial Energy Intensity,” 2004). All other processes were compared to this value, and the result was a per pound energy estimation that was converted to carbon emissions. This process is shown in Appendix D-4.

To calculate transportation emissions of campus food, we acquired precise and well-known values for transportation distances for each food type. Information was collected to determine the quantity of highly consumed foods per year, shipping frequencies, and the sources of the food. Using the data about the sources of food allowed for estimations of the transportation distance per shipment. All calculations are shown in Appendix D-4 and D-5. Total emissions for food consumption are outlined in Table 2.5.4, next page.

| | |
|---|---|
| Transportation Carbon | 759 TC |
| Production Carbon | 177 TC |
| **Total Carbon** | **936 TC** |

**Table 2.5.4** Summary of food emissions

### *2.5.2.4 Waste Disposal*

***Waste Water Management*** A summary of Purdue's waste stream quantities used in this section's calculations are given in Table 2.5.5 below**.**

| **Wastewater Treatment** | |
|---|---|
| Volume | 600 million gallons |
| Energy use | 722,000 kW |
| **Other Waste Disposal** | |
| Landfilled | 4,724 T |
| Recycled | 753 T |
| Total treated waste | 72 T |

**Table 2.5.5** Summary of waste quantities for 2005

Purdue is billed for 600 million gallons of water each year. To calculate Purdue's energy emission contribution, a proportion was used to compare the total amount of water treated and total amount of energy used. The facility treats 3.2 billion gallons of water, and uses 3,849,000 kWh and 62,588 therms of electricity and natural gas, respectively, to process the waste (Downer, 2007). Therefore, Purdue contributes emissions through the use of 721,688 kW-h electricity and 11,735 therms natural gas. The carbon emissions from this process follow the calculations given in the general methods section and also use conversions to natural gas as shown below ("Unit Conversions," 2004).

$$11{,}735\, therms \times \frac{100{,}000\, BTU}{therms} \times \frac{0.120\, lb\, CO_2}{1\, ft^3} \times \frac{1\, ft^3}{970\, BTU} \times \frac{1T\, CO_2}{2{,}204.6\, lb\, CO_2} \times \frac{12\, TC}{44\, T\, CO_2} = 18\, TC$$

**Equation 2.5.8** Conversion from natural gas to carbon emissions

Table 2.6.5 summarizes the waste water treatment results, including the electricity and natural gas emissions contributions.

| | |
|---|---|
| Electricity Carbon | 58 TC |
| Natural Gas Carbon | 18 TC |
| **Total Carbon** | **76 TC** |

**Table 2.5.6** Wastewater treatment results

***Landfill Waste Transportation*** Purdue sent 4,724 T of waste to a landfill in 20 yd$^3$ capacity trucks to a transfer site five miles from campus. From the transfer station the waste was taken to Southside Landfill in Indianapolis, located some 68 miles away (Zarate, 2007). Refuse is compacted to a density of 159 kg/yd$^3$ to 181 kg/yd$^3$ by a garbage truck with an assumed fuel economy of 7.4 mpg ("Municipal Solid Waste," 2004). The assumed capacity of a semi trailer is the largest it can legally measure (53'x 110" x 102") with thickness of walls taken into account, for a volume of 144 yd$^3$ ("ALS University," 2006). Applying transportation calculation standards, the contribution is totaled in Table 2.5.7.

| | |
|---|---|
| Transportation to Transfer Station | 1.5 TC |
| Transportation to Landfill | 3.2 TC |
| **Total Carbon** | **4.7 TC** |

**Table 2.5.7** Landfill waste transportation related carbon

***Landfill Waste Energy*** Energy is needed to dispose of the waste at the landfill site. Purdue disposes of its wastes at South Side Landfill, which uses methane produced by decomposing wastes as an alternative energy source ("South Side Landfill," 2001). Actual disposal of the waste requires 0.33 MBtu of energy per ton of waste (Choate, et. al., 2005). Using this conversion factor and others cited earlier, the amount of energy needed to dispose of the waste is calculated to be 43.8 TC. The final landfill waste energy totals are summarized in Table 2.5.8.

| | |
|---|---|
| Wastewater | 76 TC |
| Solid Waste Transport | 4.7 TC |
| Solid Waste Energy in Use | 43.8 TC |
| **Total Carbon** | **124.5 TC** |

**Table 2.5.8** Net emissions from waste disposal

### 2.5.3 Results

The following table shows our final estimation on carbon emissions from consumable materials based on currently available data. More detailed information about emission calculations can be found in Appendices D-1 to D-5.

| *Paper Products* | *Plastic Products* | *Food Products* | *Waste Disposal* |
|---|---|---|---|
| 3,104.63 TC | 228.5 TC | 936 TC | 124.5 TC |
| *Total Emissions* | | | |
| 4,393.63 TC | | | |

**Table 2.5.9** Summary of consumables carbon emissions

## 2.6 Land Use

### 2.6.1 Boundary

This sector focuses on aspects that relate to land use and land cover including parks, buildings, trees, greenhouses, roads, water bodies, and industrial areas on the Purdue Campus. The land taken into consideration includes all land owned or managed by Purdue University within Tippecanoe County including the Agronomy Research Farm, Animal Science Farm, Throckmorton-Purdue Agricultural Center, Martell Forest, and Old Horticultural Farm. Roads, buildings, and other non-green areas are not included when determining land areas to avoid overlap with other sectors.

### 2.6.2 Methods/Assumptions/Data

The total carbon impact of land use at Purdue was calculated by finding the carbon sequestered by forest growth as well as the carbon emissions generated by land use-related fertilizer consumption. Forests are the only type of vegetation considered because carbon sequestered by non-woody vegetative growth such as that of crops and grasses is balanced by carbon emitted during annual decomposition.

Soil sequestration was not considered for soils under constant forest or prairie vegetation because carbon stocks remain relatively stable and annual net carbon sequestration for these soils is negligible. Carbon stocks are not stable, however, when management practices such as tillage are applied to soils. Due to ever-changing nature of tillage on Purdue's research farms, sufficient data was not available to accurately calculate the annual sequestration of carbon due to the implementation of no-till and reduced tillage practices. A preliminary calculation determined that the impact of soil sequestration was minimal, despite the fact that the assumptions required for the calculation generate an overestimated value (See Appendix E-1). Due to the minimal impact and limited accuracy of this value, it was not included in the footprint.

#### *2.6.2.1 Forest Sequestration*

Forest growth can serve as a carbon credit because carbon is sequestered in the woody biomass of trees during annual growth. Equations 2.6.1 and 2.6.2 (Paustian, et. al., 2005) are used to calculate the annual change in carbon stock related to biomass ($\Delta C_B$). Equation 2.6.1 estimates $\Delta C_B$ by subtracting annual decrease in carbon stocks due to biomass loss ($\Delta C_L$) from the annual increase in carbon stocks due to biomass growth ($\Delta C_G$). Since Purdue's forests are managed for preservation, it assumed that biomass losses are negligible and $\Delta C_G$ and $\Delta C_B$ are approximately equal.

$$\Delta C_B = \Delta C_G - \Delta C_L$$

**Equation 2.6.1** Calculation of forest biomass carbon stock change

$$\Delta C_G = A \cdot G_{TOTAL} \cdot CF$$

**Equation 2.6.2** Calculation of forest biomass growth

The area of Purdue's forests (A, 630 ha) is multiplied by the mean annual biomass growth ($G_{TOTAL}$) from Appendix E-2 and the carbon fraction of dry matter (CF) from Appendix E-3. This is computed for above ground and below ground matter. The Above Ground/Below Ground Biomass Ratio (AGB/BGB) of 0.24 is selected from the 2006 *IPCC Guidelines for National Greenhouse Gas Inventories*, Volume 4 as it corresponds to broadleaved forests with an aboveground biomass of more than 150 metric tons per hectare. CF values are assumed to be the same for aboveground and belowground biomass. The total change in carbon will be equal to that sequestered by aboveground biomass plus that sequestered by belowground biomass.

$$\Delta C_{G_{AGB}} = 630\ ha \times \frac{4\ T\ dry\, matter}{ha} \times \frac{0.48\ TC}{T\ dry\, matter} = 1{,}210\ TC$$

**Equation 2.6.3** Calculation of carbon sequestration by aboveground biomass growth

$$\Delta C_{G_{BGB}} = 630\ ha \times \frac{4\ T\ dry\, matter\ AGB}{ha} \times \frac{0.24\ T\ dry\, matter\ BGB}{T\ dry\, matter\ AGB} \times \frac{0.48\ T\ C}{T\ dry\, matter} = 290\ TC$$

**Equation 2.6.4** Calculation of carbon sequestration by belowground biomass growth

$$\Delta C_{G_{TOTAL}} = \Delta C_{G_{AGB}} + \Delta C_{G_{BGB}} = 1{,}210\ TC + 290\ TC = 1{,}500\ T$$

**Equation 2.6.5** Calculation of total carbon sequestration by forest biomass growth

### *2.6.2.2 Fertilizer Calculations*

Fertilizer use for all farms is extrapolated from the Agronomy Research Farm's fertilizer use as was done for fuel use in the transportation sector. Four different kinds of nitrogen fertilizer are used on Purdue's farms: Anhydrous ammonia, urea, ammonium nitrate, and a nitrogen-phosphorus-potassium blend. The Haber-Bosch process is used to convert atmospheric nitrogen into ammonia. The process releases 0.375 moles of carbon per mole of nitrogen produced (Izaurralde, et. al., 2005). The total amount of fertilizer was multiplied by the percentage of nitrogen embodied in the fertilizer and converted to TC emissions. Equation 2.6.6 (next page) is an example calculation for anhydrous ammonia and a table containing all fertilizer values.

$$1{,}321.3\ ha \times \frac{32\ T\ \ Fertilizer}{372.3\ ha} \times \frac{0.82\ T\ \ N}{1\ T\ \ Fertilzer} \times \frac{0.375\ mol\ C}{1\ mol\ \ N} \times \frac{12.01\ TC}{14.01\ TN} = 29.9\ TC$$

**Equation 2.6.6** Example calculation of carbon emissions resulting from fertilizer manufacture

| Fertilizer | Agry. Research Farm Fertilizer Use (T) | Total Cropland Fertilizer Use (T) | Percent Nitrogen | Total N (T) | Carbon Emissions (TC) |
|---|---|---|---|---|---|
| Ammonium Nitrate | 2 | 7.1 | 33.5 | 2.4 | 0.8 |
| Anhydrous Ammonia | 32 | 113.6 | 82 | 93.1 | 29.9 |
| N-P-K Blend | 18 | 63.9 | 23 | 14.7 | 4.7 |
| Urea | 45 | 159.7 | 45 | 71.9 | 23.1 |
| **Total** | | | | | **58.5** |

**Table 2.6.1** Estimated carbon contributions from agriculture-related fertilizer use.[7]

### 2.6.3 Final Results and Discussion

The use of Purdue University's land results in both sequestration and emission of carbon. The annual growth of Purdue's forests results in a 1,500 TC credit. The use of conservation tillage also results in a small carbon credit which is incalculable with the available data. The use of fertilizers on Purdue's farms contributes 58.5 TC emissions per year. This contribution is conservative, as it does not take potassium and phosphorus fertilizers into account, which are mined.

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[7] Agronomy Research Farm Information Archive provided area and fertilizer use data.

## 2.7 Total Carbon Footprint

We combined the individual footprint sector totals to obtain Purdue University's total carbon footprint for 2005. According to our calculations, Purdue's net emissions were 182,956 TC in the fiscal year 2005/06. Below is a summary of the carbon emissions broken down by each footprint sector in Table 2.7.1 and Figure 2.7.1.

| **Footprint Sector** | **Carbon Emissions (TC)** | **Percentage of total** |
|---|---|---|
| On-Campus Energy | 103,165 | 56% |
| Off-Campus Energy | 48,008 | 26% |
| Transportation | 11,054 | 6% |
| Permanent Materials | 17,790 | 10% |
| Consumables | 4,394 | 2% |
| Land-Use | 59 | 0% |
| Land-Use Sequestration | (1,500) | N/A |
| **PURDUE'S TOTAL CARBON FOOTPRINT:** | **182,970** | 100% |

**Table 2.7.1** Summary of Purdue's total carbon footprint

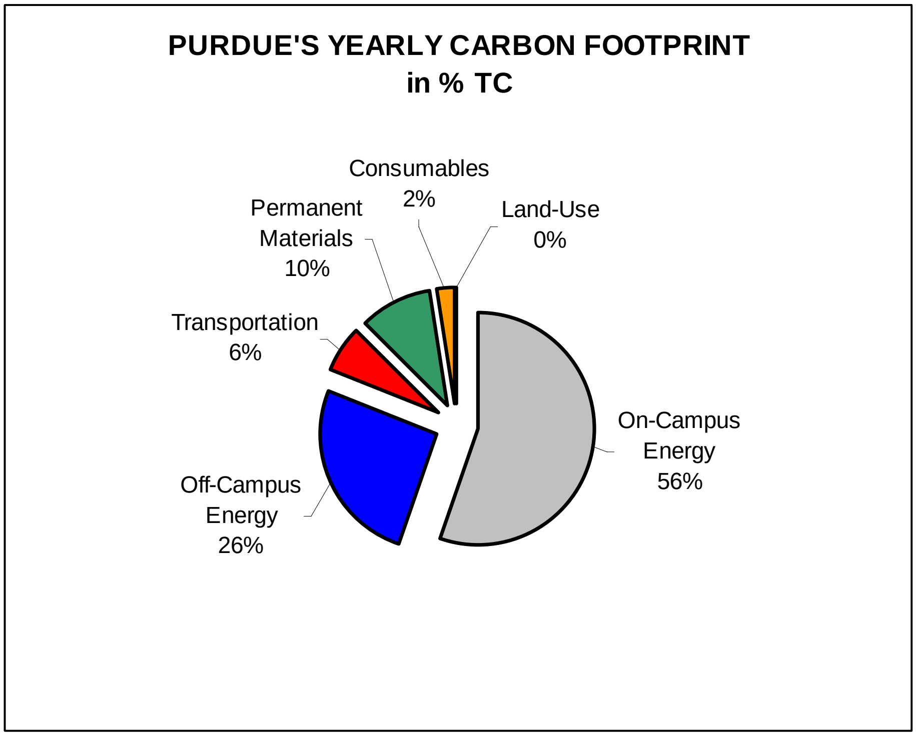

**Figure 2.7.1** Purdue's total carbon footprint

# 3. Managing Purdue University's Carbon Footprint

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## 3.1 Management Strategy

For our initial carbon neutrality report, we chose to create a menu of options for potential ways to reduce Purdue's carbon footprint. We determined that the university's energy consumption should be addressed from both the supply and demand sides. We developed options to reduce amount of carbon-intensive energy that Purdue produces and/or purchases, as well as the amount of energy required and utilized throughout the campus. In the future, we would recommend the development of a plan with incremental steps to reduce the university's carbon emissions along a manageable timeline. The university could realistically adopt carbon mitigation goals to be achieved in the next 2, 5, 10, or 20 years, and pursue steps to reach those benchmarks. We believe our menu of options approach provides an excellent introduction to the carbon mitigation strategies available to Purdue University at this juncture.

## 3.2 Energy Supply

Energy supply makes up the largest portion of Purdue's carbon footprint and consequently provides the greatest opportunity for reduction. There are a number of existing technologies that would allow Purdue to meet its energy needs while reducing carbon emissions. The Supply Management group investigated the possibility of using carbon capture technologies, biomass, wind, and solar as well as offsets to reduce Purdue's footprint. The results of that work are presented as a number of scenarios for implementation, costs associated with doing so, and carbon emissions saved by adopting the various strategies outlined above and incorporated them into a practical timeframe for implementation. Any strategy to effectively mitigate Purdue carbon emissions will likely incorporate a number of these options.

### 3.2.1 Wade Utility Plant

The Wade Utility Plant is by far the single largest source of carbon emissions at Purdue. These emissions arise mostly from the burning of coal, but also include burning of natural gas and very limited tests with biomass burning. Due to the complexity and capital costs involved in new boiler systems, the recommendations in this section are structured to give guidance as to the carbon impacts of various technologies and relative costs of these technologies that could be invested in for the Wade Utility Plant. It is clear that continuing to burn traditional coal in the present manner will not result in a significant reduction of carbon emissions. Purdue University should carefully consider the future scenarios for energy production at Wade as the cost of emitting carbon is regulated as a pollutant. In order to meet a long term goal of carbon neutrality the university will need to consider significant capital investment in future boiler systems that either are able to capture carbon ("The Future of Coal," 2007), or transition away from coal fired boilers toward lower-carbon energy production systems such as natural gas turbines or significant biomass.

#### *3.2.1.1 Carbon Reduction*

In Table 3.2.1 (next page) we explore the impact of various technologies on the carbon output of the Wade Utility Plant while keeping demand constant at 4,497 billion BTUs (bBTU). In this manner we can investigate the impact that the given technology will have on carbon emissions.

|  | **Carbon Emissions Factor (TC/bBTU)** | **Carbon Emissions (TC/year)** (under current Purdue load of 4,497 bBTU/year)[d] | **Percent Reduction of Carbon per year** |
|---|---|---|---|
| Coal[a] | 21.64 | 103,165 | 0% |
| Clean Coal (90% C capture)[b] | 2.16 | 10,317 | 90% |
| Natural Gas[c] | 14.47 | 69,120 | 33% |
| Biomass (20% of boiler load) | 0 | 82,532 | 20% |

**Table 3.2.1** Carbon output at Wade Utility Plant with constant demand

[a] Calculated from emissions at Purdue CEMS and measured BTU demand detailed in Wade Utility Plant Footprint Section and validated against industry averages ("Table B1," 1998)

[b] 90% capture goal from MIT Coal Report ("The Future of Coal," 2007)

[c] EIA ("Table B1," 1998)

[d] From footprint of Wade Utility Plant

Considering our preliminary calculations, investing in technologies used to capture $CO_2$ emissions from the boilers themselves is the most powerful method of carbon reduction if Purdue continues to rely on coal for energy production.

#### *3.2.1.2 Additional Benefits*

The additional benefits of implementing increasingly carbon neutral systems vary based on the chosen system. Biomass burning has the additional benefit of burning local waste and reducing transportation costs involved in moving other fuels. "Clean coal" technology has the potential benefit of being able to remove other pollutants and particulates at the same time as carbon is removed, thus potentially removing harmful heavy metals from Wade's emissions. Natural gas turbine systems are essentially jet engines running on the ground and can be much more responsive to demand than boiler-based systems; these systems can generate both steam and direct rotation of generators. Further exploration of the implications of replacing one of Wade's boilers with a turbine system should be explored.

#### *3.2.1.3 Estimated Cost*

The cost of implementing carbon emissions reductions at the Wade Utility Plant are complex and dynamic due to the nature of the energy commodity market and emerging technologies. We will not attempt to quantify them explicitly in these recommendations. Over the next 20 years it would be advisable for Purdue to invest in a balance of carbon reduction technologies with increasing aggressiveness as costs come down. We believe that by doing this, while monitoring potential future policies such as carbon taxes or a cap-and-trade system for $CO_2$ emissions, significant carbon emissions reductions can be achieved at the Wade plant. Natural gas is attractive from a carbon standpoint, but has the greatest price volatility in commodity cost of any of the proposed options. Exploration of turbine systems that are flex fuel might be a way to balance out the costs over the long run. Biomass fuels such as biodiesel and ethanol could be run in turbine systems such as natural gas turbines, but further investigation is needed to determine how flexible turbine systems are to varied fuels. From our investigation of clean coal technology there are no off-the-shelf technologies that are ready to be delivered at the scale of the Wade Utility Plant. The technologies that are available for clean coal have significant capital investments associated with them and are currently only recommended for plants designed around the technology ("The Future of Coal," 2007). However, we believe that Purdue could be perceived as a leader in the field if they invest and seek funding for research and development of the Wade Utility plant as an operational laboratory for the academic exploration and future commercialization of clean coal technologies while maintaining Wade as an operational utility plant.

| Cost Category | Technology | Notes |
|---|---|---|
| Low Cost | Biomass | Fuel can be added to current fluidized bed boiler at minimal additional capital cost. System for mixing biomass with coal uniformly would be needed. |
| Medium Cost | Natural gas | Explore the mix of natural gas and coal in boiler systems to explore how natural gas could lower carbon emissions. Future, investigate replacing some boilers with natural gas turbines. |
| High Cost | Clean coal technology | High cost of infrastructure to support carbon scrubbing systems. Long term high capital cost. |

**Table 3.2.2** Costs associated with different carbon-emission-reducing technologies

#### *3.2.1.4 Estimated Payback Period*

Paybacks for the Wade Utility Plant recommendations vary by the chosen technologies. Technologies such as biomass burning, which is considered to be renewable and carbon neutral, would offer immediate financial benefits in terms of avoiding costs for coal if they were mixed in with coal on the fluidized bed boiler currently installed at the plant. With the additional purchase of fluidized bed boiler systems increased biomass can be burned. Natural gas energy generating can have roughly a 33% impact on carbon emissions for the same BTU generated, but assumes all systems at Wade are replaced with natural gas. It is possible to run natural gas in the boilers, and in fact this is done during high-demand heating periods. Optimizing this mix during low-demand times could achieve a reduction in carbon emissions. In short the payback is difficult to quantify because of the complexity of the proposed solutions, however we feel that there is ample opportunity to further explore through the capital replacement cycle technologies which could aid in the reduction of carbon emissions. Rough paybacks can be explored using the values in Table 3.2.1.

### 3.2.2 Wind Supply

Supplementing current coal-fired electricity supply with renewable wind generated electricity represents an avenue for significant carbon footprint reduction. For each kilowatt-hour (kWh) of coal fired electricity replaced by electricity from wind power, Purdue's carbon footprint will be reduced by 0.27 kg ("Clean Air Markets," 2005; "Electric Power Annual," 2006). In the fiscal year 2005-2006 Purdue purchased 153,510,279 kWh of electricity from off campus sources (Schuster, personal communication, January 2007), about 98% of which came from coal fired generation. This represents 45,761 TC emissions, or about 25% of the total Purdue footprint. Offsetting a portion of these emissions with wind-generated electricity would have a substantial impact on the carbon footprint.

With several wind studies underway and Purdue farms in locations with favorable conditions there is potential for the adoption of wind generation in the immediate future. It is proposed that Purdue develop one or more wind farms to generate wind electricity to eventually offset all external fossil fuel generated energy over the next 5 to 10 years. The amount of wind capacity required to do so is on the order of 80 MW at an operating capacity of 30% to accommodate any increases in demand. The carbon reduction associated with the production of 80 MW of wind generated electricity will be approximately 56,800 TC.

#### *3.2.2.1 Additional Benefits*

If wind farms are developed locally, on Purdue University land, substantial reductions in energy transmission losses could be achieved. Purdue-owned wind generation will also be a financially stable source of energy, not subject to market price fluctuations. The university would also be seen as an innovator in the use of wind energy, and the farm could be used to study and improve existing wind energy technology.

#### *3.2.2.2 Estimated Cost and Savings*

An 80 MW wind farm operating at 30% capacity could potentially produce 210,240,000 kWh/yr, at a capital cost of around $80 million. The capital cost for wind-generated electricity is approximately $1 million per MW (McGowan, 2000). In the fiscal year 2005-2006 Purdue paid a weighted average of $0.0440/kWh for electricity (Schuster, personal communication, January 2007). Taking into account a projected increase of 2% per year on average in the cost of electricity, the annual savings from investing in an 80 MW wind farm ranges from $9.25 million to $14.8 million.

#### *3.2.2.3 Estimated Payback Period*

Using the above cost and savings information, a discount rate of 6%, a useful life of 25 years, and operation and maintenance costs of 2% of the capital investment, a payback period of approximately 10 years with an internal rate of return of 12% is expected.

### 3.2.3 Solar Power

Supplementing coal-fired electricity supply with renewable photovoltaic electricity could also significantly reduce Purdue’s carbon footprint. In addition, electricity and heating demands can be reduced by utilizing incoming solar radiation to provide lighting and heat building materials, domestic water, and ventilation air.

Significant reductions in Purdue’s carbon emissions could be achieved by incorporating flat-plate photovoltaic arrays into Purdue’s electricity production infrastructure. In order to produce enough electricity to generate all of that which is purchased from off campus producers, a 120,164,571 Watt photovoltaic system would be required. This would reduce Purdue’s carbon footprint by 45,761 metric tons of carbon per year.

While it may be impractical to produce all of Purdue’s off-campus generated electricity in this manner, other technologies that utilize solar radiation could significantly reduce Purdue’s electricity demand and carbon footprint. Transpired air collectors collect solar energy and utilize it to preheat outside air for ventilation. These systems capture 80% of incoming solar radiation and can preheat intake air by as much as 40º F (“Solar Buildings,” 2006). Another option that utilizes solar radiation for heating purposes would involve the use of active solar water heating systems. A typical 120-gallon solar water heating system can provide 40%-70% of water heating requirements for six people, generating hot water equivalent of 2,500 kWh/year at a cost of about $.08/kWh ("Technology Options," 2005). Hybrid solar lighting technology, which captures and filters incoming solar radiation, is another technology that could reduce Purdue's electricity demand and carbon footprint. One of these systems powers eight hybrid light fixtures, illuminating over 1,000 square feet. One such system costs an average of $3,200 installed, and produces light at a cost of about $.074/kWh, with a cost recovery time of about 3-8 years (Muhs, 2000).

#### *3.2.3.1 Additional Benefits*

Solar-powered energy generation would locally generate needed electricity, significantly cutting down on transmission losses. This option is also not subject to market price fluctuations. Also, because Purdue is already researching solar power options, Purdue-owned solar generation systems can be used to further study and improve solar technology. Finally, technology that utilizes solar radiation has very low operating costs and maintenance requirements compared to other energy production options.

#### *3.2.3.2 Estimated Savings and Payback Periods*

Table 3.2.1 (next page) summarizes the estimated costs, savings, and payback periods for the various solar power options discussed above.

#### *3.2.3.3 Assumptions*

Some assumptions were made in calculating the above impact of solar energy on Purdue's carbon footprint. These were: Purdue University receives 3.5 hours of usable solar radiation per day with an average radiation density of 3,500 watts per square meter ("State Energy Alternatives," 2007), the average cost of installing a large-scale photovoltaic system is $4 per Watt ("Solar Energy," 2007), photovoltaic arrays have a working lifetime of 30 years, maintaining a photovoltaic system costs on average 0.1% of the initial capital investment per year (Moore, 2005).

### 3.2.4 Offsets

Institutions and individuals can also reduce their carbon footprints through the process of "offsetting." When an entity buys a carbon offset, they effectively pay for a reduction of carbon emissions in some other location, taking credit for that reduction toward their own carbon reduction goal. The reduction of carbon can be achieved in several ways, but a specific offset

| | |
|---|---|
| **Photovoltaics** | |
| Installed Capacity | 120 MW |
| Capital Investment (over 30 years) | $495 Million |
| Electricity Cost | $0.074/kWh (“A Performance Calculator,” 2007) |
| Avoided Carbon Emissions/year | 46,223 TC |
| **Solar Hot Water** | |
| Equivalent Energy Reduction (per 120 gallon system) | 2,500 kWh/year |
| Energy Cost | $0.08/kWh |
| Estimated Time to Recovery of Initial Investment | 4-10 years |
| **Hybrid Solar Lighting** | |
| Capital Investment/Hybrid Lighting System | 3,200/1,000 sq. ft. |
| Cost of Lighting 1,000 square feet | $0.074/kWh |
| Estimated Time to Recovery of Initial Investment | 3-8 years |
| **Transpired Air Collector** | |
| Capital Investment (per sq. ft. of floor size) | $1-7 (new construction)<br>$7-10 (retrofitting) |
| Operating Cost/ Maintenance Cost | $0/year |
| Estimated Time to Recovery of Initial Investment | 3-10 years |

**Table 3.2.3** Estimated costs, savings, and payback periods for solar energy

can be categorized as either a reduction in carbon emissions, or the sequestration of existing atmospheric carbon. A unique feature of offsets is their instantaneous nature. Purdue could in theory purchase enough offsets to compensate for a large portion or all of its carbon footprint immediately; however, this option would be expensive and not very sustainable. Carbon offsets are available for purchase from many different vendors, and are also available for purchase as a commodity on the open market through the Chicago Climate Exchange (CCX). There has been some controversy over the regulation and quality of various offsets on the market, some of which are less reliable than others in terms of ensuring long-term carbon reductions. Prices vary widely depending on the vendor and the nature of the offset, but the recent price for an offset ton of $CO_2$ emissions (equivalent to 0.27 metric tons of carbon) was approximately $3.70 on the CCX (“CCX,” 2007).

#### *3.2.4.1 Carbon Reduction*

Purdue does not have the capacity to sequester or “internally-offset” all of its carbon emissions, so it may consider purchasing carbon offset credits to externally offset them temporarily. While the larger carbon neutrality plan emphasizes actual emissions reductions at

Purdue through conservation and supply changes, buying offsets is another potentially cost effective way for Purdue to offset at least some of its emissions in the short term while other institutional and behavioral changes take effect.

#### *3.2.4.2 Additional Benefits*

An additional benefit of purchasing carbon offsets is providing monetary support for renewable energy projects, agricultural practices like no till farming, and other "climate friendly" activities. The monetary cost of purchasing credits at market price can thus serve as a mechanism to help make emissions reductions cheaper around the globe. In theory, Purdue could even create its own offsets by funding innovative technologies and businesses to develop new emissions reduction that are then marketed through CCX or other offset brokers.

#### *3.2.4.3 Estimated Cost*

The net cost/year is completely dependent on the market price of any offsets purchased, which prices currently range from \$3 to \$40 per ton of $CO_2$ or more.

### 3.2.5 Conclusions

Since energy production is responsible for the majority of Purdue's carbon footprint, it is also the sector in which the greatest cuts need to be made in order to make any sort of tangible reduction of carbon emissions. Wind energy will likely be the long-term replacement for a portion of Purdue's energy supply needs, but we would need 80 MW of wind power to decrease our footprint by 56,800 TC. Photovoltaics are another possibility for supply some energy, but more than 120 MW would be needed to reduce the footprint by 46,223 TC. Mixing biomass in with coal in existing boilers or using biomass as the sole source of energy could be both a short and long-term solution. We recommend using a combination of wind, photovoltaics, combustion of biomass and smaller-scale projects such as solar hot water, hybrid solar lighting, and transpired air collectors to reduce the university's dependence on coal for energy supply. In addition, capturing the emissions from the combustion of coal results in a carbon emission reduction of about 90% under ideal conditions, and could lower the on-campus energy sector's footprint to 10,300 TC. To achieve full neutrality in this sector, any remaining emissions could be offset through purchases from the Chicago Climate Exchange or another reliable vendor.

## 3.3 Institutional Consumption

The Institutional Consumption group focused on four strategies which we believe would be most effective at decreasing Purdue University's carbon footprint. These four strategies are retrocommissioning of existing buildings, implementation of Leadership in Energy and Environmental Design (LEED) standards, installation of geothermal heat pumps, and installation of green roofs. It should be stressed here that identification of the most cost-effective projects and strategies will only be possible after metering of electricity, steam, and chilled water is implemented throughout campus. Therefore, we also describe two necessary preliminary measures for the implementation of this management plan: metering and sub-metering campus buildings and the establishment of an administrative position to manage and optimize energy use on campus.

### 3.3.1 Preliminary Institutional Management Measures

The two preliminary measures we believe are necessary for the implementation of the rest of our management suggestions are the metering of all campus buildings and the establishment of an Energy Manager administrative position on campus. Management of any resource requires an understanding of how and where that resource is used. Currently, end-users of electricity, heating, and cooling at Purdue do not pay for their use of these resources, nor is there a good method of determining how much electricity, chilled water, or steam is used in any building. Metering and submetering campus buildings for electricity, chilled water, and steam is a necessary initial step for determining where energy is used and where energy conservation projects will be most beneficial. Effective management of energy use in an organization as large and complex as Purdue will also require the appointment of an Energy Manager, whose responsibility will be to oversee the optimization of energy use on campus. Currently, it is our understanding that no single individual is responsible for identifying and implementing energy conservation strategies, and no single person has the authority to investigate and implement changes to Purdue's physical facilities with the goal of increasing energy efficiency and decreasing energy consumption. Ideally, the Energy Manager should be assisted by an Energy Management Team composed of members from Engineering, Utilities, and Construction (EUC); Radiological Environmental Management (REM); and Buildings and Grounds (B&G).

#### *3.3.1.1 Benefits*

No direct monetary benefit or carbon reduction can be quantified for the implementation of these two strategies. However, the implementation of these two strategies seems essential to us if the University wishes to reduce its carbon footprint. Specifically, metering would allow departments to be billed for their energy use or given a credit for energy conservation below a baseline, which would encourage departments to conserve energy. The creation of an Energy Manager position will streamline the implementation of other innovative conservation projects.

#### *3.3.1.2 Costs*

The cost to implement metering of 90 buildings on the Texas A&M campus between 1995 and 1998 was approximately $1 million. The creation of an Energy Manager administrative position will incur the cost of the Manager's salary. However, it cannot be stressed enough that the ultimate utility of the strategies proposed in the remainder of this document cannot be determined without these two initial steps.

### 3.3.2 Retrocommissioning of Existing Buildings

Commissioning is the process of optimizing new buildings to ensure that all systems meet performance specifications, while retrocommissioning is the systematic process of optimizing existing building performance. Building processes which are traditionally addressed during commissioning and retrocommissioning are: heating, ventilation, and air conditioning (HVAC); lighting; steam; and chilled water (Thorne and Nadel, 2004). Most of the facilities on Purdue University's campus have never been commissioned or have had several additions which were not properly set in place with the building's main system. Elements of a retrocommissioning project can include insulation of steam pipes and valves; installation of variable air volume flow in HVAC equipment; replacement or calibration of controls, valves, and other equipment; optimization of settings on thermostats to prevent simultaneous heating and cooling; and the installation of heat recovery units.

#### *3.3.2.1 Carbon Reduction*

A typical retrocommissioning of an existing building yields between 10-20% energy use reduction. Retrocommissioning of the Physical Facilities Service Building (PFSB) on the Purdue University campus in 2002 produced a 24% reduction in natural gas use and a 16% reduction in electricity consumption compared to the previous year (2001-2002). However, retrocommissioning of older buildings like the PFSB usually produces more significant energy savings than retrocommissioning of newer buildings.

It is also worth nothing that the PFSB is very well metered for both electricity and natural gas. This metering allowed the PFSB staff who performed the retrocommissioning to target their optimization measures to achieve the aforementioned impressive reductions in energy consumption. The PFSB retrocommissioning project thereby demonstrates the benefit of metering and submetering of campus buildings with regards to energy conservation and the optimization of building systems.

If all the buildings on the Purdue campus were retrocommissioned, we estimate total on and off campus energy use would be reduced by approximately 15%, or 22,000 TC, thereby reducing Purdue's total carbon footprint by 12%. A far more exact estimate could be calculated for the Purdue campus if individual building metering were implemented.

#### *3.3.2.2 Additional Benefits*

Recent studies have shown that retrocommissioning results in significant energy savings, improved building performance, and reduced peak energy demand. The greatest investment return is usually seen on buildings larger than 100,000 square feet. In addition to energy savings, retrocommissioning has several external benefits which include extended equipment life; $CO_2$ emissions reduction; improved indoor air quality; reduced operating and maintenance costs; improved comfort and worker productivity; reduced chilled water, electricity, and steam peak demands; and a building staff more knowledgeable about operating building systems (Haasl, et. al., 2007).

#### *3.3.2.3 Estimated Net Costs and Payback Period*

A study of retrocommissioned buildings yielded an average project investment in the range of \$0.03 to \$0.43 per square foot, with an average of \$0.23/ft$^2$. In a study of 60 retrocommissioned commercial buildings conducted in 1996 by the Lawrence Berkeley National Laboratory, and in an alternate study in 1996 of 44 retrocommissioned buildings, the typical payback period for each building was less than 2 years (Thorne and Nadel, 2003).

### 3.3.3 Sustainable and Green Design with LEED

We suggest using a sustainable design approach that requires the use of lifecycle costing and LEED (Leadership in Energy and Environmental Design) for all new buildings and construction projects. Lifecycle costing, which would be included in new design proposals, is necessary to estimate not only the cost of physical building materials but also the energy consumption of the new building over its lifetime. Using lifecycle costing and LEED concepts, approval of all new construction designs would depend upon the design firm's demonstration of energy conservation and an emphasis on sustainable building and design principles. Such energy conservation and design principles would primarily come from the use of LEED guidelines.

#### *3.3.3.1 Carbon Reduction*

The reductions in energy and carbon are proportional; therefore the average decrease in emissions for new LEED buildings is the same as the average decrease in energy consumption, which is around 28%. Table 3.3.1 below shows the estimated reduction in energy use for each level of LEED certification (Kats, 2004).

| | *Certified* | *Silver* | *Gold* | *Average* |
|---|---|---|---|---|
| Energy Reduction | 8% | 30% | 37% | 28% |

**Table 3.3.1** Percentage energy reductions for new LEED buildings

#### *3.3.3.2 Additional Benefits*

Beyond the immediate and direct energy reductions that save money and carbon emissions, there are secondary benefits to LEED building. The holistic building approach LEED offers will lead to decreased maintenance from the highly efficient operations, and the sustainable design would help draw attention to Purdue's outstanding facilities and leadership.

#### *3.3.3.3 Estimated Net Costs and Payback Period*

The estimated costs for green buildings are dependent on how the reductions are to be achieved, but silver certified LEED buildings typically have a 1-3% premium, whereas platinum certified are closer to a 7-10% premium (Langdon, et. al., 2004). Using data from the most recent Purdue construction the payback of a platinum certified building is estimated to be about 25 years (see Table 3.3.2, next page).

### 3.3.4 Geothermal Heat Pump Systems

Geothermal (or ground source) heat pump systems provide heating, cooling, and pre-heated hot water year-round by exploiting the nearly constant temperature (about 50°F) of the ground below a depth of approximately four to six feet. Geothermal systems contain four primary components: underground pipes, a liquid heat exchanger medium, a heat pump unit (or

| | |
|---|---|
| Average Purdue Building Cost ($/GSF*) | 244 |
| Average LEED Premium (%) | 3% |
| Premium for LEED ($/GSF) | 7.32 |
| Typical Building Size (GSF) | 100,000 |
| Total Differential Cost for LEED ($) | 732,000 |
| Average Energy Cost ($/GSF) | 1.06 |
| LEED Energy Efficiency (%) | 28% |
| Average Energy Savings ($/GSF) | 0.30 |
| Total Energy Savings ($/year) | 29,540 |
| **Payback Period in Energy (years)** | **25** |

* $/GSF is dollars per Gross Square Foot

**Table 3.3.2** Average Cost and Payback of Green Building at Purdue

compressor), and an air delivery system. The ground is used both as a heat sink and a heat source. In the winter, heat is transferred from the earth to the building; in the summer, heat is transferred from the building to the earth. This heat transfer process also provides reduced-cost hot water. There are several configurations available for geothermal systems which allow them to be tailored to the needs of almost any existing building or new construction project ("Geothermal Heat Pumps," 2007; "Down to Earth Energy," 2007).

#### *3.3.4.1 Carbon Reduction*

Space heating and cooling account for almost 40% of the energy consumption in commercial and residential facilities ("1995 Commercial Delivered End-Use Energy," 2006). Geothermal heat pump systems save an average 25%-50% on energy consumption over traditional HVAC systems ("Geoexchange," 2003). Therefore, the installation of a geothermal system to supplement or replace a traditional HVAC system can save between 10% and 20% on the total energy consumption of the facility in which it is installed.

Purdue's carbon footprint for on- and off-campus energy (the energy used to power academic and residential facilities on campus) is 153,500 TC. A 10% savings in consumption of on- and off-campus energy would reduce Purdue's carbon footprint by 15,350 TC, while a 20% savings in consumption would reduce the footprint by 30,700 TC.

#### *3.3.4.2 Additional Benefits*

Besides the obvious financial savings which result from a reduction in energy consumption, geothermal heat pump systems offer the following benefits: they can simultaneously heat and cool different parts of the same building, are extremely quiet, provide greater freedom in building design because they require 50-80% less mechanical room space, have no outside equipment to hide, eliminating vandalism and roof top units, use pipes that have a 50-year life expectancy, reduce boiler and chiller maintenance, employ ground heat exchangers which are maintenance free and last 40+ years, are competitive on initial costs and lower lifecycle costs than most HVAC systems, lower peak demand, thereby lowering operating costs, provide water heated with waste heat from air conditioning at no cost in the summer and at substantial savings in the winter, are often eligible for rebates or incentives (“Incentives for Geoexchange Systems,” 2007), and are energy efficient, with the earth providing over 70% of the energy required to heat and cool (“1995 Commercial Delivered End-Use Energy,” 2006).

#### *3.3.4.3 Estimated Net Costs and Payback Period*

Only installation costs are significant. Maintenance costs will actually be less than on existing systems. Geothermal systems cost approximately $2,500 per ton of cooling capacity (“Geothermal Heat Pumps,” 2007).

The typical payback periods for geothermal systems are between 2 and 10 years (“Geothermal Heat Pumps,” 2007). With low maintenance and a 40+ year life expectancy for the ground heat exchanger and typical 50-year life expectancies for pipes, almost all energy savings are immediately available to pay back the initial investment.

### 3.3.5 Green Roofs

Green Roof (GR) Systems are a vegetated cover placed on top of a roof. They range from a mossy vegetation on a growing medium (extensive GR) to full scale gardens, meadows or trees on specialized structures on the tops of buildings (intensive GR). Extensive GR can be retrofitted to any roof which has been resurfaced in the last 5 years. Designs for intensive GR need to be incorporated to building plans so that the structure is adequate for the added weight of the soil and its water retaining capacity. GR are typically installed on flat roofs but can be put on roofs with up to a 30° slope. GR are composed of waterproofing, root barrier, drainage mat, water retention fleece, planting substrate, and vegetative material (“Simply. Smarter.,” 2007).

#### *3.3.5.1 Carbon Reduction*

Typical roofs have to be replaced every 15 to 20 years, and Purdue University has many buildings which would lend themselves to installing GR. The cooling demand for the university in the fiscal year 2005-2006 was 84,012,746 Ton-hrs, and the demand for the months of April through September was 62.1% of the total. Studies of green roofs have demonstrated a 75% reduction in energy demand during the spring and summer season for a one story building (Liu, 2002). We assume that campus buildings have on average 4 floors, and that only the top floor would experience a 75% energy demand reduction, so we multiplied by a building fraction of 1/4.

$$84{,}012{,}746\ tonhrs \times \frac{12{,}000\ Btu}{1\ tonhr} \times \frac{1\ kWh}{3413\ Btu} \times 0.621 \times \frac{1}{4} \times 0.75 = 34{,}394{,}000\ \frac{kWh}{yr}$$

**Equation 3.3.1** Energy savings from implementation of green roofs

This translates to a carbon reduction of 8,321 TC/yr, or a reduction in the total energy demand for campus of 11.6%. This calculation does not take into account any growth of campus or the fact that some roofs are not flat and thus costs of installing a GR would be increased and may not be practical or desirable.

#### *3.3.5.2 Additional Benefits*

Green Roof systems are aesthetically pleasing. They lengthen roof lives two to three times because the roof membrane itself does not experience large temperature fluctuations and is not exposed to the elements. GR systems also reduce nitrogen runoff by filtering the water that goes through them, lessen the loads of water treatment plants, reduce air pollution, reduce sound transmission by up to 40dB, and enhance property values (Berkshire, 2005). Most importantly they have been shown to lessen rainfall runoff impacts and increase thermal efficiency. Experiments led by VanWoert *et al.* (2005) showed that vegetated roofs retained 82.8% water on average compared to 48.7% for gravel roofs. Similarly, the widespread use of GR has been hypothesized to reduce the urban heat island effect due to the vegetation's low solar absorbance and insulation properties (Saiz, et. al., 2006). In the warmer months of the year, more heat is absorbed while shading is provided for a building on which a GR is installed. Not only do GR decrease cooling needs of the top floor of a building by more than 75% during the spring and summer months, they also somewhat decrease heating needs during the fall and winter since they act as an insulator (Liu, 2002).

#### *3.3.5.3 Estimated Net Costs and Payback Period*

GR systems have higher installation costs than a typical roof but last two to three times longer. Price quotes range from \$8 to \$25 per square foot for extensive GR and \$40 and up for intensive GR. However, if large enough roofs are installed the cost can be much less. The Ford Motor Company River Rouge Plant GR in Dearborn, MI, for example, cost around \$4/sq. ft. for a 500,000 square foot roof ("Simply. Smarter.," 2007). At Purdue's West Lafayette campus, the total GSF of buildings which have air conditioning is 10,872,243 GSF, so that the cost for installing GR on all of them would range from $43 to $87 million.

The percent annual return for GR systems ranged from 1.7 to 3.4%. This number only includes savings from energy use reduction, and not the fact that roofs would need to be replaced 2-3 times less often.

### 3.3.6 Conclusion

The institutional management options listed herein offer the potential to reduce Purdue's total carbon footprint by up to 50 percent if fully implemented. They carry costs ranging from approximately one hundred thousand dollars (for the creation of the Energy Management position) to tens of millions of dollars (for campus-wide implementation of retro-commissioning, LEED standards, geothermal heat pumps, or green roofs).

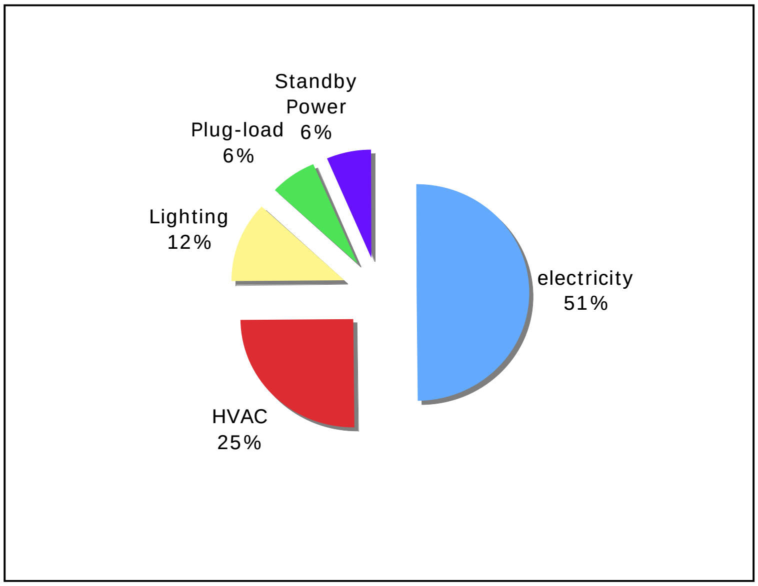
Although the two preliminary measures (creation of an Energy Manager position and metering of all campus buildings) do not provide direct reductions in carbon emissions, they are absolutely critical to proper energy management at Purdue University. Metering and sub-metering of campus buildings would allow for thorough monitoring of energy use on campus, thereby providing the information necessary to develop targeted energy conservation programs. The Energy Manager, with authority to develop and implement such programs, would supply oversight and accountability, streamlining the implementation process to more quickly and economically reduce Purdue's carbon footprint.

## 3.4 Individual Consumption

In order for any carbon reduction plan to be successful, the responsibility must be partly vested in the individuals of the Purdue community. The general goal of this part of the management plan is to propose viable options for achieving energy conservation at the individual level. A more specific aim is to suggest plans that will be relatively inexpensive and therefore cost efficient for Purdue to implement. Because the majority of the footprint is calculated for the construction of buildings, heating/cooling, and other activities that may not necessarily be specifically contributed to the individual, it is fairly difficult to estimate the specific carbon reduction that can result from individual behavior modification. Nevertheless, we do expect that if people were held accountable for their actions and were aware of all the different ways they were able to make a difference; their individual reduction will be significant. Our management plan was developed with an aim of changing individual consumption behaviors in three major aspects: *lab and electronic devices, transportation, and heating/cooling***.**

### 3.4.1 Electrical Devices and Standby Power

Purdue faculties, staff, and students use a great deal of energy in labs and by using various types of electronic devices. A large proportion of this energy is used in a very wasteful way, through appliances that are in "Standby Mode". Standby power refers to power that is used when an electrical device is in its lowest mode ("Things That Go Blip," 2001). On average, standby electrical devices (of TVs, computers, rice cookers, micro-ovens etc.) will correspond to 5-26% of the homes' annual electricity use (Ross and Mier, 2000). Therefore, managing individual consumption behaviors in using electrical devices and standby powers would contribute to a fairly significant reduction in Purdue's carbon footprint. Our major management goals are to reduce unnecessary energy use through lighting, plug-load as well as various standby electrical devices. As Figure 3.4.1 (next page) shows, our major management goal will target 75% of Purdue's energy consumption.



"electricity" refers to electrical devices other than lights in various buildings.
**Figure 3.4.1** Percentage of Purdue's Energy Use

### 3.4.2 "Turn it off" Campaign

A "Turn it Off" campaign would involve large instructional, informational, and educational efforts to teach faculty, staff, and students to be as energy efficient as possible, culminating in one day when everyone is encourage to shut all electronic devices off when not in use. A follow-up campaign would begin after this designated "Turn It Off Day" to highlight the amount of energy saved during this day compared to an average day. The goal of this campaign will be to encourage people to continue the activities of "Turn it Off" day throughout the entire year.

#### *3.4.2.1 Carbon Reduction*

The specific value of carbon reduction per year is contingent upon how many people would be involved in this activity, how long people will turn off their un-used electrical devices, and unplug their stand-by powered devices. In order to estimate the optimal results in individual energy conservation, we assumed that all Purdue students, faculty and staff would be involved (roughly 50,000 people). It is also known that the GSF of the Purdue campus is 14 million, with an average energy cost per GSF per year of $1.055. 6.25% of this energy is used for plug load, and another 6.25% is used for standby powers (vampire equipment).

1. *Savings in Standby Powers and Plug Loads (100% reduction is achievable)*

If we assume that all people turn off their standby powers and disconnect their plugs throughout the entire year:

***Total Annual Savings in Energy*** =

$$\$1.055 / GSF / yr \bullet (0.0625 + 0.0625) \bullet 14{,}000{,}000 GSF = \$1{,}846{,}250 / yr$$

***Per Capita Annual Savings*** = $\$1{,}846{,}250 / yr \div 50{,}000 = \$36.925 / yr$

***Total Savings in One Day*** = $\$1{,}846{,}250 / yr \div 365 days / yr = \$5{,}058 / day$

***Per Capita Savings in One Day*** = $\$36.925 / yr \div 365 days / yr = \$.101 / day$

2. *Reducing Energy Use in Lighting and Other Electrical Devices*

Assuming that all people try to reduce 10% of the energy use in lighting and electrical devices:

***Total Annual Savings =***

$$\$1.055 / GFS / yr \times (.12 + .50) \times 10\% \times 14{,}000{,}000 \, GFS = \$915{,}740$$

Taking a more ambitious goal, if all Purdue employees and students could reduce 20% of the energy use in lighting and electrical devices, then the total annual savings will be $1,831,480, and per capita annual savings will be $36.62/yr.

Based on the assumptions mentioned above, the optimal result will be to reduce 18-24% of Purdue's energy consumption. Given that Purdue's energy consumption (on-campus/off campus) accounts about 80% of Purdue's carbon footprint, the optimal results in reducing energy use through electrical devices and standby powers could reduce 14.4-19.2% of Purdue's carbon emissions.

The real effect of carbon reduction will be contingent upon how many people in Purdue would be involved to change their behaviors in using electrical devices. Table 3.4.1 project possible scenarios with assumptions about how many people will change their behaviors.

| Number of People Involved | Energy Savings ($) | % of Purdue's Footprint |
|---|---|---|
| 1 | 75.002 | 0.0384 |
| 500 | 37515.8 | 0.192 |
| 5,000 | 375158 | 1.92 |
| 10,000 | 750316 | 3.84 |
| 25,000 | 1875790 | 9.60 |
| 50,000 | 3751580 | 19.2 |

**Table 3.4.1** Possible Participation and Reduction Scenarios

### *3.4.2.2 Estimated Net Costs*

A majority of the cost for this management plan is designated as funds for various activities in making information packets or pamphlets, advertising and educational projects. Table 3.4.2 (next page) shows the estimated cost for information campaign proposals

| ***Information Campaign & Educational Programs*** | ***Estimated Cost[8] (with examples)*** |
|---|---|
| Creating a Purdue Energy Management webpage | Web-design cost: $ 500/*yr*<br>Regular Maintain Cost:[9] ($15/hour)(3 hour/day)(365 day/year) = $16,425 per year |
| "Turn-it-off" Pamphlets/ Information packets and Posters (1,000 brochures+ 200 posters) | 1) Brochure (11 x 17, 80# Gloss Cover stock, full color, 2-sided) Qty 1,000= $505<br>2) Posters (sample size: 11 x 17, 80# Gloss Text, bleeds, trim.<br>Qty 150=$150, Qty 200=$180)<br>Total cost 1000 brochures+ 200 posters= $ 685 per year |
| Advertising on Exponent | Weekly Frequency Contract, Classified colorful 63-inch column display.<br>($8.19/inch)(63 inches/display)(52 displays/year) = $26,830.44 per year |
| Email Information Campaign[10] | Paid<br>($15/hour)(1 hour/week)(52 weeks/year) = $780 per year |
| Setting Special Funding for Relevant Student Clubs for information campaign | Proposal of $2,000 |
| **Total Estimated Cost =** $ 21,452 **(**Web-cite design and maintain) +$ 685 (Brochure and Pamphlets) + $ 26830.44 (Newspaper Advertisement) + $ 780 (Email Flyer) +$2,000 student club fund = **$ 51,747.44** | |

**Table 3.4.2** Estimated cost of energy information campaign

### *3.4.2.3 Additional Benefits and Estimated Payback Period*

As estimated in the previous section, if one Purdue student could try to unplug all standby powers and reduce 20% his/her own regular energy use in lighting and electrical devices in one year, the annual energy savings for that individual would be about $75. Thus, the cost for all proposed information/education activity is approximately equal to the savings from only 700 people at Purdue reducing their individual energy consumption consistently throughout a given year (see Figure 3.4.2, next page).

## 3.4.3 Transportation: Reduction of Student Commuting

Most Purdue students and faculty do not realize the amount of money they spend on transportation each year. In order to reduce the amount of carbon emitted from personal transportation, we suggest a university-wide information campaign. If we inform students, faculty, and staff, about the money they spend on transportation every year, they may have a greater desire to reduce their transportation carbon footprint. Using the assumptions from the transportation footprint section, the average vehicle gets 23.31 MPG, and the average Purdue

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[8] Cost for web-design, brochure printing is based on Purdue printing, Cost for campus wide advertisement is estimated based on ***Exponen***t advertisement rate. "Advertising Rates," *The Exponent.* <http://www.purdueexponent.org/?module=leftside&target=adRates> (2 May 2007).

[9] We assume that 3 hours/day is necessary for regular website maintain and update, the estimated cost for hiring student assistant to maintain the website will be $15/ hour.

[10] Assume that email flyer will be arranged weekly, updating about Purdue energy information as well as advertising the ideas about turning off un-used electronic devices. We assume that 1 hour/ week is necessary. The cost is also estimated based on labor-cost of student assistant.

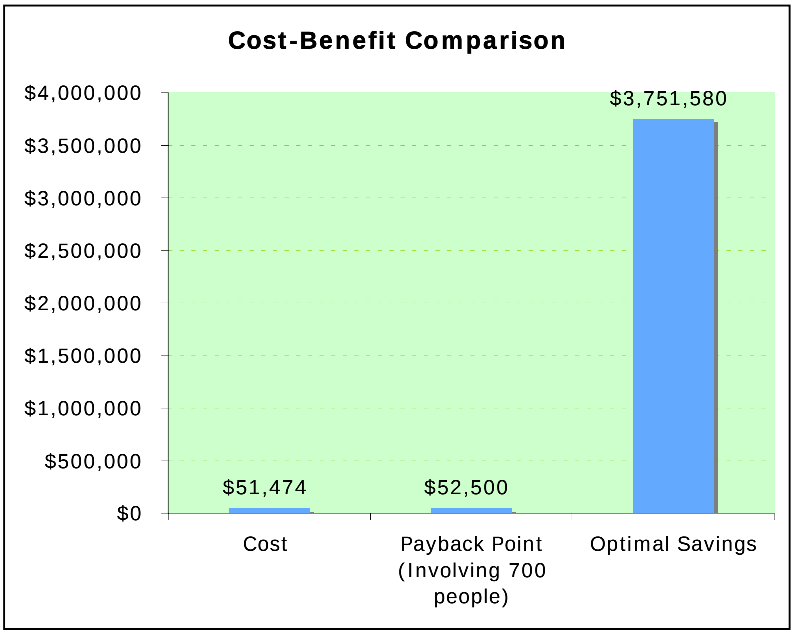

**Figure 3.4.2** Cost-Benefit Comparison of "Turn it Off" campaign

commuter drives 24.00 miles in a day, 6 days a week for 34 weeks of classes. Using an average of $2.70/gallon, the estimated price for gas is $567.10 per year.

### *3.4.3.1 Carbon Reduction*

According to the transportation footprint, the average amount of carbon emitted/year from commuting is approximately 5100 TC. If individuals at Purdue could reduce transportation by a combined 10% in two years, this would be a 255 TC/yr reduction.

### *3.4.3.2 Additional Benefits*

Less campus commuting will save students and faculty money. In addition to the money saved from reducing gasoline purchasing, one will save extra by not needing a parking pass ($80/C pass, $200/A pass), avoiding unnecessary tire wear, oil changes, and car mileage, which negatively affects the dollar value of the personal vehicle. Faculty and staff can use local transit to get to the downtown train station eliminating the cost of fuel and parking. Also, one is able to do work the entire trip on a train without any electronic device restrictions. Biking and walking is always a great option for those who live close enough to do so. Not only does it lead to a decrease in Purdue's footprint but also is a great source of exercise.

### *3.4.3.3 Estimated Net Costs*

The university itself would not need to contribute to costs needed to reduce the carbon footprint due to commuting. We would like to suggest that campus-wide organizations can donate money for advertisement in newspapers, fliers in freshmen packets, webmaster, email distributions, etc. These organizations could include the Purdue Climate Change Research Center, Greek fraternities and sororities, the Purdue University Meteorological Association, etc. Some of these organizations have outreach and education as part of their mission, and would therefore be willing to contribute to the costs of educating students and faculty

### 3.4.4 Heating and Cooling: Meter Installation

Our suggestion is for Purdue to install electronic monitors that would make the university capable of monitoring the usage of energy in each building on the Purdue University Campus, as noted in the previous section on institutional management. In addition, these meters could also enable individuals to view their personal energy consumption through additional monitors inside the buildings. It has been shown that individuals curb their usage when they can monitor their own energy consumption. These monitors would be placed within all academic buildings on Purdue's West Lafayette campus, as well as all graduate and undergraduate residence halls. This would give individuals who work or live within these areas an easy way to check their collective and personal usage.

Since these individuals do not pay for their individual amount of energy consumption, it could be assumed that they will use these meters to monitor their usage but not necessarily make any behavioral changes. Therefore in order to achieve a reduction in consumption, there will need to be incentive-based programs set up to make individuals accountable for their personal usage. These programs can include university competitions between dormitories or academic buildings resulting in a prize for the buildings with the largest reduction in energy use. These prizes could include a variety of options. A few suggestions are: bookstore vouchers (redeemable at local bookstores for the purchase of textbooks), pizza parties (for all individuals living in the same dormitory), and food vouchers (for local and on-campus restaurants). Another suggestion could be an agreement by the university that if campus consumption (or consumption within individual dormitories) decreases, then there will be a reduction in the cost of the "student activity fee" for the students involved in the decrease.

#### *3.4.4.1 Carbon Reduction*

Studies that have been conducted on meter installation and personal consumption have shown that consumption can be reduced by up to 11% with meter installation (King and Delurey, 2005; Siegel, 2007; "Energy Consumption Review," 2007). Although these studies accounted for meter installation in homes and buildings where individuals pay for their personal consumption, we feel that it is still possible that this reduction could be met by other means of accountability (such as the programs suggested earlier). Assuming total compliance with this program, Purdue can estimate that it would achieve a reduction that is approximately equivalent to 16,629 TC per year.

$$11\% \ast [103{,}165 \text{ TC (on-campus footprint)} + 48{,}008 \text{ (off-campus footprint)}] = 16{,}629.03 \text{ TC}$$

*3.4.4.2 Additional Benefits*

The university would save approximately \$2,276,844.66 if these meters are installed and compliance reaches 11%, based on the calculation below:[11]

$$11\% \ast \text{ on campus electricity } (3{,}426{,}000\text{MmBtu}) \ast (\$2.452/\text{MmBtu}) = \$924{,}060.720$$

$$11\% \ast \text{ off campus electricity } (153{,}510{,}279 \text{ kWh}) \ast \$\frac{(0.0702)}{2} = \$1{,}185{,}406.37$$

$$11\% \ast \text{ off campus natural gas } (145{,}876 \text{ Dth}) \ast \$\frac{(9.87)}{2} = \$158{,}377.57$$

Total Avoided Energy Costs: \$2,276,844.66

*3.4.4.3 Estimated Net Costs*

The cost for installing meters in each building would vary depending on the system installed. If meters were installed to be read manually the estimated cost would be \$5,000 per building (Schuster, 2007). If electronic meters were installed with the capability of connecting them to a website, allowing individuals to view personal consumption online, this would cost the university approximately \$15,000 per building (Schuster, 2007). While this may be a significantly more costly program, it is significantly more convenient for individuals, and would therefore lead to higher compliance and more monetary savings on the supply side. The total cost of both of these installation programs varies depending on which buildings the university chooses for meter installation. If limited to academic buildings and university residence halls, the cost will be approximately \$470,000 for the manually read meters and \$ 1,410,000 for the electronically read meters.[12]

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[11] The amount \$.0702 was the average for the given electricity cost per kWh (residential and commercial) in Indiana. “Average Retail Price of Electricity to Ultimate Customers by End-Use Sector, by State,” *Energy Information Administration.* 2007. <http://www.eia.doe.gov/cneaf/electricity/epm/table5_6_a.html> (2 May 2007).

The amount \$9.87 was the average for the given costs of natural gas per Dth (hedged and unhedged) provided by personal communication with Physical Facilities at Purdue University

[12] Accounting only for 94 buildings in total (not including Hilltop Apartments or Purdue Village

#### *3.4.4.4 Estimated Payback Period*

Assuming 11% reduction in personal consumption, Purdue would be able to pay off this installation program within the first year. Since the installation is a one time fee, with the assumption of relatively low maintenance fees, the university would save approximately $2,000,000 each year.

### 3.4.5 Conclusion

The suggested management plans given above are aimed specifically at changing individual behavior in ways that would lead to further reduction in personal consumption and therefore a decrease in Purdue's carbon footprint. The success of each plan is dependent upon the number of individuals that choose to participate. If each suggestion is implemented to the extent described above, Purdue's carbon footprint would decrease by approximately 47,874 TC in one year. This figure assumes that the total reductions from transportation (255 TC) and heating/cooling (16,629) sections, and the averaged goal (16.8% totaling: 30,990) of the electrical devices section, are met.

## 3.5 Management Conclusion

The previous three sections outline what we consider to be a diverse array of viable options for the reduction of Purdue University's carbon impact. To realize the goal of complete carbon neutrality at this institution, management options from all three sectors will be required. Although true carbon neutrality is an ambitious goal, we believe it to be a worthy and attainable one for the University, particularly given its international reputation in the areas of science, engineering, and technology. The ambitious scope of such an objective requires a measured approach, however, and the implementation of a plan with manageable incremental and intermediate goals is essential for success. The options outlined in this document present an opportunity to reduce Purdue's carbon footprint over a range of timescales and with varying levels of emissions reduction, thereby facilitating movement toward carbon neutrality at a variety of possible speeds and initial costs. Although the options presented herein are certainly not the only solutions open to the University, we believe that they represent an excellent menu of ideas for providing the greatest reduction in carbon emissions for Purdue University as well as a host of additional benefits in the most efficient manner possible.

## 4. Conclusion

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After an intensive semester of research, we believe that one of our most valuable contributions to carbon neutrality at Purdue is the development of methods for calculating the university's carbon footprint. Our methods can be used again in the future to track changes in the university's total carbon emissions. We have provided a model and a baseline for future students and faculty to build upon. Also, other universities may be interested in using our calculation methods to create their own campus footprints. Most of all, we are pleased to have put the concept of carbon neutrality on the Purdue map. We believe we have sparked the interest of campus administration, faculty, students, and the surrounding community. Although these initial efforts are exciting, we see nothing but room for improvement and expansion of our initiative in the future. Our class is just a first step in what we hope will be a long and collaborative working relationship between university administrators, faculty, and students. We believe that there is real support for this type of initiative, from a broad range of academic disciplines and areas at Purdue University.

# 5. Appendices

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## 5.1 Appendix A – Off-Campus Energy

### A-1. Calculation of the efficiency of Indiana's coal-fired power plants.

Since Duke Energy is Purdue University's primary outside energy provider, an attempt was made to obtain the efficiency rate of one of Duke Energy's average base-load carbon burning power plants directly from Duke Corporation. However, Duke Energy was not forthcoming with this information for homeland security reasons and another method of estimating this efficiency factor was developed. According to the Energy Information Administration's 2005 Annual Electric Power report, the amount of coal entering Indiana's coal-fired power sector is known (54,440,800 metric tons), as well as the actual output of electricity ($1.228*10^{11}$ kWh) ("Electric Power Annual," 2006). Since the amount of coal entering the system is known, a theoretical output based upon 100% efficiency can be calculated:

$$\frac{22.3506\ \mathit{million\ Btu}}{\mathit{metric\,ton\ \ Coal}} * \frac{54{,}440{,}800\ \ \mathit{metric\,tons\ \ Coal}}{\mathit{year}} * \frac{10^6\ \ \mathit{Btu}}{1\,\mathit{million\,Btu}} * \frac{1\,kWh}{3412\,Btu} = 3.566x10^{11}\ \frac{kWh}{year}$$

**Equation 5.1.1** Theoretical power output

Using the actual output (W) and the theoretical output ($Q_h$), the average efficiency of Indiana's coal fired power sector can be calculated:

$$\text{Efficiency}\,(\eta) = \frac{W}{Q_h} \ = \frac{122.8\mathit{billion\,kWh}}{356.6\mathit{billion\,kWh}} = 34.4\%$$

**Equation 5.1.2** Efficiency of Indiana's coal power sector

This efficiency value is very close to the national average of 32.7%, and is within the range of 30 to 35% efficiency for most coal-fired power plants.

### A-2. Thermodynamic calculations of the natural gas carbon footprint.

The second method of calculating the carbon footprint of natural gas usage involved calculating the carbon intensities of its constituent gases. Natural gas is made of up approximately 92.5% methane, 3.3% ethane, 2.9% nitrogen (which is assumed to be inert), 1.0% propane, and 0.3% butane. The combustion of these gasses is assumed to be complete and to take place in the presence of pure diatomic oxygen. The following balanced chemical equations (next page) represent the combustion of the constituent gases:

Methane:
$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O + Q_M$

Ethane
$2C_2H_6 + 5O_2 \rightarrow 2CO_2 + 6H_2O + Q_E$

Propane
$C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O + Q_P$

Butane
$2C_4H_{10} + 13O_2 \rightarrow 8CO_2 + 10H_2O + Q_B$

The "Q" term in each equation represents the amount of heat that is produced by burning one mol of the respective hydrocarbon, commonly referred to as the heat of combustion. This value can be determined using the enthalpy of formation (a measure of how much energy is embodied in a molecule) of the molecules involved in the combustion and an energy balance. The following table contains the enthalpy of formation values for each of the constituent gases and molecules involved in the combustion reaction (Moran and Shapiro, 2003).

| **Component** | **Enthalpy of Formation (J/mol)** | **Component** | **Enthalpy of Formation (J/mol)** |
|---|---|---|---|
| Methane | -74,850 | Carbon Dioxide | -393,520 |
| Ethane | -84,680 | Water Vapor | -241,820 |
| Propane | -103,850 | Oxygen | 0 |
| Butane | 126,150 | | |

**Table 5.1.1.** Enthalpy of formation for natural gas constituents

The heat of combustion, H$_c$, can be calculated using the balanced chemical equation and the enthalpy of formation. The following is an example of this calculation for methane.

$$\Delta H_C = \sum H_{F\,\mathrm{Products}} - \sum H_{F\,\mathrm{Reactants}}$$
$$\Delta H_C = Q_M = 2H_{H2O} + H_{CO2} - \left(H_{CH4} + 2H_{O2}\right)$$
$$Q_M = 2(-241{,}820) + (-393{,}520) - (-74{,}850 + 2(0)) = -802{,}310\ J/mol\,CH_4$$

**Equation 5.1.3** Calculation of the heat of combustion of methane

The coefficients of each term are determined from the balanced chemical equation. The value obtained represents the amount of heat obtained from burning one mole of methane. The process was applied to each of the other gases to determine their respective heats of combustion. For those gases whose hydrocarbon coefficient is not one, the heat of combustion obtained was divided by the hydrocarbon coefficient to convert the heat of combustion value to a per mole basis. Table 5.1.2 (next page) shows the results of these calculations.

| Constituent Gas | Heat of Combustion (J/mol hydrocarbon) |
|---|---|
| Methane | -802,310 |
| Ethane | -1,034,300 |
| Propane | -2,043,990 |
| Butane | -2,657,030 |

**Table 5.1.2** Heat of combustion for natural gas constituents

The heat of combustion was used to determine the carbon intensity, CI, of the gases by converting from moles of hydrocarbon to moles of carbon dioxide and then from a molar to a mass basis. The following is an example of the conversion for methane.

$$\frac{1}{CI_M} = \left|-802{,}310\right| \frac{J}{mol\,CH_4} * \frac{1\,mol\,CH_4}{1\,mol\,CO_2} * \frac{1\,mol\,CO_2}{44.01\,g\,CO_2} * \frac{44.01\,g\,CO_2}{12.01\,g\,C} * \frac{1000\,g}{1\,kg} = 6.68 * 10^7\ J/kg\,C$$

$$CI_M = 1.50 * 10^{-8}\ kg\,C/J$$

**Equation 5.1.4** Determination of carbon intensity

For comparison with the values obtained from MacDonald the CI value was converted into units of kg C/GJ.

$$CI_M = 1.50 * 10^{-8}\ \frac{kg\,C}{J} * \frac{10^9\,J}{1\,GJ} = 15.0\ kg\,C/GJ$$

**Equation 5.1.5** Conversion of carbon intensity to kg C/GJ

In order to determine its relative impact in natural gas this value was multiplied by the percent composition of methane in natural gas.

$$CI_M = 15.0\ kg\,C/GJ * 92.5\% = 13.9\ kg\,C/GJ$$

**Equation 5.1.6** Methane contribution to carbon intensity

At 13.9 kg C per giga-joule this value verified the value obtained from literature. Applying this process to each other gas allowed the determination of the total CI of natural gas. Table 3 shows the results of those calculations.

| Constituent Gas | CI (kg C/GJ) | Percent Composition in Natural Gas | Relative CI (kg C/GJ) |
|---|---|---|---|
| Methane | 15.0 | 92.5% | 13.9 |
| Ethane | 11.6 | 3.3% | 0.38 |
| Propane | 17.6 | 1.0% | 0.18 |
| Butane | 18.1 | 0.3% | 0.05 |
|  |  | **Total Impact:** | **14.5** |

**Table 5.1.3** Relative impact of natural gas constituents on carbon intensity

By including the additional components, a CI value of 14.5 kg C/GJ of natural gas combusted was obtained. Using this value in conjunction with the data obtained from Purdue produces a carbon footprint of 2,225,668 kg C/yr with respect to natural gas combustion. The addition of pipeline losses results in a total footprint of 2,348,794 kg C/yr or 2,348.79 T C/year, a

4.5% increase over the footprint calculated with the literature value.

The greatest uncertainty in these calculations comes from the assumption of complete combustion. By assuming complete combustion with pure oxygen some other products of combustion, such as carbon monoxide and nitrogen oxides, have been neglected. The result of this assumption may be a slightly higher CI value than if those products were included. The error associated with these calculations is difficult to calculate but also very small in magnitude due to the high accuracy of the data for Purdue natural gas use. Uncertainty associated with direct burning of natural gas is assumed to be approximately ±1%. Also, uncertainty in how much natural gas is actually lost in transmission is taken to be ±1%. The total error associated with the natural gas carbon footprint therefore ±2%. This value represents, in our opinion, a conservative estimate of the error associated with these calculations.

## 5.2 Appendix B – Transportation

### B-1. Survey Methodology

The survey was conducted with the goal of obtaining 0.5-1% of the total population of faculty, staff and students at Purdue University. In total, excluding the surveys that were highly incomplete or unreadable, we surveyed 35 faculty (including deans and department heads), 44 staff, 32 graduate students and 140 undergraduate students, which corresponds to 1.22% of the faculty, 0.57% of the staff, 0.71% of the graduate students, and 0.36% of the undergraduates in 2005. The survey had three parts – commuter travel (for faculty, staff and students); research and business trips (for faculty, staff and graduate students); and university organization-based travel (for undergraduate students).

We administered the survey across campus over the course of a week by breaking the campus up into 5 sectors and assigning people to those sectors. Students were only surveyed if they drove to campus or traveled as part of a university organization. Very few people (<10) refused to take the survey so that we feel confident no bias was introduced in this manner. A previous survey of transportation choices of Purdue students completed in 2005 reported that students drove on average 8.6 miles per day to and from campus (Torgnyson, 2005). Our survey reveals a similar pattern in that we found that students, faculty and staff drove on average 9.0 miles per day.

Our survey questions are shown below:

*Commuter travel*

1. Are you a faculty, staff, 1st year student, other undergraduate student, or graduate student?
2. Do you have a parking permit? If yes, which one? (A, B, C lot, C garage, Other)
3. On average, how many miles do you drive per day round trip to campus?
4. How many days a week, and weeks per year do you drive to campus?
5. Are you alone in the vehicle? If no, how many people ride with you?
6. What fuel economy do you get on average? What type of fuel? (gas, diesel, E85, etc.)

*Only for faculty, staff and grad students (reimbursed research and business travel)*

1. Estimate the number of trips (1 trip = roundtrip) you drove with your personal car for the year 2005 within the following distances from Purdue:
    a. Within 25 miles
    b. 26-120 miles
    c. 121-200 miles
    d. 201-300 miles
    e. 301-400 miles
    f. 401-500 miles
2. Estimate the number of trips you drove with a Purdue vehicle for the same distance

categories.

3. Estimate how many trips you took on a commercial airline for each of the following categories:
    a. Domestic flights (i.e. within the U.S., Canada and Mexico)
    b. Transatlantic flights (i.e. to Europe) or to South America
    c. Transpacific flights (i.e. to Asia, Australia) or to Africa

*Only for undergraduate students (club travel)*

The same questions and categories as for faculty, staff, and grad students.

## B-2. Parking Permit Standard Deviation Calculations

$$s_y = y * \sqrt{\left(\frac{s_a}{a}\right)^2 + \left(\frac{s_b}{b}\right)^2 + \left(\frac{s_c}{c}\right)^2}$$

$$= 3509 * \sqrt{\left(\frac{12.43}{14.02}\right)^2 + \left(\frac{0.93}{4.99}\right)^2 + \left(\frac{10.59}{48.32}\right)^2} = 3270\,TC$$

**Equation 5.2.1** Absolute error of A permit calculation. “s” is the standard deviation of the value “a”, “b” or “c”. “y” is the total value for which the total standard deviation is being calculated for.

| Permit | St. dev. (mi/day) | St. dev. (days/wk) | St. dev. (wks/yr) | St. dev. (mpg) | Relative error ($s_y$/y) | Absolute error ($s_y$ [TC]) |
|---|---|---|---|---|---|---|
| A | 12.43 | 0.93 | 10.59 | 5.38 | 0.93 | 3270 |
| B | 1.41 | 2.31 | 2.83 | 5.38 | 0.48 | 219 |
| C | 14.25 | 1.00 | 9.02 | 5.38 | 1.19 | 1502 |
| | | | | | **Total** | **3605** |

**Table 5.2.1** Standard deviations for commuter footprint calculations

## B-3. University-Reimbursed Travel Calculations

| | 2004-2005 | 2005-2006 | Average (2005) |
|---|---|---|---|
| Money Reimbursed ($) | 2,244,800 | 2,2640,530 | 2,442,670 |
| Fare Constant ($/mi) | 0.129 | 0.129 | 0.129 |
| Miles Flown (mi) | 17,401,550 | 20,469,220 | 18,935,390 |
| Mileage Constant (mpg) | 0.3 | 0.3 | 0.3 |
| Gallons of Fuel (gal) | 58,005,166 | 68,230,733 | 63,117,966 |
| Carbon Constant per Gallon (kg C/gal) | 2.61 | 2.61 | 2.61 |
| Carbon Emission per Flight (TC) | 151,393 | 178,082 | 164,738 |
| **Total Carbon Emission for Purdue (TC)** | 977 | 1149 | **1063** |

**Table 5.2.2** University-reimbursed travel on domestic flights in the years 2004-05, 2005-06, and the average to represent the 2005 calendar year

| | 2004-2005 | 2005-2006 | Average (2005) |
|---|---|---|---|
| Money Reimbursed ($) | 1,295,990 | 1,739,340 | 1,517,663 |
| Fare Constant ($/mi) | 0.104 | 0.104 | 0.104 |
| Miles Flown (mi) | 12,461,440 | 16,724,420 | 14,592,880 |
| Mileage Constant (mpg) | 0.2 | 0.2 | 0.2 |
| Gallons of Fuel (gal) | 62,307,200 | 83,622,100 | 72,964,400 |
| Carbon Constant per Gallon (kg C/gal) | 2.61 | 2.61 | 2.61 |
| Carbon Emission per Flight (TC) | 162,621 | 218,253 | 190,437 |
| **Total Carbon Emission for Purdue (TC)** | 464 | 624 | **544** |

**Table 5.2.3** University reimbursed travel on international flights during 2004-05, 2005-06, and the average to represent the 2005 calendar year

## B-4. Business Travel Information

| | | | Category for airline travel (avg # flights/yr*person) | | |
|---|---|---|---|---|---|
| **Population group** | **# of people** | **driving (mi)** | **A** | **B** | **C** |
| Deans + faculty | 2858 | 625.6 | 3.02 | 0.28 | 0.11 |
| Students | 38712 | 317.8 | 0.54 | 0.02 | 0.02 |
| Staff | 7647 | 936.7 | 1.2 | 0.2 | 0.06 |
| Grads | 4461 | 26.4 | 0.14 | 0.03 | 0 |

**Table 5.2.4** Essential information for calculating Purdue's business travel carbon footprint

## B-5. Land-use Fuel Consumption

| Farms<br>Diesel | Area [ha] | Conversion Factor area relationship | Diesel Fuel [gal] | Conversion Factor [kg C/gal] | Carbon [kg C] | **Carbon TC /yr** |
|---|---|---|---|---|---|---|
| Agronomy Research Farm | 372.3 | 1.00 | 7525 | 2.77 | 20844 | **20.84** |
| Animal Research Farm | 613.1 | 1.65 | 12392 | 2.77 | 34326 | **34.33** |
| Throckmorton | 335.9 | 0.90 | 6789 | 2.77 | 18806 | **18.81** |
| **Total** | | | | | | **73.98** |
| Farms<br>Gasoline | Area [ha] | Conversion Factor area relationship | Gasoline [gal] | Conversion Factor [kg C/gal] | Carbon [kg C] | **Carbon TC /yr** |
| Agronomy Research Farm | 372.3 | 1.00 | 3334 | 2.42 | 8068 | **8.068** |
| Animal Research Farm | 613.1 | 1.65 | 5490 | 2.42 | 13287 | **13.29** |
| Throckmorton | 335.9 | 0.90 | 3008 | 2.42 | 7279 | **7.279** |
| **Total** | | | | | | **28.63** |

**Table 5.2.5** Estimated carbon contributions from land-use (farm) related fuel consumption

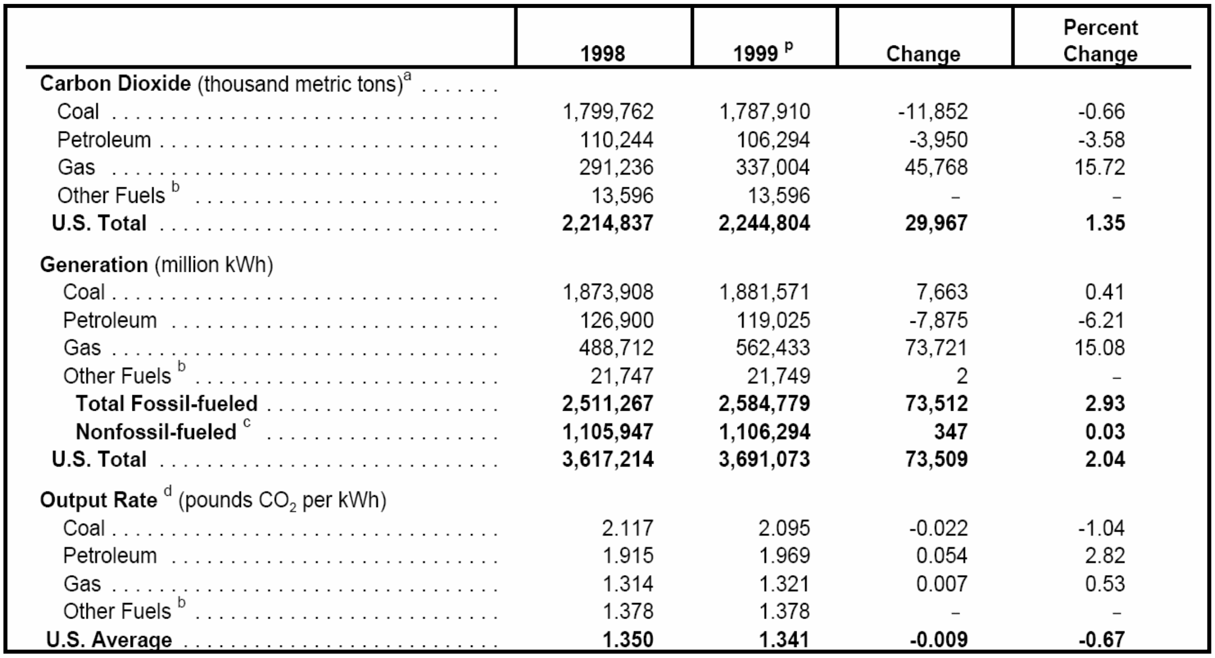
## B-6. Total Transportation Sector Carbon Footprint

| **Transportation Area** | **Fuel Type** | **Fuel Amount (gal)** | **Carbon emissions (TC)** |
|---|---|---|---|
| Purdue auto fleet | | | |
| | Gasoline | 300,000 | 730±73 |
| | Diesel | 60,000 | 170±17 |
| Total | All | | 900±75 |
| Purdue Fire Department | | | |
| | Gasoline | | 0.481 |
| | Diesel | | 1.41 |
| Total | All | | 1.90 |
| Purdue air fleet | | | |
| Pipers | 100LL | 80,400 | 184±18 |
| Turbines | Jet Fuel A | 57,600 | 151±15 |
| Total | All | | 340±23 |
| Daily commutes | | | |
| A Permit holders | All | | 3510±3300 |
| B Permit holders | All | | 458±220 |
| C Permit holders | All | | 1265±1500 |
| Total | All | | 5233±3600 |
| CityBus | | | |
| Purdue-related | Diesel | 288,000 | 800±40 |
| Reimbursed travel | | | |
| Air travel | Jet Fuel A | | 2774±1200 |
| Vehicle travel | Gasoline | | 902±90 |
| Total | All | | 3676±1780 |
| Agriculture | | | |
| | Gasoline | | 28.63±3 |
| | Diesel | | 73.98±7 |
| Total | All | | 103±8 |
| **Total carbon footprint** | | | **11054±4000** |

**Table 5.2.6** Transportation sector carbon footprint total, organized by sector subcategory

## 5.3 Appendix C – Permanent Materials

**C-1. Weighted average of carbon dioxide emissions from fuel split** (“Carbon Dioxide Emissions, 2000)**.**



| | 1998 | 1999 [p] | Change | Percent Change |
|---|---|---|---|---|
| **Carbon Dioxide** (thousand metric tons)[a] | | | | |
| Coal | 1,799,762 | 1,787,910 | -11,852 | -0.66 |
| Petroleum | 110,244 | 106,294 | -3,950 | -3.58 |
| Gas | 291,236 | 337,004 | 45,768 | 15.72 |
| Other Fuels [b] | 13,596 | 13,596 | – | – |
| **U.S. Total** | **2,214,837** | **2,244,804** | **29,967** | **1.35** |
| **Generation** (million kWh) | | | | |
| Coal | 1,873,908 | 1,881,571 | 7,663 | 0.41 |
| Petroleum | 126,900 | 119,025 | -7,875 | -6.21 |
| Gas | 488,712 | 562,433 | 73,721 | 15.08 |
| Other Fuels [b] | 21,747 | 21,749 | 2 | – |
| **Total Fossil-fueled** | **2,511,267** | **2,584,779** | **73,512** | **2.93** |
| **Nonfossil-fueled** [c] | **1,105,947** | **1,106,294** | **347** | **0.03** |
| **U.S. Total** | **3,617,214** | **3,691,073** | **73,509** | **2.04** |
| **Output Rate** [d] (pounds $CO_2$ per kWh) | | | | |
| Coal | 2.117 | 2.095 | -0.022 | -1.04 |
| Petroleum | 1.915 | 1.969 | 0.054 | 2.82 |
| Gas | 1.314 | 1.321 | 0.007 | 0.53 |
| Other Fuels [b] | 1.378 | 1.378 | – | – |
| **U.S. Average** | **1.350** | **1.341** | **-0.009** | **-0.67** |

**Table 5.3.1** Fuel split values used for calculations

**C-2. New Construction at Purdue University in 2005**

| Building Name | Start Date | Completion Date | Time Factor | Floor Area ($m^2$) | GFA ($m^2$) | Project Description |
|---|---|---|---|---|---|---|
| Biomedical Engineering | 6/1/2004 | 4/1/2006 | 0.32 | 8,630.04 | 2,761.61 | New Building |
| Computer Sciences | 6/30/2004 | 6/24/2006 | 0.25 | 10,033.53 | 2,508.38 | New Building |
| Aquaculture Building | 9/25/2005 | 4/1/2006 | 0.50 | 730.87 | 365.43 | Reconstruction of building destroyed by fire |
| Schwartz Tennis Center | 10/1/2005 | 11/1/2006 | 0.23 | 5,237.87 | 1,204.71 | New Building |
| Lynn Radiation Therapy | 3/1/2005 | 12/25/2005 | 1.00 | 213.68 | 213.68 | Building Addition |
| Forney Hall of Chemical Engineering | 1/1/2003 | 3/1/2006 | 0.16 | 4,523.22 | 723.71 | New construction addition of 4500 $m^2$ |

**Table 5.3.2** Summary of new construction at Purdue in 2005

## C-3. Renovations at Purdue University in 2005

| Building Name | Start Date | Completion Date | Time Factor | Floor Area ($m^2$) | GFA ($m^2$) | Project Description |
|---|---|---|---|---|---|---|
| Cary Quad South | 6/4/2004 | 7/30/2006 | 0.46 | 13,553.35 | 6,234.54 | Replacement of heating, electrical, plumbing, and sprinkler systems, refinishing walls, floors, ceilings, and doors, and renovating bathrooms |
| Brown Laboratory | 9/20/2005 | 8/7/2006 | 0.35 | 4,544.26 | 1,590.49 | Roof replacement |
| Smith Hall Room 174/178 | 6/30/2005 | 3/1/2006 | 0.75 | 348.39 | 261.29 | Renovated to a 320 $m^2$ office/wet lab complex |
| Entomology Environmental Lab | 7/21/2005 | 11/18/2005 | 1.00 | 1,316.99 | 1,316.99 | Installation of chilled water lines |
| Wetherill Laboratory | 9/26/2005 | 8/7/2006 | 0.35 | 5,221.24 | 1,827.44 | Roof replacement |
| Hovde Hall Third Floor | 4/12/2005 | 3/1/2006 | 0.82 | 789.68 | 647.53 | Renovation of restrooms, corridors, and offices |
| Forney Hall of Chemical Engineering | 1/1/2003 | 3/1/2006 | 0.16 | 4,523.22 | 723.71 | Renovation of approx. 4500 $m^2$ |
| Pao Hall of Visual and Performing Arts | 9/24/2005 | 6/30/2006 | 0.33 | 2,322.58 | 766.45 | Area site development and landscaping |

**Table 5.3.3** Summary of major renovations at Purdue in 2005

## C-4. Building materials and embodied carbon (continued next page).

| Material | Metric Tons of Carbon | MJ / kg | MJ / $m^2$ | kg $CO^2$ / $m^2$ | kg C / $m^2$ |
|---|---|---|---|---|---|
| Sand | 8,030.00 | 0.60 | 660.00 | 545.00 | 148.64 |
| Gravel | 2,350.00 | 0.20 | 64.38 | 53.16 | 14.50 |
| Cement (in concrete) | 1,320.00 | 3.70 | 669.04 | 552.46 | 150.67 |
| Water (in concrete, drywall, etc) | 622.00 | 0.20 | 17.04 | 14.07 | 3.84 |
| Steel, EAF | 471.00 | 12.30 | 793.60 | 655.32 | 178.72 |
| Brick | 386.00 | 2.70 | 142.77 | 117.89 | 32.15 |
| Mortar | 173.00 | 0.10 | 2.37 | 1.96 | 0.53 |
| Flyash (in concrete) | 168.00 | 0.10 | 2.30 | 1.90 | 0.52 |
| Cement (fireproofing) | 110.00 | 3.70 | 55.75 | 46.04 | 12.56 |
| Steel, primary, cold rolled | 84.00 | 28.00 | 322.19 | 266.05 | 72.56 |
| Gypsum, synthetic | 80.00 | 0.10 | 1.10 | 0.90 | 0.25 |
| Steel, primary, electrogalvanized | 76.00 | 30.60 | 318.58 | 263.06 | 71.74 |
| Steel, secondary, hot rolled | 72.00 | 14.10 | 139.07 | 114.84 | 31.32 |
| Gypsum, primary | 66.00 | 0.90 | 8.14 | 6.72 | 1.83 |
| Kraft paper | 61.00 | 37.70 | 315.03 | 260.13 | 70.95 |
| Bauxite ore (fireproofing) | 53.00 | 0.60 | 4.36 | 3.60 | 0.98 |
| Cast iron | 49.00 | 32.80 | 220.16 | 181.80 | 49.58 |
| Glass | 47.00 | 6.80 | 43.78 | 36.15 | 9.86 |
| Granite | 35.00 | 0.10 | 0.48 | 0.40 | 0.11 |

| | | | | | |
|---|---|---|---|---|---|
| SBR latex | 31.00 | 70.00 | 297.26 | 245.46 | 66.94 |
| Polyamide/nylon, primary | 30.00 | 125.00 | 513.70 | 424.19 | 115.69 |
| Copper, primary, extruded | 21.00 | 71.60 | 205.97 | 170.08 | 46.39 |
| Glass fiber, primary | 21.00 | 17.60 | 50.63 | 41.81 | 11.40 |
| Starch | 18.00 | 15.00 | 36.99 | 30.54 | 8.33 |
| Steel, stainless | 17.00 | 8.20 | 19.10 | 15.77 | 4.30 |
| Aluminum, primary | 15.00 | 207.00 | 425.34 | 351.23 | 95.79 |
| Paver tile | 14.00 | 0.50 | 0.96 | 0.79 | 0.22 |
| Copper tube | 12.00 | 65.80 | 108.16 | 89.32 | 24.36 |
| Limestone | 12.00 | 0.10 | 0.16 | 0.14 | 0.04 |
| Clay (fire proofing) | 11.00 | 32.40 | 48.82 | 40.31 | 10.99 |
| Paper, secondary | 10.00 | 6.90 | 9.45 | 7.81 | 2.13 |
| Polypropylene | 10.00 | 75.00 | 102.74 | 84.84 | 23.14 |
| Polyisocyanurate | 9.00 | 70.00 | 86.30 | 71.26 | 19.44 |
| Titanium dioxide | 8.00 | 73.80 | 80.88 | 66.78 | 18.21 |
| Rubber | 7.00 | 143.00 | 137.12 | 113.23 | 30.88 |
| EPDM | 7.00 | 183.00 | 175.48 | 144.90 | 39.52 |
| Kaolin (ceiling tiles) | 7.00 | 1.30 | 1.25 | 1.03 | 0.28 |
| Ceramic and quarry tile | 6.00 | 5.50 | 4.52 | 3.73 | 1.02 |
| Polystyrene | 6.00 | 94.40 | 77.59 | 64.07 | 17.47 |
| Glass fiber, post-industrial | 5.00 | 11.90 | 8.15 | 6.73 | 1.84 |
| Wood | 3.00 | 10.80 | 4.44 | 3.66 | 1.00 |
| Vinyl resilient flooring | 3.00 | 50.80 | 20.88 | 17.24 | 4.70 |
| Ethylene glycol | 1.00 | 85.10 | 11.66 | 9.63 | 2.63 |
| Argon | 1.00 | 6.80 | 0.93 | 0.77 | 0.21 |
| Waxes | 1.00 | 52.00 | 7.12 | 5.88 | 1.60 |
| Acrylate lacquer (carpet grout) | 1.00 | 30.80 | 4.22 | 3.48 | 0.95 |
| Xylene (paint, waterproofing) | 1.00 | 60.20 | 8.25 | 6.81 | 1.86 |
| Asphalt | 1.00 | 50.20 | 6.88 | 5.68 | 1.55 |
| Polyethylene | 1.00 | 79.50 | 10.89 | 8.99 | 2.45 |
| Toluene diisocyanate | 1.00 | 101.00 | 13.84 | 11.42 | 3.12 |
| Toluene | 1.00 | 67.90 | 9.30 | 7.68 | 2.09 |

**Table 5.3.4** Summary of common building materials and their embodied carbon values

## C-5. Table 5.3.5 Embodied carbon for each building material and its contribution to each building (see following two pages).

| | **Building and GFA (m^2)** | Biomedical engineering | Schwartz Tennis Center | Lawson CS building | Lynn Hall Radiation Therapy Facility | Forney hall of Chemical Engineering Addition | Aquaculture building re-construction | Pao hall of VPA landscaping | Brown Laboratory roof | Wetherill Laboratory roof | Cary Quad Renovation | Entomology lab infrastructure upgrade | Forney Hall of Chemical Engineering Renovation | Hovde Hall third floor renovations | Smith Hall rooms 174/178 renovation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Building Material** | **Kg C / m^2** | 2761.61 | 1204.71 | 2508.38 | 213.68 | 723.71 | 365.43 | 766.45 | 1590.49 | 1827.44 | 6234.54 | 1316.99 | 723.71 | 647.53 | 261.29 |
| Sand | 148.64 | 410.47 | 179.06 | 372.83 | 31.76 | 107.57 | 54.32 | 113.92 | -- | -- | 926.67 | -- | -- | -- | -- |
| Gravel | 14.50 | 40.04 | 17.47 | 36.37 | 3.10 | 10.49 | 5.30 | 11.11 | 23.06 | 26.50 | 90.40 | -- | 10.49 | -- | -- |
| Cement | 150.67 | 416.09 | 181.51 | 377.94 | 32.20 | 109.04 | 55.06 | 115.48 | -- | -- | -- | -- | -- | -- | -- |
| Water | 3.84 | 10.60 | 4.62 | 9.63 | 0.82 | 2.78 | 1.40 | 2.94 | -- | -- | 23.93 | -- | 2.78 | 2.49 | 1.00 |
| Steel, EAF | 178.72 | 493.56 | 215.31 | 448.31 | 38.19 | 129.34 | 65.31 | -- | -- | -- | -- | -- | -- | -- | -- |
| Brick | 32.15 | 88.79 | 38.73 | 80.65 | 6.87 | 23.27 | 11.75 | -- | -- | -- | 200.45 | -- | -- | -- | -- |
| Mortar | 0.53 | 1.47 | 0.64 | 1.34 | 0.11 | 0.39 | 0.20 | -- | -- | -- | 3.33 | -- | 0.39 | 0.35 | -- |
| Flyash | 0.52 | 1.43 | 0.62 | 1.30 | 0.11 | 0.38 | 0.19 | -- | -- | -- | 3.23 | -- | -- | -- | -- |
| Cement | 12.56 | 34.67 | 15.13 | 31.50 | 2.68 | 9.09 | 4.59 | -- | -- | -- | 78.28 | -- | 9.09 | 8.13 | -- |
| Steel, primary, cold rolled | 72.56 | 200.38 | 87.41 | 182.01 | 15.50 | 52.51 | 26.52 | -- | -- | -- | -- | -- | -- | -- | -- |
| Gypsum, synthetic | 0.25 | 0.68 | 0.30 | 0.62 | 0.05 | 0.18 | 0.09 | -- | -- | -- | 1.54 | -- | 0.18 | 0.16 | 0.06 |
| Steel, electro galvanized | 71.74 | 198.13 | 86.43 | 179.96 | 15.33 | 51.92 | 26.22 | -- | -- | -- | -- | -- | -- | -- | -- |
| Steel, secondary | 31.32 | 86.49 | 37.73 | 78.56 | 6.69 | 22.67 | 11.44 | -- | -- | -- | -- | -- | -- | -- | -- |
| Gypsum, primary | 1.83 | 5.06 | 2.21 | 4.60 | 0.39 | 1.33 | 0.67 | -- | -- | -- | 11.42 | -- | 1.33 | -- | -- |
| Kraft paper | 70.95 | 195.92 | 85.47 | 177.96 | 15.16 | 51.34 | 25.93 | -- | -- | -- | 442.31 | -- | 51.34 | 45.94 | 18.54 |
| Bauxite ore | 0.98 | 2.71 | 1.18 | 2.46 | 0.21 | 0.71 | 0.36 | -- | -- | -- | 6.12 | -- | 0.71 | -- | -- |
| Cast iron | 49.58 | 136.93 | 59.73 | 124.37 | 10.59 | 35.88 | 18.12 | -- | -- | -- | -- | 65.30 | -- | -- | -- |
| Glass | 9.86 | 27.23 | 11.88 | 24.73 | 2.11 | 7.14 | 3.60 | -- | -- | -- | 61.47 | -- | 7.14 | -- | 2.58 |
| Granite | 0.11 | 0.30 | 0.13 | 0.27 | 0.02 | 0.08 | 0.04 | -- | -- | -- | 0.67 | -- | 0.08 | 0.07 | -- |
| SBR latex | 66.94 | 184.87 | 80.65 | 167.92 | 14.30 | 48.45 | 24.46 | -- | -- | -- | 417.37 | -- | 48.45 | -- | 17.49 |
| Polyamide primary | 115.69 | 319.48 | 139.37 | 290.19 | 24.72 | 83.72 | 42.28 | -- | -- | -- | 721.26 | -- | -- | -- | 30.23 |
| Copper, primary | 46.39 | 128.10 | 55.88 | 116.35 | 9.91 | 33.57 | 16.95 | -- | -- | -- | 289.20 | 61.09 | 33.57 | 30.04 | 12.12 |
| Glass fiber, primary | 11.40 | 31.49 | 13.74 | 28.60 | 2.44 | 8.25 | 4.17 | -- | -- | -- | 71.09 | -- | 8.25 | -- | 2.98 |
| Starch | 8.33 | 23.00 | 10.03 | 20.89 | 1.78 | 6.03 | 3.04 | -- | -- | -- | 51.93 | -- | 6.03 | -- | 2.18 |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Steel, stainless | 4.30 | 11.88 | 5.18 | 10.79 | 0.92 | 3.11 | 1.57 | -- | -- | -- | 26.81 | -- | 3.11 | 2.78 | 1.12 |
| Aluminum, primary | 95.79 | 264.53 | 115.40 | 240.28 | 20.47 | 69.32 | 35.00 | -- | -- | -- | 597.20 | -- | -- | -- | 25.03 |
| Paver tile | 0.22 | 0.60 | 0.26 | 0.54 | 0.05 | 0.16 | 0.08 | 0.17 | -- | -- | 1.35 | -- | 0.16 | 0.14 | 0.06 |
| Copper tube | 24.36 | 67.27 | 29.35 | 61.10 | 5.21 | 17.63 | 8.90 | -- | -- | -- | 151.87 | 32.08 | 17.63 | 15.77 | 6.36 |
| Limestone | 0.04 | 0.10 | 0.04 | 0.09 | 0.01 | 0.03 | 0.01 | -- | -- | -- | 0.23 | -- | -- | 0.02 | 0.01 |
| Clay | 10.99 | 30.36 | 13.25 | 27.58 | 2.35 | 7.96 | 4.02 | -- | -- | -- | 68.55 | -- | 7.96 | 7.12 | 2.87 |
| Paper, secondary | 2.13 | 5.88 | 2.56 | 5.34 | 0.45 | 1.54 | 0.78 | -- | -- | -- | 13.27 | -- | 1.54 | 1.38 | 0.56 |
| Polypropylene | 23.14 | 63.90 | 27.87 | 58.04 | 4.94 | 16.74 | 8.46 | -- | -- | -- | 144.25 | -- | -- | -- | 6.05 |
| Polyisocyanurate | 19.44 | 53.67 | 23.41 | 48.75 | 4.15 | 14.07 | 7.10 | -- | -- | -- | 121.17 | -- | -- | -- | 5.08 |
| Titanium dioxide | 18.21 | 50.30 | 21.94 | 45.69 | 3.89 | 13.18 | 6.66 | -- | -- | -- | 113.55 | -- | 13.18 | -- | 4.76 |
| Rubber | 30.88 | 85.28 | 37.20 | 77.46 | 6.60 | 22.35 | 11.28 | -- | 49.12 | 56.43 | 192.53 | -- | 22.35 | -- | 8.07 |
| EPDM | 39.52 | 109.14 | 47.61 | 99.13 | 8.44 | 28.60 | 14.44 | -- | 62.85 | 72.22 | 246.38 | -- | -- | -- | 10.33 |
| Kaolin | 0.28 | 0.78 | 0.34 | 0.70 | 0.06 | 0.20 | 0.10 | -- | -- | -- | 1.75 | -- | 0.20 | 0.18 | 0.07 |
| Ceramic | 1.02 | 2.81 | 1.23 | 2.55 | 0.22 | 0.74 | 0.37 | -- | -- | -- | 6.35 | -- | 0.74 | 0.66 | 0.27 |
| Polystyrene | 17.47 | 48.25 | 21.05 | 43.83 | 3.73 | 12.65 | 6.39 | -- | -- | -- | 108.94 | -- | 12.65 | 11.31 | 4.57 |
| Glass fiber | 1.84 | 5.07 | 2.21 | 4.60 | 0.39 | 1.33 | 0.67 | -- | -- | -- | 11.44 | -- | 1.33 | 1.19 | 0.48 |
| Polyamide, secondary | 0.01 | 0.03 | 0.01 | 0.02 | 0.00 | 0.01 | 0.00 | -- | -- | -- | 0.06 | -- | 0.01 | 0.01 | 0.00 |
| Wood | 1.00 | 2.76 | 1.20 | 2.51 | 0.21 | 0.72 | 0.37 | -- | -- | -- | 6.23 | -- | 0.72 | 0.65 | 0.26 |
| Vinyl | 4.70 | 12.98 | 5.66 | 11.79 | 1.00 | 3.40 | 1.72 | -- | -- | -- | 29.31 | -- | 3.40 | 3.04 | 1.23 |
| Polyvinyl-chloride | 3.75 | 10.34 | 4.51 | 9.39 | 0.80 | 2.71 | 1.37 | -- | -- | -- | 23.35 | 4.93 | 2.71 | 2.43 | 0.98 |
| Brass | 7.37 | 20.36 | 8.88 | 18.49 | 1.58 | 5.34 | 2.69 | -- | -- | -- | 45.97 | -- | 5.34 | 4.77 | 1.93 |
| Ethylene glycol | 2.63 | 7.25 | 3.16 | 6.59 | 0.56 | 1.90 | 0.96 | -- | -- | -- | 16.37 | -- | 1.90 | 1.70 | 0.69 |
| Argon | 0.21 | 0.58 | 0.25 | 0.53 | 0.04 | 0.15 | 0.08 | -- | -- | -- | 1.31 | -- | 0.15 | 0.14 | 0.05 |
| Waxes | 1.60 | 4.43 | 1.93 | 4.02 | 0.34 | 1.16 | 0.59 | -- | -- | -- | 10.00 | -- | 1.16 | 1.04 | 0.42 |
| Acrylate lacquer | 0.95 | 2.62 | 1.14 | 2.38 | 0.20 | 0.69 | 0.35 | -- | -- | -- | 5.92 | -- | 0.69 | 0.62 | 0.25 |
| Xylene | 1.86 | 5.13 | 2.24 | 4.66 | 0.40 | 1.34 | 0.68 | -- | -- | -- | 11.58 | -- | 1.34 | 1.20 | 0.49 |
| Asphalt | 1.55 | 4.28 | 1.87 | 3.88 | 0.33 | 1.12 | 0.57 | 1.19 | 2.46 | 2.83 | 9.66 | -- | 1.12 | 1.00 | 0.40 |
| Polyethylene | 2.45 | 6.77 | 2.95 | 6.15 | 0.52 | 1.77 | 0.90 | -- | -- | -- | 15.29 | -- | 1.77 | 1.59 | 0.64 |
| Toluene diisocyanate | 3.12 | 8.60 | 3.75 | 7.82 | 0.67 | 2.25 | 1.14 | -- | -- | -- | 19.43 | -- | 2.25 | 2.02 | 0.81 |
| Toluene | 2.09 | 5.78 | 2.52 | 5.25 | 0.45 | 1.52 | 0.77 | -- | -- | -- | 13.06 | -- | 1.52 | 1.36 | 0.55 |
| **∑ (□ ones) = 17790.19** | | 3929.66 | 1714.25 | 3569.32 | 304.06 | 1029.81 | 519.99 | 244.81 | 137.49 | 157.98 | 5413.83 | 163.40 | 284.74 | 149.28 | 171.55 |

## 5.4. Appendix D – Consumables

### D-1. Quantity Consumed (Paper Products)

**Books**: 49,636 (purchased volumes)
**Journals**: 35,728 (purchased volumes)
**Printing/Copy Paper** (used in the ITAP-labs): 16,000 sheets/day
**Other Paper Products:** We do not have complete data about exact quantity consumed in 2005 for other paper products, such as newspaper, mail organizers, office paper consumed in all departmental and administrative offices, napkins and paper packages, etc. We intend to estimate this part of the quantity from the data about Purdue's solid waste management in 2005.

### D-2. Paper Products in Purdue's Solid Waste, 2005

| Category | Percentage | Tons | Metric Tons |
|---|---|---|---|
| Office paper | 13% | 887 | 804.67 |
| Newspaper | 9% | 614 | 557.0 |
| Mixed Paper | 19% | 1,297 | 1,176.6 |
| Cardboard | 11% | 751 | 681.3 |
| Restroom (Napkin/paper Towel) | 12% | 819 | 743.0 |
| | | **Total** | **= 3,961.67 T** |

### D-3. Solid Waste Generation Rate (as % of the consumption stream) in California (Solid Waste Characterization Database)

| Location | Newspaper | Office Paper | Restroom | Card-board | Mixed Paper | Total Paper |
|---|---|---|---|---|---|---|
| LA (all counties) | 4.1% | 7.7% | 11.5% | 7.8% | 2.7% | 33.8% |
| SF (all counties) | 4.7% | 7.9% | 11.7% | 8.6% | 3.4% | 36.3% |
| SBT (all counties) | 4.4% | 7.2% | 11. 9% | 8.2% | 4.6% | 36.3 |
| Average | 4.4% | 7.93% | 11.7% | 8.2% | 3.6% | 35.83 |
| Solid Waste as % of paper products (Avg % / Total %) | 12.28% | 22.13% | 32.65% | 22.89% | 10.01% | 100% |

**Table 5.4.1** Solid Waste Generation Rate in California

## D-4. Data and Calculation Tables for Emissions through Food Production

| High Volume Food Consumption Sources | Food Items | Quanity (lbs) | Food – Production | | |
|---|---|---|---|---|---|
| | | | Rank (0-1) | Equiv. Energy (kW-h/lb) | Emissions (lb CO2/yr) |
| **BULK Food (lbs)** | | | | | |
| SLICED DELI MEAT | 115,809 | 115809 | 0.7 | 0.1225 | 0 |
| GROUND BEEF & BEEF PATTIES | 210,820 | 210820 | 0.6 | 0.105 | 25316 |
| CHICKEN BREASTS, QTRS, WINGS & WHOLE | 140,340 | 140340 | 0.6 | 0.105 | 46086 |
| CHICKEN STRIPS, NUGGETS, POPCORN, BREADED | 152,750 | 152750 | 0.7 | 0.1225 | 35792 |
| CHICKEN STIR FRY STRIPS | 47,360 | 47360 | 0.7 | 0.1225 | 38957 |
| FROZEN SEAFOOD | 72,490 | 72490 | 0.6 | 0.105 | 10353 |
| FRENCH FRIES | 310,000 | 310000 | 0.7 | 0.1225 | 18488 |
| PASTA | 55,000 | 55000 | 0.5 | 0.0875 | 56473 |
| RICE | 44,000 | 44000 | 0.5 | 0.0875 | 10019 |
| WASHINGTON APPLES | 135,000 | 135000 | 0 | 0 | 0 |
| BANANAS | 149,550 | 149550 | 0 | 0 | 0 |
| CORN, FROZEN | 19,000 | 19000 | 0.3 | 0.0525 | 16346 |
| GREEN BEANS, CANNED | 25,000 | 25000 | 0.3 | 0.0525 | 2077 |
| DANNON BULK YOGURT | 36,000 | 36000 | 0.6 | 0.105 | 5465 |
| CEREAL BULK - (most popular – Kellogg's Lowfat Granola) | 34,000 | 34000 | 0.6 | 0.105 | 7870 |
| **INDIVIDUAL Food (# of items)** | | | | | |
| KELLOGG'S CEREAL BOWLS (OTG) (most popular – Frosted Flakes) | 170,000 | 18739 | 0.7 | 0.1225 | 0 |
| BAGELS BULK – Harlen | 83,000 | 15553 | 0.6 | 0.105 | 4096 |
| BAGELS – Otis Spunkmeyer (OTG) Individually Wrapped | 46,000 | 8620 | 0.7 | 0.1225 | 3967 |
| "ON THE GO" YOGURT – 4 oz. | 152,000 | 45850 | 0.7 | 0.1225 | 2198 |
| MINUTE MAID MINPAK JUICE | 72,000 | 47628 | 0.7 | 0.1225 | 11693 |
| PILLSBURY BISCUITS | 157,000 | 20767 | 0.5 | 0.0875 | 8676 |
| PIZZA DOUGH 7", 14", 16" | 194,000 | 76984 | 0.5 | 0.0875 | 3783 |
| TURANO BREADSTICKS | 281,000 | 37169 | 0.5 | 0.0875 | 14024 |
| KEEBLER ICE CREAM CONES | 414,400 | 25580 | 0.7 | 0.1225 | 9480 |
| KELLOGG'S NUTRI-GRAIN BARS | 111,000 | 24471 | 0.7 | 0.1225 | 6524 |
| KELLOGG'S POP TARTS | 130,000 | 30093 | 0.7 | 0.1225 | 6241 |
| OTIS SPUNKMEYER COOKIES (most popular – Choc Chunk) | 404,000 | 38298 | 0.7 | 0.1225 | 7675 |
| VARIETY OATMEAL PACKETS (QUAKER) | 20,000 | 1543 | 0.5 | 0.0875 | 6977 |
| **LIQUIDS (gals)** | | | | | |
| BELGIAN WAFFLES (make your own) | 148,000 | 1235341 | 0.5 | 0.0875 | 0 |
| CATSUP | 8,000 | 66775 | 0.5 | 0.0875 | 225042 |
| MILK | 152,540 | 1317799 | 0.3 | 0.0525 | 7299 |
| KRAFT SALAD DRESSING | 9,000 | 1158645 | 0.6 | 0.105 | 288076 |
| SALAD DRESSING PACKETS | 61,000 | 7344 | 0.7 | 0.1225 | 295498 |
| TOTALS | | 5724318 | | | 1174491 |

**Table 5.4.2** Food production emissions data

## D-5. Data and Calculation Tables for Emissions through Food Transportation

| Food – Transportation | | | | |
|---|---|---|---|---|
| Shipping/mo. | Suppliers/Location | Distance (mi/mo) | Transport (mi/yr) | Emissions (lb CO2/yr) |
| 8 | Indianapolis | 1120 | 13440 | 48189 |
| 8 | Indianapolis | 1120 | 13440 | 48189 |
| 8 | Indianapolis | 1120 | 13440 | 48189 |
| 8 | Indianapolis | 1120 | 13440 | 48189 |
| 8 | Indianapolis | 1120 | 13440 | 48189 |
| 8 | Indianapolis | 1120 | 13440 | 48189 |
| 4 | Florida, Mexico | 16000 | 192000 | 688413 |
| 2 | Battle Creek, MI | 900 | 10800 | 38723 |
| 4 | Midwest | 2000 | 24000 | 86052 |
| 4 | Various | 8000 | 96000 | 344206 |
| 1 | Indianapolis | 140 | 1680 | 6024 |
| 1 | Midwest | 500 | 6000 | 21513 |
| 2 | SouthEast US | 3000 | 36000 | 129077 |
| 8 | Iowa, Illinois | 6800 | 81600 | 292575 |
| 8 | Iowa, Illinois | 6800 | 81600 | 292575 |
| 8 | Iowa, Illinois | 6800 | 81600 | 292575 |
| 8 | Iowa, Illinois | 6800 | 81600 | 292575 |
| 4 | Various | 8000 | 96000 | 344206 |
| 1 | Minnesota | 16060 | 192720 | 690994 |
| 1 | Missouri | 660 | 7920 | 28397 |
| 30 | Frankfort, IN | 2400 | 28800 | 103262 |
| 2 | Wisconsin, Chicago | 1540 | 18480 | 66260 |
| 2 | Florida, Wisconsin | 7200 | 86400 | 309786 |
| 2 | West Coast | 8520 | 102240 | 366580 |
| 1 | Florida | 10300 | 123600 | 443166 |
| 30 | Illinois | 10200 | 122400 | 438863 |
| | | | | |
| TOTALS | | | 1552080 | 5564958 |

**Table 5.4.3** Food transportation emissions data

## 5.5 Appendix E: Land Use

### E-1. Soil Carbon Sequestration Calculation

The Agricultural Research Farm at Purdue changes the management of different fields depending on current experimental designs, which make the evaluation of accumulations or losses in soil carbon stock difficult and impractical to calculate for any amount of time, given the amount of obtainable data. Due to the assumptions necessary, this calculation only gives a rough estimate of the ability of Purdue's soils to serve as a carbon credit. Following is a stepwise calculation of soil carbon stock increases. The following equations are adapted from the 2006 *IPCC Guidelines for National Greenhouse Gas Inventories*, Volume 4. All data is also drawn from this report.

$$SOC = SOC_{REF} \cdot F_{LU} \cdot F_{MG} \cdot F_I \cdot A$$

**Equation 5.5.1** Calculation of soil organic carbon before and after the inventory period.

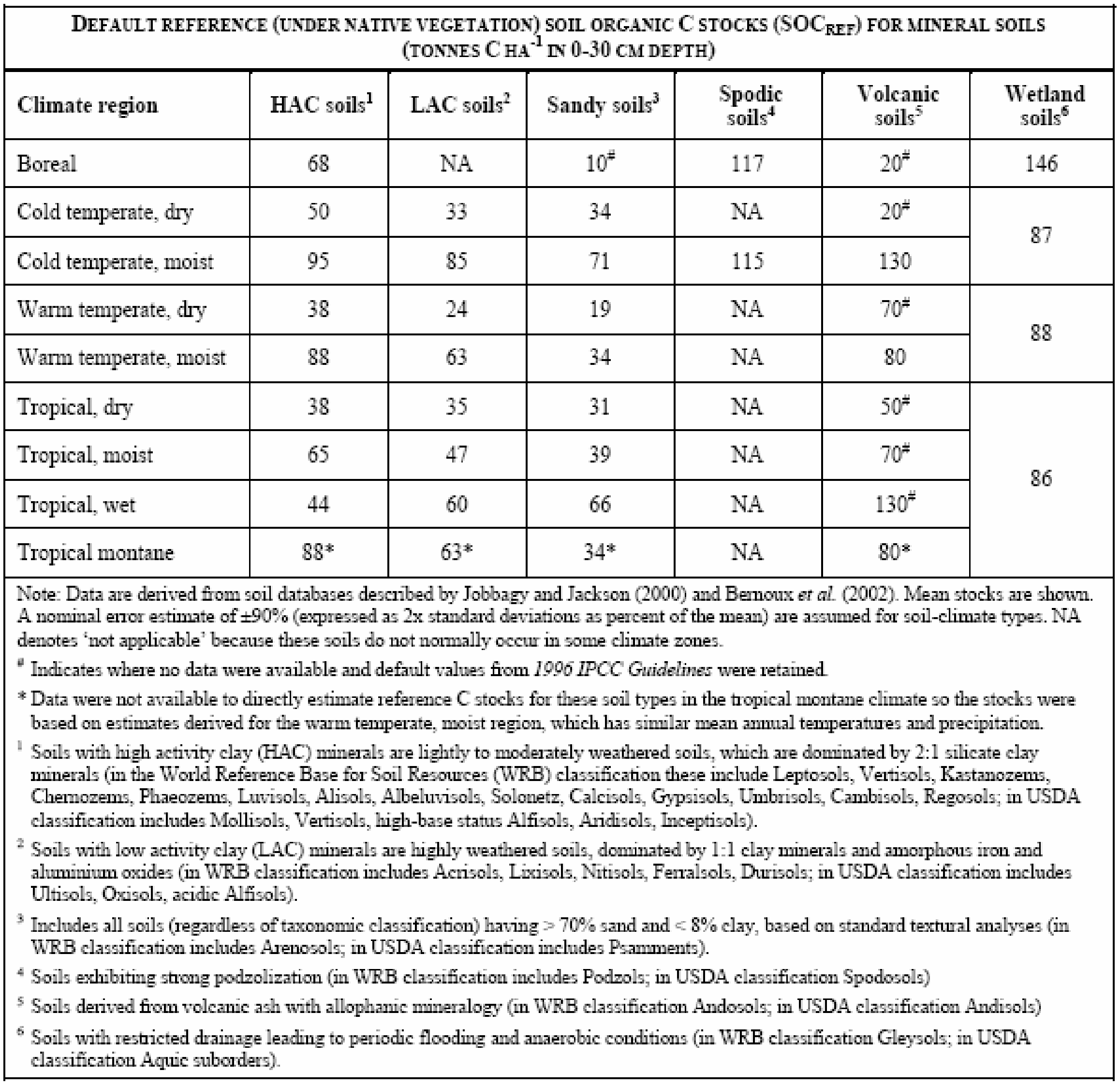
$$\Delta C_{Mineral} = \frac{SOC_0 - SOC_{0-T}}{D}$$

**Equation 5.5.2** Calculation of the change in mineral soil carbon stocks.

$$\Delta C_{Soils} = \Delta C_{Mineral} - L_{Organic} + \Delta C_{Inorganic}$$

**Equation 5.5.3** Calculation of total change in soil carbon stocks.

1. The area of Purdue's arable land subject to different tillage practices is calculated.
2. $SOC_0$ (soil organic carbon at the end of the inventory period) and $SOC_{0-T}$ (soil organic carbon at the beginning of the inventory period) are calculated using Equation 5.5.1.
    a. The $SOC_{REF}$ value, or the default carbon stock reference, is selected from Table 5.5.1 below. Purdue soils are classified as mineral, high activity clay (HAC) soils in a cold, temperate, moist climate, so a $SOC_{REF}$ value of 95 TC/hectare is selected. This value is the same in the $SOC_0$ and $SOC_{0-T}$ calculations.



**DEFAULT REFERENCE (UNDER NATIVE VEGETATION) SOIL ORGANIC C STOCKS ($SOC_{REF}$) FOR MINERAL SOILS (TONNES C HA$^{-1}$ IN 0-30 CM DEPTH)**

| Climate region | HAC soils[1] | LAC soils[2] | Sandy soils[3] | Spodic soils[4] | Volcanic soils[5] | Wetland soils[6] |
|---|---|---|---|---|---|---|
| Boreal | 68 | NA | 10[#] | 117 | 20[#] | 146 |
| Cold temperate, dry | 50 | 33 | 34 | NA | 20[#] | 87 |
| Cold temperate, moist | 95 | 85 | 71 | 115 | 130 | |
| Warm temperate, dry | 38 | 24 | 19 | NA | 70[#] | 88 |
| Warm temperate, moist | 88 | 63 | 34 | NA | 80 | |
| Tropical, dry | 38 | 35 | 31 | NA | 50[#] | 86 |
| Tropical, moist | 65 | 47 | 39 | NA | 70[#] | |
| Tropical, wet | 44 | 60 | 66 | NA | 130[#] | |
| Tropical montane | 88* | 63* | 34* | NA | 80* | |

Note: Data are derived from soil databases described by Jobbagy and Jackson (2000) and Bernoux *et al.* (2002). Mean stocks are shown. A nominal error estimate of ±90% (expressed as 2x standard deviations as percent of the mean) are assumed for soil-climate types. NA denotes 'not applicable' because these soils do not normally occur in some climate zones.

[#] Indicates where no data were available and default values from *1996 IPCC Guidelines* were retained.

* Data were not available to directly estimate reference C stocks for these soil types in the tropical montane climate so the stocks were based on estimates derived for the warm temperate, moist region, which has similar mean annual temperatures and precipitation.

[1] Soils with high activity clay (HAC) minerals are lightly to moderately weathered soils, which are dominated by 2:1 silicate clay minerals (in the World Reference Base for Soil Resources (WRB) classification these include Leptosols, Vertisols, Kastanozems, Chernozems, Phaeozems, Luvisols, Alisols, Albeluvisols, Solonetz, Calcisols, Gypsisols, Umbrisols, Cambisols, Regosols; in USDA classification includes Mollisols, Vertisols, high-base status Alfisols, Aridisols, Inceptisols).

[2] Soils with low activity clay (LAC) minerals are highly weathered soils, dominated by 1:1 clay minerals and amorphous iron and aluminium oxides (in WRB classification includes Acrisols, Lixisols, Nitisols, Ferralsols, Durisols; in USDA classification includes Ultisols, Oxisols, acidic Alfisols).

[3] Includes all soils (regardless of taxonomic classification) having > 70% sand and < 8% clay, based on standard textural analyses (in WRB classification includes Arenosols; in USDA classification includes Psamments).

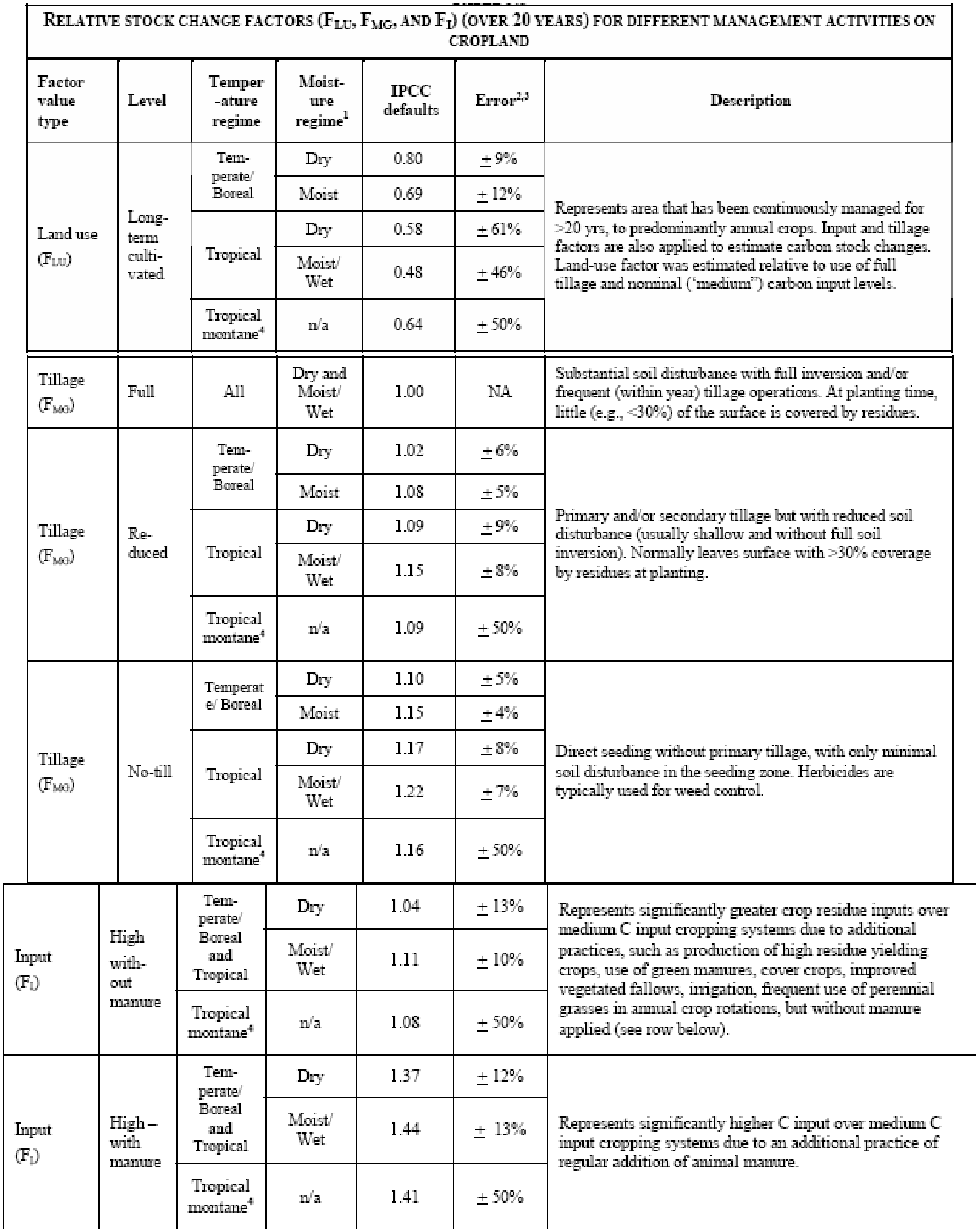
[4] Soils exhibiting strong podzolization (in WRB classification includes Podzols; in USDA classification Spodosols)

[5] Soils derived from volcanic ash with allophanic mineralogy (in WRB classification Andosols; in USDA classification Andisols)

[6] Soils with restricted drainage leading to periodic flooding and anaerobic conditions (in WRB classification Gleysols; in USDA classification Aquic suborders).

**Table 5.5.1** Soil organic carbon stock values

b. Land-use factor ($F_{LU}$), management factor ($F_{MG}$) and carbon input levels ($F_I$) from Table 5.5.2 below are assigned to each land category.
    i. $F_{LU}$ values are selected to be 0.69 for long-term cultivated soils in a temperate climate.
    ii. $F_{MG}$ values are selected to be 1 for conventional tillage; 1.08 for reduced tillage (such as disk and strip-tillage); and 1.15 for no-till in the $SOC_0$ calculation. For the original soil organic carbon stock ($SOC_{0-T)}$ calculation, $F_{MG}$ is assumed to be one.
    iii. Purdue's arable soils are assumed to all be high-input without manure, so an $F_I$ value of 1.11 is used.



**RELATIVE STOCK CHANGE FACTORS ($F_{LU}$, $F_{MG}$, AND $F_I$) (OVER 20 YEARS) FOR DIFFERENT MANAGEMENT ACTIVITIES ON CROPLAND**

| Factor value type | Level | Temper-ature regime | Moist-ure regime[1] | IPCC defaults | Error[2,3] | Description |
|---|---|---|---|---|---|---|
| Land use ($F_{LU}$) | Long-term culti-vated | Tem-perate/ Boreal | Dry | 0.80 | ± 9% | Represents area that has been continuously managed for >20 yrs, to predominantly annual crops. Input and tillage factors are also applied to estimate carbon stock changes. Land-use factor was estimated relative to use of full tillage and nominal ('medium") carbon input levels. |
| | | | Moist | 0.69 | ± 12% | |
| | | Tropical | Dry | 0.58 | ± 61% | |
| | | | Moist/ Wet | 0.48 | ± 46% | |
| | | Tropical montane[4] | n/a | 0.64 | ± 50% | |
| Tillage ($F_{MG}$) | Full | All | Dry and Moist/ Wet | 1.00 | NA | Substantial soil disturbance with full inversion and/or frequent (within year) tillage operations. At planting time, little (e.g., <30%) of the surface is covered by residues. |
| Tillage ($F_{MG}$) | Re-duced | Tem-perate/ Boreal | Dry | 1.02 | ± 6% | Primary and/or secondary tillage but with reduced soil disturbance (usually shallow and without full soil inversion). Normally leaves surface with >30% coverage by residues at planting. |
| | | | Moist | 1.08 | ± 5% | |
| | | Tropical | Dry | 1.09 | ± 9% | |
| | | | Moist/ Wet | 1.15 | ± 8% | |
| | | Tropical montane[4] | n/a | 1.09 | ± 50% | |
| Tillage ($F_{MG}$) | No-till | Temperate/ Boreal | Dry | 1.10 | ± 5% | Direct seeding without primary tillage, with only minimal soil disturbance in the seeding zone. Herbicides are typically used for weed control. |
| | | | Moist | 1.15 | ± 4% | |
| | | Tropical | Dry | 1.17 | ± 8% | |
| | | | Moist/ Wet | 1.22 | ± 7% | |
| | | Tropical montane[4] | n/a | 1.16 | ± 50% | |
| Input ($F_I$) | High with-out manure | Tem-perate/ Boreal and Tropical | Dry | 1.04 | ± 13% | Represents significantly greater crop residue inputs over medium C input cropping systems due to additional practices, such as production of high residue yielding crops, use of green manures, cover crops, improved vegetated fallows, irrigation, frequent use of perennial grasses in annual crop rotations, but without manure applied (see row below). |
| | | | Moist/ Wet | 1.11 | ± 10% | |
| | | Tropical montane[4] | n/a | 1.08 | ± 50% | |
| Input ($F_I$) | High – with manure | Tem-perate/ Boreal and Tropical | Dry | 1.37 | ± 12% | Represents significantly higher C input over medium C input cropping systems due to an additional practice of regular addition of animal manure. |
| | | | Moist/ Wet | 1.44 | ± 13% | |
| | | Tropical montane[4] | n/a | 1.41 | ± 50% | |

**Table 5.5.2** Relative carbon stock change factors

**c.** The values listed in (a) and (b) are multiplied by the area to calculate $SOC_0$ and $SOC_{0-T}$ as shown in Table 5.6.3 (next page).

| Farm | Tillage | Area | $SOC_{REF}$ | $F_{LU}$ | $F_{MG}$* | $F_{I}$ | SOC $_{(0)}$ | $SOC_{(0-T)}$ | **Δ C $_{Mineral}$ MTC $yr^{-1}$** |
|---|---|---|---|---|---|---|---|---|---|
| | Practice | ha | MTC $ha^{-1}$ | | Dimensionless | | MTC | MTC | **(Annually)** |
| Agronomy | Plow | 110.1 | 95 | 0.69 | 1 | 1.11 | 8011 | 8011 | 0 |
| | Chisel | 99.6 | 95 | 0.69 | 1 | 1.11 | 7247 | 7247 | 0 |
| | Disk | 16.6 | 95 | 0.69 | 1.08 | 1.11 | 1304 | 1208 | 3 |
| | No Till | 89.4 | 95 | 0.69 | 1.15 | 1.11 | 7481 | 6505 | 33 |
| | Strip-tillage | 6.1 | 95 | 0.69 | 1.08 | 1.11 | 479 | 444 | 1 |
| | **Total** | **372.3** | | | | | | | **37** |
| Animal | Conservation | 339.9 | 95 | 0.69 | 1.08 | 1.11 | 26710 | 24731 | 66 |
| | Conventional | 190.6 | 95 | 0.69 | 1 | 1.11 | 13868 | 13868 | 0 |
| | **Total** | **530.5** | | | | | | | **66** |
| Throckmorton | Conservation | 202.3 | 95 | 0.69 | 1.08 | 1.11 | 15897 | 14719 | 39 |
| | Conventional | 89 | 95 | 0.69 | 1 | 1.11 | 6476 | 6476 | 0 |
| | **Total** | **291.3** | | | | | | | **39** |
| | **Grand Total** | | | | | | | | **142** |

**Table 5.5.3**[13] Sample calculations for carbon sequestration

3. Equation 5.5.2 is used to calculate the change in mineral carbon annually, where D is the time of the inventory period. Since the Agronomy Farm has been in production for about thirty years, 30 is used for D as an estimate of how long each parcel of land has been cultivated.
4. Equation 5.5.3 shows that the total change in carbon in the soil is equal to the change in organic carbon stocks in mineral soils ($\Delta C_{Mineral}$) as calculated above minus losses of carbon from drained organic soils ($L_{Organic}$) plus the change in inorganic carbon stocks in the soil ($\Delta C_{Inorganic}$). Since Purdue's soils are not organic soils, $L_{Organic}$ is not relevant to the calculation. The change in inorganic carbon stocks is assumed to be zero, so the change in carbon stocks in the soil is approximately equal to $\Delta C_{Mineral}$, or 142 TC sequestered annually. Based on this estimate, therefore, Purdue's arable soils only have the capacity to sequester less than a tenth of a percent of Purdue's total footprint. Since this is such a minor part of the footprint and data availability limits the accuracy of the calculation, it is not included in the total footprint.

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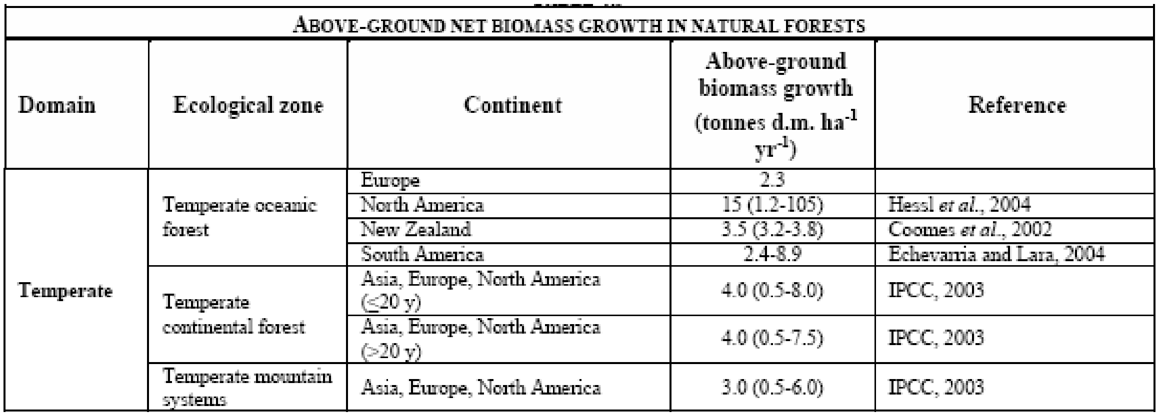
[13] Agronomy Research Farm Information Archive provided area and tillage information.

## E-2. Natural Forest Above-Ground Biomass Growth (Paustian, 2006b)

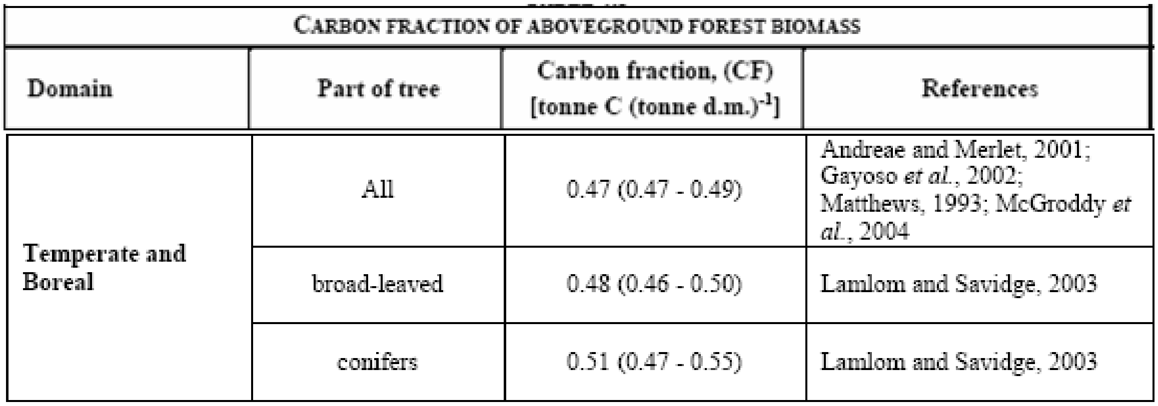


ABOVE-GROUND NET BIOMASS GROWTH IN NATURAL FORESTS

| Domain | Ecological zone | Continent | Above-ground biomass growth (tonnes d.m. ha$^{-1}$ yr$^{-1}$) | Reference |
|---|---|---|---|---|
| **Temperate** | Temperate oceanic forest | Europe | 2.3 | |
| | | North America | 15 (1.2-105) | Hessl *et al.*, 2004 |
| | | New Zealand | 3.5 (3.2-3.8) | Coomes *et al.*, 2002 |
| | | South America | 2.4-8.9 | Echevarria and Lara, 2004 |
| | Temperate continental forest | Asia, Europe, North America (≤20 y) | 4.0 (0.5-8.0) | IPCC, 2003 |
| | | Asia, Europe, North America (>20 y) | 4.0 (0.5-7.5) | IPCC, 2003 |
| | Temperate mountain systems | Asia, Europe, North America | 3.0 (0.5-6.0) | IPCC, 2003 |

**Table 5.5.4.** Forest above-ground biomass growth

## E-3. Natural Forest Above-Ground Biomass Carbon Fraction (Paustian, 2006b)



CARBON FRACTION OF ABOVEGROUND FOREST BIOMASS

| Domain | Part of tree | Carbon fraction, (CF) [tonne C (tonne d.m.)$^{-1}$] | References |
|---|---|---|---|
| **Temperate and Boreal** | All | 0.47 (0.47 - 0.49) | Andreae and Merlet, 2001; Gayoso *et al.*, 2002; Matthews, 1993; McGroddy *et al.*, 2004 |
| | broad-leaved | 0.48 (0.46 - 0.50) | Lamlom and Savidge, 2003 |
| | conifers | 0.51 (0.47 - 0.55) | Lamlom and Savidge, 2003 |

**Table 5.5.5** Forest above-ground carbon fraction

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