AN AUDIT
of the
CARBON FOOTPRINT
of the
DEPARTMENT OF MECHANICAL ENGINEERING
at
MICHIGAN STATE UNIVERSITY

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Executive Summary

Recently efforts to reduce Michigan State University's negative impacts on the environment have been increased, primarily by launching the "Be Spartan Green" campaign. The Department of Mechanical Engineering wishes to be a leader in the success of MSU's efforts; and so during the summer of 2008, an audit of the Department of Mechanical Engineering's carbon footprint was initiated. The measurement of its footprint as well as research into a variety of methods for its reduction, will allow the department to start working towards carbon neutrality.

Energy use was the largest contributor to the carbon footprint of the Department, as might be expected and accounted for of **442 tC** (metric tons of carbon) per annum. This resulted mainly from the electricity consumption in labs, classrooms, and offices, as well as steam from the T.B. Simon Power Plant used for HVAC purposes. Transportation was also found to be a significant contributor with **108 tC** emitted. This resulted primarily from commuting, but also from travel by faculty and students that was reimbursed by the Department. Comparatively, material usage was a minor contributor, at less than 2% (7 tC) based on records of purchases. Paper was the only significant consumable material while permanent materials included computers, steel, wood, plastic, and aluminum**.** The Department had no carbon offsets so the total annual carbon footprint is the sum of contributions from energy, transportation and material usage, i.e. **557 ± 53 tC.**

There are many possibilities for reducing this footprint, such as using renewable energy sources, purchasing offsets, purchasing recycled materials, or investing in new technologies. The most viable solutions for the Department are: to purchase more recycled materials and carbon offsets (for about $25,000p.a) in the short-term; to seek efficiency gains in energy and transportation usage in the medium-term; and to investigate renewable energy sources and establishing a forest to provide permanent offsets in the long-term. It is possible, with the reductions described above, that the Department could make a large impact on its footprint within a single year.

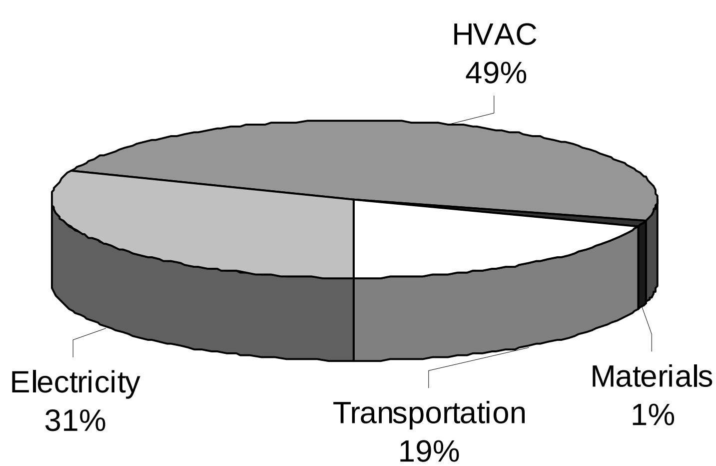

Figure 1: Carbon Footprint (557 tC) for the Department of Mechanical Engineering at MSU

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1. Introduction

1.1 Global Warming

The issue of global warming is one of the biggest topics of conversation and debate today. Greenhouse gases, sometimes referred to as “heat-trapping” gases, are gases that trap heat in the Earth’s atmosphere. As the level of greenhouse gases in the atmosphere rises, the amount of “trapped” energy increases, contributing to a rise in the surface temperature of the Earth[1]. These gases are released by both human and natural processes; however, the levels emitted by humans have been increasing dramatically since the start of the industrial revolution[2] and despite efforts in recent years, the United States has failed to reverse or even slow this trend. Between 1995 and 2005, the United States increased emissions by over 700 million metric tons of carbon dioxide to a total of 6045 million metric tons[3]. The United States uses 26% of the world’s energy and is responsible for 23% of the world’s carbon emissions, while only making up 5% of the population[4].

The most abundant greenhouse gas (aside from H_2O) is CO_2[1], which is primarily released from burning fossil fuels and waste, or in chemical reactions used in industrial processes. The current CO_2 levels in the atmosphere are approximately 380 ppm, about 100 ppm higher than they were at the start of the industrial revolution[1]. This increase in greenhouse gas levels is believed to have contributed to a temperature rise of about 1°F since the mid-1970s[2]. CO_2 emissions in the U.S. have increased by 20% since 1990 despite efforts to increase awareness about the effects of climate change[2]. The Intergovernmental Panel on Climate Change[5] has stated that “*the understanding of anthropogenic warming and cooling influences on climate has improved…leading to very high confidence that the global net effect of human activities since 1750 has been one of*

[1] “What Is Global Warming?” *wecansolveit.org* 2008, <http://www.wecansolveit.org/content/pages/60/?source=GoogleSearch&subsource=Google_BrandedMonitor_1x1> Accessed 8 July 2008.
[2] “Climate Change,” *U.S. Environmental Protection Agency,* 2008, < http://www.epa.gov/climatechange/> Accessed 8 July 2008.
[3] “U.S. Emissions Data,” *Energy Information Administration*, 2006, <http://www.eia.doe.gov/oiaf/1605/ggrpt/carbon.html> Accessed 21 July 2008.
[4] “Energy Facts,” *Solar Energy International,* 2008, <http://www.solarenergy.org/resources/energyfacts.html> Accessed 9 July 2008.
[5] IPCC, 2007: Summary for Policymakers. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

warming" and "*warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global sea level*".

1.2 Carbon Footprint and Carbon Neutrality

"Carbon footprint" is a term used to describe the levels of greenhouse gases that are emitted as a result of the actions of an individual or an organization. The determination of a carbon footprint is becoming an increasingly popular exercise for organizations, either as a requirement to report to a third party or to use as a reference for reducing carbon emissions. A carbon footprint can be a simple measurement of the consumption of energy provided by coal, natural gas, and other fuels, or it can encompass much more by including factors such as transportation, use of materials for daily tasks or for large construction and renovation projects, and emissions from livestock.

Table 1: **Global Warming Potentials.**

Gas	GWP
CO_2	1
CH_4	21
N_2O	310
HFC-23	11,700
HFC-32	650
HFC-125	2,800
HFC-134a	1,300
HFC-143a	3,800
HFC-152a	140
HFC-227ea	2,900
HFC-236fa	6,300
HFC-4310mee	1,300
CF_4	6,500
C_2F_6	9,200
C_4F_{10}	7,000
C_6F_{14}	7,400
SF_6	23,900

Carbon emissions are typically reported as mass of CO_2 or mass of carbon, but there are many other greenhouse gases that are more harmful than CO_2 that typically exist at much lower levels. These other gases are measured in "global warming potential" (GWP) relative to CO_2 (see Table 1). Some of them absorb radiation directly, like CO_2, while others influence other greenhouse gases or produce greenhouse gases through chemical processes. By using global warming potentials, rather than reporting each gas individually, a carbon footprint can be stated in terms of equivalent levels of CO_2. When reporting emissions by the quantity of carbon alone, the mass of carbon in tC (metric tons of carbon) is typically used. In this report, all emissions will be given in tC (1 tC is equivalent to 0.2729 tons of CO_2).

The ultimate goal when reducing a carbon footprint is to achieve *carbon neutrality*. "Carbon neutral" is defined as having zero net carbon emissions. Organizations can reduce emissions by using renewable energy sources, purchasing carbon offsets and recycled materials, or simply reducing energy and material use. Individuals must reduce their own footprint for an organization to be successful in this goal. Changes in daily habits leading to the consumption of less energy and lower emissions from transportation by using alternate modes and carpooling are the most significant contributions most individuals can make.

1.3 Going "Green" At Michigan State University

Michigan State University has recently launched its "Be Spartan Green" campaign in an attempt to increase the environmental awareness amongst its students, staff, and faculty and to reduce the carbon footprint of the University. Initiatives being taken as part of this campaign include encouraging less energy use in the dorms, promoting recycling, and planning a new campus recycling facility. MSU has identified 3100 acres of its land which is under-developed and provides the potential for various methods of carbon reduction[6] including the installation of renewable energy sources such as wind turbines or solar panels, or the generation of carbon offsets by planting trees.

The Department of Mechanical Engineering at Michigan State University would like to be a major participant in this campaign by measuring and reducing its own footprint and providing a model for other departments to follow. An essential first step towards becoming carbon neutral is to determine the size and composition of the carbon footprint of the Department. This will allow the Department to identify which parts of the footprint have the greatest potential for reductions and to establish appropriate goals. Research on associated technologies is already taking place in the Department and it is anticipated that

[6] "MSU Facts," *Michigan State University Division of University Relations,* 2008, <http://newsroom.msu.edu/snav/184/page.htm> Accessed 19 May 2008.

an audit of its carbon footprint will provide additional focus and motivation for this research activity in the Department, as well as raising awareness amongst faculty, students and alumni.

1.4 Organization of Carbon Emissions

"A Corporate Accounting and Reporting Standard" which is a document prepared by the Greenhouse Gas Protocol (a partnership between the World Resources Institute and the World Business Council for Sustainable Development), provides organizational and reporting guidelines for organizations wishing to report their carbon emissions[7]. The methods provided by this document were used as a reference to determine the scope and structure of this carbon audit including emission sources to consider.

1.4.1 Organizational Boundaries

Organizational or system boundaries provide two possibilities for calculating carbon emissions: the equity share approach and the control approach. In the equity share approach, an organization is responsible for carbon emissions based on its equity share in an operation. The control approach is used when the organization wishes to account for all operations over which it has control. In the case of the Department of Mechanical Engineering, most of the emissions due to energy consumption come from research labs, offices, and classrooms, which are within the control of the department. Other emission sources, primarily from materials and transportation, are also in the control of either the department as a unit, or its individual members. So, the control approach was believed to be the appropriate choice in this case. However, in calculating HVAC consumption by the Department the equity share approach was taken in most buildings.

1.4.2 Operational Boundaries

Operational boundaries are used to establish which emissions will be considered. The Greenhouse Gas Protocol separates all possible emissions into three "scopes":

Scope 1 consists of all direct emissions occurring from sources owned and operated by an organization. This is commonly a result of the combustion of fossil fuels for

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[7] "A Corporate Accounting and Reporting Standard," *The World Resources Institute and The World Business Council for Sustained Development,* 2004, <http://www.ghgprotocol.org/files/ghg-protocol-revised.pdf> Accessed 13 May 2008.

electricity and HVAC purposes, fuel use in vehicles owned and operated by the organization, or any chemical processes that have emissions associated with them.

Scope 2 consists of indirect emissions from the production of purchased electricity. The emissions occur at the facility that generates the electricity, but they are still considered a responsibility of the organization that consumes it.

Scope 3 is composed of all other indirect emissions not covered in Scope 2. The reporting of these emissions is considered optional by the Greenhouse Gas Protocol. These emissions are a consequence of the organization's activities, but occur from sources not owned or directly controlled by the organization. Major areas in this scope include: transportation of employees, waste, materials; use of consumable materials; and the construction and renovation of buildings.

The only emissions that fall under scope 1 for the Department are those associated with transportation of the three racing teams. Scope 2 will be the largest source of emissions, with all of the Department's energy being purchased from outside sources (energy from the T.B. Simon Power Plant is considered purchased, although payments are not made). Despite scope 3 being optional, the daily commuting of employees, faculty travel, and the purchase of materials are large contributors to the Department's footprint and it seemed inappropriate to neglect them.

These scopes provided a useful way to define, identify and account for emissions, but were not used in the calculation stages of this audit. Instead, unique categories were defined that were better suited to an academic department of engineering.

1.4.3 Emission Categories

In order to further organize emissions, four categories were created that encompass all of the emissions created or offset by the Department of Mechanical Engineering. These categories provide an easier method of measuring carbon emissions by allowing the calculation of emissions from similar sources at the same time. The four categories that were chosen are: Energy Use, Material Use, Transportation, and Carbon Offsets; although the Department had no emission offsets at the time of the audit and so no calculations were made in the last category.

1.4.3.1 Energy Use

The Department of Mechanical Engineering uses space in several buildings, four of which are powered by the T.B. Simon Power Plant at MSU, while another two are powered by off-campus providers. The primary users of energy are labs, office space, and classrooms, plus several other smaller users that were considered.

1.4.3.2 Material Use

The use of materials contributes significantly to carbon emissions. Every material has an "embodied carbon" value associated with it, which refers to the quantity of carbon emitted as a result of the production of a material. Materials can be separated into two types based on use: permanent and consumable. Permanent materials are those used in the construction and renovation of buildings, and also include anything that could be considered "permanent", such as lab equipment, machinery, etc. Consumable materials are those which are used and replaced regularly, such as paper and food.

1.4.3.3 Transportation

The daily commute of the employees of the Department contributes heavily to the carbon footprint through the combustion of fuel. Faculty and graduate students partake in a significant amount of research related travel, both by car and plane. The racing teams in the Department travel to several competitions across the country every year, with their car and most, if not all, of the team. The disposal of the Department's waste and any other Department related transportation was considered as well.

1.4.3.4 Carbon Offsets

Carbon offsets provide methods of reducing a footprint without directly reducing emissions. The easiest method to offsetting emissions is to purchase them directly at a fixed cost per unit, which can be done through various organizations. Forestation is another type of offset that has the added benefit of lasting many years. Plant life uses CO_2 as part of its natural processes, so the practice of planting trees is common for reducing levels of CO_2. With both of these methods, emissions are not actually reduced, but the reduction of CO_2 in the atmosphere is credited to the organization that pays for this reduction. At the time of the audit the Department had no carbon offsets.

2. Determination of the Carbon Footprint

2.1 Energy Use

2.1.1 Boundaries

Energy consumption was considered for all of the activities that are a direct result of research, teaching, and outreach in the Department. There are four on-campus buildings in which the Department of Mechanical Engineering occupies space as well as two that are off-campus. These buildings contain offices and labs used by Departmental faculty, staff, and students. There are several teaching labs that are used only by the Department of Mechanical Engineering, but the remaining Mechanical Engineering classes take place in rooms that are not controlled by a single department.

The energy used in offices, labs, classrooms, and during events such as meetings and seminars was included. Any energy used by members of the Department that is not directly related to the Department's functions, such as energy use in dormitories, was not considered part of this carbon footprint.

2.1.2 Assumptions

Undergraduate students were assumed to take only the required number of credits to graduate with a B.S. in Mechanical Engineering. Requirements providing students with several different classes to choose from, primarily senior electives, were assumed to have a consistent number of students taking each course from year to year. Only the energy consumed in the classroom during class time was considered (plus an additional ten minutes to account for students/faculty arriving early and leaving late). The Department of Mechanical Engineering has not taken responsibility for the energy consumed by lights or computers that are left on, unless this occurs in space controlled directly by the Department.

HVAC is provided to buildings using steam supplied to campus from the T.B. Simon Power Plant. Steam use was assumed to be uniform throughout each building due to difficulties encountered in measuring the steam used in each room.

The T.B. Simon Power Plant burns primarily coal, but small amounts of natural gas are used as well during peak times and in other situations that call for it. The reason for each use of natural gas was not available, so it will be treated as if it were used at a constant rate for steam production.

2.1.3 Data/Results

2.1.3.1 T.B. Simon Power Plant

The appropriate information was provided by the T.B. Simon Power Plant to allow an estimate of the quantity of carbon emitted per unit of steam and electricity. During the 2006-2007 fiscal year, the power plant burned (M_c=) 231×10^6 kg of coal and (V_g=) 10.1 million cubic meters of natural gas. This resulted in the production of (S_T=) 2.282 billion kgs of steam of which (S_E=) 1.011 billion kg were used to generate (E=) 319.4 GWh of electricity and the rest (S_{HVAC}=1.271 billion kg) was sent to campus for use in HVAC. Hence, based on this data, (S_e=) 3168.8 kg of steam[C7♣] are required for each MWh of electricity. One kg of steam uses (m_c=) 0.101 grams of coal[C8] and (v_g=) 0.0044 cubic meters of natural gas [C9]. When a kg of coal is burned it releases 0.715 kg C[8] and each cubic meter of natural gas releases 0.527 kg C[8]. As a result, (c_e=) 0.229 tC are emitted for every MWh of electricity consumed[C12], and (c_{HVAC}=) 0.075 tC for each kg of steam sent to campus[C13].

Table 2: Survey Results for office usage by faculty and staff in Mechanical Engineering.

Employee Type	Faculty	Staff
Time in Office (hrs/day)	8.1	7
Desktop computers (/office)	1.12	1.5
Monitors (/office)	1.47	2.17
Computers on all day	75%	90%
Computers on all night	71%	83%
Lights on all day	47%	34%
Energy consumption (kWh/ft^2/yr)	5.07	7.07
Energy consumption (kWh/year)	43810	43662

2.1.3.2 Office Space

Ceiling lights and computers are the primary consumers of electrical energy in most offices with other devices such as fans, lamps, or radios making up small contributions either as a result of infrequent use or small power requirements. A survey was distributed to faculty and staff in order to establish levels of office occupancy and

♣ Cx refers to the line number in Appendix C where the calculation of a quantity is provided.
[8] "Direct Emissions From Stationary Combustion Sources," *U.S. Environmental Protection Agency*, 2008, <http://www.epa.gov/stateply/documents/resources/stationarycombustionguidance.pdf> Accessed 4 June 2008.

appliance or device usage. Approximately 43% of faculty and 29% of staff responded and the results, together with details of typical power ratings of appliances were used to calculate an annual power consumption in all faculty and staff offices which were found to be (E_f=) 46.7 MWh and (E_s=) 44.3 MWh respectively, or 5 and 7 kWh/sqft (see Table 2). Photocopying was handled separately and the annual energy consumption by copy machines in the department was found to be (E_c=) 623 kWh. Hence the total electricity consumption in all of the faculty and staff office space in the department was estimated to be (E_o=) 91.6 MWh per annum[C17]. The uncertainty in this data was estimated to be 14%.

2.1.3.3 Research Labs

Workshops, design labs, and teaching labs used outside of classroom hours as well as research labs were included in this category. Lab visits and surveys distributed to graduate students were used to identify the energy usage and characteristics of labs and the equipment in them (Appendix A). The annual electrical energy consumption was found to vary from the order of 1 MWh to 15 MWh with a total for all labs estimated to be (E_L=) 236 MWh annually with an uncertainty of 17.5% which took account of variations in appliance usage and consumption characteristics.

Table 3: Classroom Usage by Faculty in the Department of Mechanical Engineering

Classroom Size (No. of Students)	Light Fixtures Used (~73W)	Preferred Teaching Method				Weekly Lecture Hours
		Chalk Board	Overhead Projector (~500W)	Slideshow Presentation (~500W)	Use of Microphones (~200W)	
Small(<50)	9.9	50%	17%	17%	17%	49.39
Medium(50-150)	24.9	29%	29%	42%	0%	35.5
Large(>200)	-	-	-	-	100%	13
% Energy used in classrooms	81%	33%	27%	27%	13%	-

2.1.3.4 Classrooms

Lectures and computer labs utilize electricity for ceiling lights, computers, and projectors. Similarly, teaching labs contain these, plus several pieces of high power equipment. By counting the number of lights, projectors, etc. in each room, an average number of devices per lecture were determined. A survey was distributed to gather information regarding teaching habits (i.e. use of lights, projectors, microphones, etc.) so the average consumption in each type of classroom during a lecture could be determined. Then using data on the average number of students enrolled in each required course in the BSME degree for the past several years, the total consumption in lectures was determined (see table 3). Several incomplete responses resulted in a lack of data for large lectures. A list of graduate level courses and the number of students enrolled in them was used to determine the classroom emissions from M.S. and PhD courses. This resulted in estimates of (E_{CR}=) 19.6 MWh, (E_{CL}=) 950 kWh, and (E_{TL}=) 7.1 MWh for lectures, computer labs, and teaching labs, respectively, giving a combined total of (E_{MEC}=) 27.7 MWh annually for all classrooms used by the Department[C22]. The uncertainty on this calculation was estimated to be 18% and took account of extra credit taken amongst other factors.

2.1.3.5 HVAC

It was assumed that steam usage was constant throughout a building and the usage by the Department was calculated based on the proportion by volume of the building occupied by the Department; or in the case of space not under the control of the Department, such as classrooms, by the time for which the space was used by the Department. These data are summarized in Table 4 from which it was deduced that the Department used about (S_{ME}=) 2.8×10^6 kgs of steam, which creates emissions of (C_{HVAC}=) 237.1 tC annually[C24]. The uncertainty on this calculation was estimated to be 14%.

Table 4: HVAC Use in Buildings used by the Department of Mechanical Engineering

Building	Percent of Building Space Used by ME	Building Steam Use (kg)	ME Steam Use (kg)	Carbon Emission (kg C)
EB	14.4%	4212	595	44,458
ERC*	27.2%	7615	2068	154,551
Fee Hall	1.47%	10192	149	11,165
All	10.7%	21928	2813	210,174

2.1.3.6 Composite Vehicle Research Center (CVRC)

The CVRC is an off-campus facility, so energy for all purposes is provided by the Lansing Board of Water and Light in the form of electricity and natural gas. The CVRC is

* Energy and Automotive Research Laboratories (EARL) included in the Engineering Research Complex

one of two tenants in the building for which a single energy bill is received by the landlord, the MSU Foundation. The Foundation has conducted some studies of quarterly energy consumption by the CVRC and based on this data its total consumption was estimated to be (V_{CRVC}=) 2226 million cubic feet of gas annually which creates (C_{CVRCG}=) 33.2 tC of emissions[C26] and (E_{CVRC}=) 294 MWh of electricity. The uncertainty on this calculation was estimated to be 11%.

2.1.3.7 Water Use

Water provided to MSU's campus is pumped from a reservoir using electric motors. Specific information regarding these motors was not available, therefore it was not possible to determine the energy used to provide water to campus facilities. This is likely small compared to the rest of the energy usage, so it has been neglected.

2.1.3.8 Other Contributors

The Division of Engineering Computing Services maintains several public-access computer labs for engineering students which Mechanical Engineering students sometimes use for their coursework thus contributing to the Department's footprint. Although information on the HVAC and electricity consumption in these labs could have been calculated, no data on the usage of these rooms by Mechanical Engineering students was available and so this potential source of emissions has been neglected in the audit.

The use of conference/meeting rooms makes a relatively small contribution to the footprint. The Department of Mechanical Engineering controls five of these rooms for which it maintains booking sheets. These booking sheets were utilized to estimate the energy consumption based on the number of lights per room and the availability of an LCD projector. The energy consumption was estimated to be (E_{SR}=) 1.2 MWh per year.

The three racing teams in the Department of Mechanical Engineering, i.e. Baja, Formula, and Solar Car contribute to the carbon footprint by using energy in shop facilities to build and maintain their cars. The Baja team was taken as typical and its energy consumption in the shop estimated to be about 15 MWh annually so a value of (E_{RT}=) 45 MWh for the three teams was included in the total energy consumption of the research labs.

Transmission losses are present between any buildings and their source of electrical power but it is difficult to determine losses precisely. The average level of transmission losses in the United States is currently 9.5%[9], which includes losses from voltage conversions, traveling long distances, and congestion in the power grid. This factor is difficult to calculate but should not be significant, due to the short distances between most MSU facilities and their electricity providers. Thus, based on the above information, it was estimated that 4% of power was lost in transmission. The uncertainty on this estimate was believed to be low at ± 2%.

2.1.4 Conclusion

All of the on-campus electricity usage described above results in (E_{ME}=) 695.7 MWh of energy consumption annually[C30]. After incorporating transmission losses, the carbon emissions from this electricity use were estimated at (C_E=) 171.3 tC[C31]. When this is combined with the emissions from steam and natural gas used for HVAC purposes, the total carbon emissions resulting from energy use is (C_D=) 442 tC[C32]. The uncertainties inherent in each component of this calculation were added together using a standard sum of errors approach to give an overall uncertainty of 11%.

2.2 Material Use

2.2.1 Boundaries

This section of the carbon footprint included all materials purchased by the Department. The only significant consumable material was paper, but permanent materials included steel, plastic, aluminum, and wood. There are no major construction projects planned for the department in the near future, so construction materials were not considered.

2.2.2 Assumptions

Purchases through the department or with department funds were the only factors considered for material emissions. Members of the department probably make personal purchases for their work, but these are insignificant, difficult to monitor and were neglected. A sample was taken by examining purchasing records for three months (July 2007, October 2007, and March 2008) because there was insufficient time to review all purchases made during a year. The carbon emissions from the production of desktop

[9] "Overview of the Electric Grid," *U.S. Department of Energy,* 2006, <http://www.energetics.com/gridworks/grid.html> Accessed 12 August 2008.

Table 5: Estimated quantities of materials purchased during the 2007-2008 fiscal year

Material	Mass (kg)	kg CO_2/kg[2]	kg CO_2	Percent of Total
Paper	7242	1.37	9922	38.68
Plastic	214.3	2.53	542.3	2.114
Steel	3595	1.82	6543	25.51
Rubber	17.43	3.3	57.53	0.224
Stainless Steel	5.444	6.15	33.47	0.130
Wood	1472	0.476	700.5	2.731
Glass	58.04	0.77	44.70	0.174
Aluminum	116.8	8.53	996.4	3.884
Vinyl	3.628	2.29	8.308	0.032
Copper	9.524	3.78	36.00	0.140
Polycarbonate	27.39	6	164.4	0.641
Polyester	1.814	2.7	4.898	0.019
Nylon	37.10	5.5	204.0	0.795
Polypropylene	9.705	3	29.12	0.114
Polystyrene	3.084	2.7	8.327	0.032
PVC	78.19	2.5	195.5	0.762
Silicon	2.721	5	13.61	0.053
Polytetraflouroethylene	1.542	0.1	0.154	0.001
Argon	638.8	0.1	63.88	0.249
Graphite	7.982	0.1	0.798	0.003
Neoflon	0.508	2.53	1.285	0.005
Cobalt	1.361	3.78	5.143	0.020
Zinc	0.907	3.2	2.902	0.011
Brass	1.814	3.71	6.730	0.026
Ceramics	2.176	0.55	1.197	0.005
Polyethylene	18.50	1.94	35.90	0.140
Lead	18.14	1.29	23.40	0.091
Bronze	7.256	1	7.256	0.028
Desktop Computers	N/A	N/A	6000	23.39

computer emissions were included based on a study which found that the production of a computer and monitor results in approximately 250 kg CO_2[10].

2.2.3 Data/Results

2.2.3.1 Production of Materials

The total annual purchases of consumable and permanent materials by the Department were examined to determine the materials they were composed of, the quantity of these materials, and whether or not any of the materials were post-consumer recycled. If appropriate information was not available, similar products were examined and assumed to have the same specifications. The mass and a value from the literature for embodied carbon for each material were used to determine the CO_2 emissions associated with their production.

The total amount of CO_2 resulting from consumable materials purchased in the 2007-2008 fiscal year was (B_{CM}=) 9922 kg, while that from permanent materials was (B_{PM}=) 15,735 kg (see Tables 5 and 6). Together these equate to approximately (C_M=) 7.00 tC annually[C36].

2.2.3.2 Material Waste Emissions

All waste from MSU facilities is sent to the Granger landfill site in Dewitt Township. Granger has been using methane capture technologies for almost two decades to provide a renewable energy source, which helps to offset emissions. The average U.S. landfill with methane capture has a negative net emission[11]. Therefore, material waste does not increase the carbon footprint of the Department and may decrease it slightly after waste transportation has been taken into account.

2.2.4 Conclusion

The emissions from material used by the Department totaled 7.00 tC, which is a small amount compared to other sources of emissions. There are three main sources of error in this calculation, namely the use of sampling, the identification of the raw materials in products and the use of embodied carbon data from the UK where more progress has

[10] Williams, Eric. 2004. “Energy intensity of computer manufacturing: Hybrid assessment combining process and economic input-output methods” *Environmental Science & Technology,* 38(22): 6166-6174.
[11] “Global Warming – Waste,” 2008, <http://yosemite.epa.gov/oar/globalwarming.nsf/WARM?openform> Accessed 27 September 2008.

been made in reducing carbon emissions than in the US. To account for these potential errors, the uncertainty on the emissions from material use was estimated to be 28.5%.

Table 6: **Material Emissions Data based on data in Table 5**

Material	Mass (kg)	Specific Emissions ($kg\ CO_2/kg$)[10]	Emissions ($kg\ CO_2$)	Carbon Emission (tC)
Consumable Materials				2.708
Paper	7242.5	1.37	9922.2	
Permanent Materials				4.294
Steel	3594.9	1.82	6542.8	
Wood	1471.6	0.476	700.5	
Plastic	214.3	2.53	542.3	
Aluminum	116.8	8.53	996.4	
Desktop Computers	N/A	N/A	6000	
Others	N/A	N/A	953.1	
Total Materials				7.00

2.3 Transportation

2.3.1 Boundaries

Transportation emissions by the department include the daily commute of employees (faculty, staff, and graduate students), department-reimbursed travel, the transportation of waste, and travel by the department's racing teams. Traveling by undergraduate students was not included unless it was paid for by the Department or the student was a Departmental employee who must commute to work. Employees are hired to provide a service, while students are recipients of that service. In this study only the emissions that result from the provision of the service were considered.

2.3.2 Assumptions

The Boeing 757-200 airliner was the most commonly used jet airliner in the Department's flight records, and so its performance characteristics were used in all calculations; namely the plane achieves 0.3395 mpg with a passenger load of 214 and each gallon results in 9.57 kg CO_2[12] or 0.036 kg C per person per mile[13].

Ground travel by taxi was assumed to have the fuel efficiency of a 2005 Ford Crown Victoria, as these are commonly used by taxi companies. When a personal vehicle was driven and gasoline receipts were not provided, the average fuel efficiency of vehicles from the commuter survey was used. Those who commute via bike or moped were assumed to travel by car for a small fraction of the year due to inclement weather conditions.

2.3.3 Data/Results

2.3.3.1 Commuting

Responses from a survey of faculty, staff, and graduate students were used to calculate average commuting distances, fuel consumption, and the number of people per car (see Table 7) from which the emissions generated by faculty, staff, and graduate students commuting to work were calculated as (C_{CF}=) 34.35 tC, (C_{CS}=) 17.37 tC, and (C_{CGS}=) 43.97 tC, respectively and hence the total emissions per year due to commuting were estimated to be (C_{COM}=) 95.7 tC[C40] with an uncertainty of 8%.

Table 7: Summary of results from a survey on commuting habits of faculty, staff, and graduate students.

Position in Dept.	No.	Commuting Methods: % Usage				Distance (miles)/People Per Vehicle	Extra Miles /Day	Average MPG	Annual Emissions tC /Person
		Car	Bus	Bike	Moped				
Faculty	42	96	0	0	4	14.3/1.13	1.91	24.5	0.82
Staff	21	100	0	0	0	18.7/1.38	2.25	25.1	0.83
Graduate Students♣	133	66	10	24	0	8.00/2.95	1.48	26.4	0.33
All	196	76	7	16	1	10.5/2.39	1.65	25.9	0.49

[12] "Indirect CO_2 Emissions From Business Travel (Scope 3)," *World Resources Institute*, 2005, <http://www.clean-aircoolplanet.org/documents/Business_Travel_Emissionsv1.1.xls> Accessed 2 July 2008.
[13] "757-200 Technical Characteristics," *Boeing*, 2008, <http://www.boeing.com/commercial/757family/pf/pf_200tech.html> Accessed 2 July 2008.
♣ To account for variations from semester to semester, the number of graduate students is an average determined by the numbers that were enrolled for several previous semesters.

2.3.3.2 Reimbursed Air Travel

Three months of reimbursed travel were sampled (July 2007, October 2007 and March 2008) as for the material usage. In an average month 55,219 miles are flown by members of the Department resulting in the emission of (C_{AT}=) 6.5 tC per year based on the assumptions above. The use of the sample and large variability in aircraft performance led to an uncertainty of 20% on this estimate.

2.3.3.3 Reimbursed Ground Travel

From the same sample it was found that an average of 14.7 gallons of gasoline and 4.38 gallons of diesel were consumed per month. Approximately 8.8 kg CO_2 are emitted per gallon of gasoline and 10.1 kg CO_2 per gallon of diesel[14]. Consequently an estimated (C_{GT}=) 1.5 tC are emitted every year due to department reimbursed ground travel. Again an uncertainty of 20% was estimated for this figure.

2.3.3.4 Waste Transportation

On an average day, four trips are made by garbage trucks between the MSU campus and the Granger Landfill in Dewitt (about 5.5 miles one-way). The Department of Mechanical Engineering represents only about 2% of the MSU population based on student numbers and so might generate 30 garbage truck trips per year, or about 330 miles. Therefore the emissions associated with waste transportation were expected to be insignificant and have not been included.

2.3.3.5 Other Transportation

The racing teams based in the Department of Mechanical Engineering travel across the country several times per year for competitions, with several vehicles to transport the team and their car. Based on the average distance to a typical set of destinations, the average fuel efficiency of the types of vehicles, and the number of travelers, the emissions from travel of all three teams were estimated to be (C_{RT}=) 4.1 tC in a typical year.

2.3.4 Conclusion

Transportation provides a very significant source of emissions within the Department, totaling (C_T=) 108 tC[C44] and leaving a large opportunity for improvement.

[14] "Emissions Facts: Average Carbon Dioxide Emissions Resulting From Gasoline and Diesel Fuel," *Environmental Protection Agency*, 2007, <http://www.epa.gov/otaq/climate/420f05001.htm> Accessed 7 July 2008.

The majority of this is a result of commuting. The total uncertainty was estimated to be 7%.

2.4 Total Carbon Footprint

2.4.1 Reliability of Calculation

It is important to examine the level of accuracy in the audit since a data from a wide range of sources and with varying levels of reliability were employed. Consequently for each emission category the uncertainty in the calculation of carbon emissions has been estimated and stated in the preceding sections.

Standard methods for calculating uncertainties yielded an estimate of 9.5% for the uncertainty associated with the total carbon footprint of the Department. This does not take account of emissions that were intentionally or unintentionally omitted from the calculation.

A number of sources of emission were neglected in the audit in most cases due to a lack of reliable data. These sources include water supply, transportation of waste, personal purchases by employees in support of work, and usage by mechanical engineering students of public-assess computer rooms provided by the Division of Computer Services. These sources of emissions are believed to be small compared to the total footprint.

2.4.2 Combined Results

The Department of Mechanical Engineering has a carbon footprint of (C=) 557 ± 53 tC[C45]. This is approximately 2.73 tC per employee. Purdue University and the University of Pennsylvania reported a carbon footprint of 2.1 tC per person[15] and 1.9 tC per person[16] respectively. These footprints appear significantly lower initially because they were assessed for the entire university, rather than a single academic department. As a result, although these audits include major contributors such as dormitories, student organizations, and university support services, the carbon footprint is distributed among both employees and students. The equivalent figure for the Department of Mechanical Engineering at MSU is 0.55 tC. However, it seems more appropriate when considering a

[15] "Carbon Neutrality At Purdue," *Purdue University*, 2007, <http://web.ics.purdue.edu/~cneutral/CN@P_FINAL.pdf> Accessed 12 May 2008.

[16] "University Of Pennsylvania Carbon Footprint," *University Of Pennsylvania*, 2007, <http://www.aashe.org/resources/documents/PennGreenhouseGasReport.pdf> Accessed 12 May 2008.

single academic department to normalize using the number of employees since the audit considered students as 'customers' or recipients of a service, i.e. the provision of education. Consequently, the emissions from student activity were only included in the audit when they were actively engaged in partaking of the service.

Fox News recently reported that their carbon footprint had a value of 3.7 tC per person[17]. This is significantly higher, but provides a comparison between two different types of service organizations.

In the United States, the average carbon footprint per person is 5.4 tC[18, 19], so the work-related carbon footprint of the average employee in the Department of Mechanical Engineering is equal to about 51% of the total footprint of an average citizen in the US.

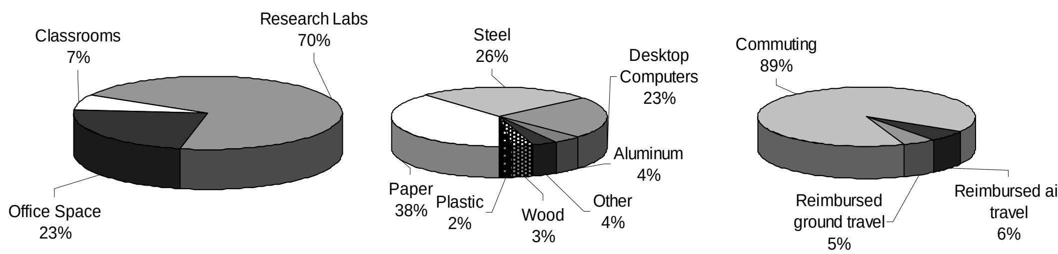

Figure 2: Pie charts showing the distribution of electricity usage (*left*); of contribution to footprint by material usage (*center*) and of contribution by transportation (*right*)

[17] "Fox News Corporation To Go Green" *TheIndependent*, <http://www.treehugger.com/files/2007/05/fox_news_corpor.php> Accessed 18 October 2008.

[18] "U.S. and World Population Clocks." *U.S. Census Bureau*, <http://www.census.gov/main/www/popclock.html> Accessed 18 October 2008.

[19] "U.S. Carbon Dioxide Emissions Reach Record High in 2007" <http://news.mongabay.com/2008/0521-energy.html> Accessed 18 October 2008.

3. Carbon Footprint Reduction

3.1 Energy Consumption

Since energy consumption is responsible for approximately 80% of the Department's carbon emission, a decrease in the emissions associated with energy use is critical to reducing the Department's footprint. A number of options are available and can be divided into those associated with reducing energy consumption and those associated with reducing carbon emissions during energy generation. Many of the latter are not viable for the Department to pursue at the moment because they would involve changing the operation of the T.B. Simon Power Plant over which the Department has no control. The use of biomass or more natural gas, and carbon capture technologies fall into this group. Carbon capture technologies potentially include air extraction devices[20] and sequestration during the power generation process[21] which would cost about (P_{CCT}=) $220 per tC or about ($P_D$=) $100,000[C47] to achieve carbon neutrality for the Department's energy consumption. The localized implementation of renewable energy generation is a possible option for the Department and some examples are explored below.

3.1.1 Renewable Energy

Renewable energy sources are the fastest growing methods of reducing carbon emissions. Costs are continuously decreasing so that a long-term payback is becoming viable.

3.1.2.1 Solar Energy

There are two main options: photovoltaic cells for power generation and solar water heating as part of an HVAC system. Michigan does not have good solar resources so that solar water heating is probably not viable. However, on average day there is 3.5 to 4 kWh/m^2 of usable sunlight[22] which is sufficient to render photovoltaic cells a viable proposition. The average capital cost of solar energy is approximately $4 per watt[23], which would produce 1.37 kWh annually. The electricity would cost approximately $0.142 per

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[20] "First Successful Demonstration of Carbon Dioxide Air Capture Technology Achieved," *Earth Institute at Columbia University*, 2007, <http://www.physorg.com/news96732819.html> Accessed 10 July 2008.

[21] "Carbon Capture Research," *U.S. Department of Energy*, 2007, <http://www.fossil.energy.gov/programs/sequestration/capture/> Accessed 28 July 2008.

[22] "State Energy Alternatives," *U.S. Department of Energy*, 2008, <http://www.eere.energy.gov/states/alternatives/resources_mi.cfm> Accessed 11 July 2008.

[23] "Solar Energy," *Regional Government Network for Sustainable Development*, 2007, <http://www.regional-renewables.org/cms/front_content.php?idcatart=50> Accessed 22 July 2008.

kWh assuming a 20-year life for the capital equipment,. However, the costs vary based on the quality and supplier. For example, GE offers a 12.6 kW system for $82,530, excluding installation fees and maintenance costs; so that a capital cost of $500,000 to $750,000 would be involved in providing sufficient generating power to meet the Department's needs which is equivalent to $150 to $225/tC over a 20-year period. Several solar companies including SolarCity and Citizenre are now exploring the option of leasing solar panels, or have already begun to do so. Some of these organizations claim that money can actually be saved on electricity bills through leasing due to the lower upfront costs[24].

3.1.2.2 Wind Energy

Michigan's west coast is considered to have "outstanding" potential for wind energy (600-800 W/m^2 at a height of 50m), however the East Lansing area is considered to have "poor" (0-200 W/m^2) or "marginal" potential (200-300 W/m^2)[22]. With these low wind potentials, wind turbines may only produce 20% or less of their total potential. Low power wind turbines typically cost between $3000 and $5000 per kW of capacity[25] which raises the cost to at least $15 per watt and up to $25 per watt.

3.1.2.3 GreenWise Electric Power

"Greenwise Electric Power" is a service provided by the Lansing Board of Water and Light to all of its customers. This program offers consumers the option of purchasing energy from renewable energy sources in (P_G=) 250 kWh blocks at $7.50 per block[26]. This would add (P_{CVRC}=) $8900 to the electricity bill for the CVRC[C49].

3.1.5 Daily Electricity Use

Since the Department does not control the design, maintenance or operation of the physical plant that it occupies there is little opportunity to use energy-saving features and devices such as geothermal heat pumps, green roofs or efficient lighting to reduce energy consumption. However, changing the habits of members of the Departments to reduce consumption is viable over a reasonable period of time and could be achieved with an information campaign based on posters, emails and the Department website.

[24] "Solar City Offering No Money Down, Residential Solar Panel Leases In California," *Tree Hugger*, 2008. <http://www.treehugger.com/files/2008/04/solar-city-lease-money-down.php> Accessed 18 November 2008.
[25] "How Much Do Wind Turbines Cost?" *Windustry*, 2007. <http://www.windustry.org/how-much-do-wind-turbines-cost> Accessed 18 November 2008.
[26] "Green-Wise Electric Power," *Lansing Board of Water and Light*, 2008, <http://www.lbwl.com/gwp.asp> Accessed 22 July 2008.

3.2 Material Use

3.2.1 Purchasing Recycled Materials

The use of materials within the Department is unlikely to decrease, but emissions can be reduced by using predominately recycled materials. Over 38% of the Department's material emissions result from paper, of which only 3% was post-consumer recycled. The use of recycled materials reduces the embodied energy of paper by more than half to 11.83 MJ/kg[10]. University Stores offers two types of 100% post-consumer recycled paper for $3.652 per ream and $3.648 per ream. So for an extra $281 annually, all of the Department's paper could be purchased as 100% post-consumer recycled with only an 11% increase in current costs. This would cut emissions by 1.5 tC or more than 20% of the material use footprint.

3.3 Transportation

3.3.1 Information Campaigns

A simply and viable method for reducing emissions from commuting is to reduce the number of vehicles traveling each day. For those who live close, alternate modes of transportation exist such as buses, biking, walking, and efficient vehicles such as mopeds. However, most faculty and staff live far enough away that driving is necessary. Carpooling can remove an entire person's daily emissions but is rarely pursued, most likely due to a lack of effort to find carpooling groups. The Department could provide assistance by collecting and organizing information to identify carpooling options. This initiative could easily expand beyond the Department and the incentives in terms of money saved on gas are considerable. If 10% of commuting journeys were eliminated the carbon footprint of the Department would be reduced by 9.6 tC.

3.3.3 Carbon Neutral Flights

Several airlines now offer passengers the option of carbon neutral flights, with an additional fee added to ticket price. The airline uses this money for carbon offsets such as forestation, or to fund renewable energy projects such as building wind farms or increasing research. Only certain airlines offer this option, but the Department could offset carbon emissions from flights by purchasing offsets from other sources.

Table 8: Costs of Recommended Reduction Methods

Method	Description/Requirements	Cost
Solar Energy	Photovoltaic solar cells. Require space open to sunlight: building roofs are the best option.	• \$500,000 - \$750,000 for all electricity needs. • \$150 - \$225 per tC (assuming a 20-year life)
Greenwise Energy	Renewable energy purchased through the Lansing Board of Water and Light.	• \$8818 p.a. to offset CVRC's electricity use • \$122 per tC
Carbon Offsets	Offset purchases that result in emissions reductions elsewhere.	• \$19,000 - \$25,000 annually to offset all of the department's emissions
Recycled Paper	Purchasing 100% post-consumer paper.	• \$188 per tC • \$281 to purchase all recycled paper
Informative Campaigns	Keeping students, faculty, and staff updated and informed on a regular basis to encourage environmentally friendly habits.	• Varying depending on the type and magnitude of the campaign
Forestation	Planting and maintaining forests. Requires large amounts of land.	• \$100 - \$300 per tC • \$55,600 - \$167,000 to offset all emissions

3.4 Carbon Offsets

3.4.1 Purchase of Offsets

Carbon offsets can be purchased through various organizations at a range of prices. The Carbon Neutral Company sells them at (p_{off}=) \$14.77 per metric ton of CO_2[27]and Native Energy offers them for \$12 per metric ton of CO_2[28]. It would cost the department about (P_{off}=) \$25,000 annually[C51] to offset all emissions, making it a potentially poor long-term solution but a viable short-term solution.

3.4.2 Forestation

If the Department could acquire a packet of land, it could pursue forestation as a source of recurring offsets. Trees use CO_2 as a part of their natural processes, resulting in an average of (F_C=) 2.4 tC sequestered per year for a typical acre of forest[29]. The costs of planting and maintaining an acre of forest can range anywhere from (P_F=) \$218 to \$729 depending on the techniques and types of plantation used[26, 30]. The Department would require about (F_{ME}=) 260 acres to offset its total footprint[C54] and this could cost up to (P_{ME}=) \$190,000[C55] to plant.

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[27] "Offset By Tonne(s)," *The Carbon Neutral Company*, 2008, <http://www.carbonneutral.com/shop/details.asp?productid=1507&productname=Offset%20by%20tonne(s)> Accessed 24 July 2008.

[28] "An Inconvenient Truth," *Native Energy*, 2008, <http://www.nativeenergy.com/pages/an_inconvenient_truth/29.php> Accessed 24 July 2008.

[29] "Benefits of Trees in Urban Areas," *Colorado Tree Coalition.* 2008. <http://www.coloradotrees.org/benefits.htm> Accessed 25 July 2008.

[30] Lynch, Loretta, Bob Tjaden. 2000. "When a Landowner Adopts a Riparian Buffer – Benefits and Costs." *Agriculture and Resource Economics, University of Maryland,* <http://www.riparianbuffers.umd.edu/fact/FS774.html> Accessed 24 October 2008

3.5 Recommendations

A wide spectrum of opportunities exists for an organization seeking to reduce its carbon footprint and some of these are summarized in Appendix A together with their applicability on campus and to the Department. The status of the Department of Mechanical Engineering as the most elementary unit in a large organization limits its freedom to pursue some of these options. The options that appear to be viable together with their estimated costs are summarized in Table 8 and listed in detail in Appendix B. Ideally, the Department would pursue several short-term solutions, such as purchasing offsets to immediately reduce its carbon footprint while simultaneously planning and investing in long-term solutions for the future such as forestation or renewable energy.

Table 9: Carbon Footprint of Department of Mechanical Engineering at Michigan State University

Emission Source	Carbon Emissions (tC/year)	Percent of Footprint
Energy Use	442	79.4%
Material Use	7	1.3%
Transportation	108	19.4%
Total	**557**	**100%**

4. Conclusions

Carbon emissions were considered in four categories: energy usage, materials, transportation and carbon offsets for the Department of Mechanical Engineering at Michigan State University. Energy consumption occurring as a direct result of the Department's research teaching and outreach activities was considered and found to generate 442 tC annually. Permanent and consumable materials purchased by the Department in a typical year were found to be the source of 7 tC. Transportation, including business travel, commuting by employees and the College racing teams was responsible for 108 tC annually. The Department has a total annual carbon footprint of 557 ± 53 tC (see table 9). This is approximately 2.73 tC per employee and compares to 2.1 and 1.9 reported by Purdue University[15] and the University of Pennsylvania[16] respectively.

The Department of Mechanical Engineering is believed to be the first academic department at MSU to have audited its carbon footprint. Only a few schools in the country have audited their carbon footprint and no evidence was found of any other individual academic departments attempting to do so. This audit was initiated to establish the level of emissions for which the Department is responsible, to allow a plan for carbon neutrality to be constructed and to raise awareness and stimulate discussion amongst students and faculty about the environment impact of engineering activities.

In the short-term the Department could achieve carbon neutrality by purchasing carbon offsets, of which it currently has none, at a cost of about $25,000 per annum. In the long-term consideration needs to be given: to reducing emissions from commuting; to the use of renewable energy sources such as local solar and wind installations and to the establishment of an ME forest to permanently offset the Department's emissions.

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Appendix A: Summary of Research Lab Visits and Surveys

Lab	Method Used	Major Energy Consumers Excluding Lighting (Approximate Energy Consumption Per Unit)	Estimated Annual Energy Consumption (kWh)
Computational Fluid Dynamics	Visit	~20 Desktop Computers (215 W)	8650
Flow Control*	Visit	Wind Tunnel Fan (6 kW); ~4 Desktop Computers (270 W)	10,600
Experimental Mechanics	Visit	Material Testing System 810 (500 W); ~3 Desktop Computers (230 W)	650
Turbomachinery	Visit	~7 Desktop Computers (160 W); CNC Mill (1.3 kW)	4900
Cardiovascular &Tissue Mechs.	Visit	~4 Desktop Computers (160 W); Refrigerator (150 W)	4500
Orthopedic Biomechanics	Survey	N/A	4600
Turbulent Mixing	Visit	3 Lasers (6 kW, 5 kW, 3.5 kW); ~7 Desktop Computers (160 W)	6100
Combustion	N/A	Not currently in use.	N/A
Turbulent Shear Flow*	Visit	Refrigerator (150 W); Wind Tunnel Fan (18.6 kW); 3 Blowers (11.1 kW, 22.3 kW, 37.3 kW); ~4 Desktop Computers (160 W)	16,900
Advanced Manufacturing*	Visit	Mill (21 kW); Material Testing System Insight (6 kW); Carbolite Furnace (3 kW); Calorimeter (2.5 kW); ~5 Desktop Computers (160 W)	15,800
Controls and Mechatronics	Visit	~3 Desktop Computers (160 W)	930
Computational Design	Survey	N/A	4000
Dynamics and Control	Survey	N/A	8600
Vibrations	Survey	N/A	4900
Computational Structural Mechanics	Survey	N/A	2200
Laser Diagnostics for Energy and Environment	Survey	N/A	840
Optical Measurements	Visit	~1 Desktop Computer (160 W)	2800
Biofluid Magnetic Research Diagnostics	Survey	N/A	3500
Biothermomechanics	Visit	~2 Desktop Computers (160 W); Cooling System (1.4 kW)	14,800
Thermal Engineering	Survey	N/A	2000
Biomechanical Design	Visit	~2 Desktop Computers (270 W);	14,800
Engine Research Labs	Visit	Hot Press (5 kW); 2 Furnaces (800W, 1 kW); 3 Pumps (2.5 kW); ~4 Desktop Computers (160 W)	49,700
Biomass Conversion	Survey	N/A	8600
Design Lab (shop for student design projects)	Visit	Belt Sander (2 kW); Band Saw (1.8 kW); Dust Collector (1.3 kW); 3 Drill Presses (1.4 kW); Soldering Iron (300 W); Power Drill (605 W); ~4	3300

* ERC lighting not in control of ME lab coordinators and employees contribute approximately 2000-3000 kWh per lab.

		PCs (160 W)	
Machine Shop	Visit	3 Drill Presses (1.2 kW); Belt Sander (2.1 kW); 3 Welders (12.6 kW); Band Saw (1.9 kW); 5 Lathes (3.5 kW); 2 Mills (2.9 kW)	41,400

Appendix B: Overview of Options for Reduction of Carbon Emission

Reduction Method	Category Affected	Effectiveness	Current Viability	Viability in Future
Carbon Capture Technologies	All	Potential to reduce emissions by power plant.	Poor	Good
Solar Power	Energy Use	Very effective as a zero emission electricity source.	Good with payback potential.	Excellent, price may reduce while efficiency increases.
Wind Power	Energy Use	May not be effective due to East Lansing's low wind potential.	Weak with low payback.	Good, if efficiency increases significantly.
Biomass	Energy Use	Very effective as a completely carbon neutral source.	Weak: power plant can only burn small amounts currently.	Increased research at MSU gives this high potential for the future.
Greenwise Energy	Energy Use	Very effective. Carbon neutral energy can be purchased.	Excellent: easily obtained with reasonable cost.	Excellent: price could decrease over time.
Natural Gas	Energy Use	Effective, reduces emissions significantly.	Poor: too expensive.	Poor.
Geothermal Heat Pumps	Energy Use	Effective, reduces HVAC needs.	Poor due to retrofit difficulties	Good for new buildings
Green Roofs	Energy Use	Effective, reduces HVAC needs and lengthens roof lifetimes.	Poor due to retrofit difficulties	Good for new buildings
Efficient Lighting	Energy Use	Effective, reduces daily energy use.	Excellent with a low and one-time expense.	Excellent & should be updated as lighting efficiency increases.
Informative Campaigns	All	Effectiveness can vary significantly.	Excellent: easy and low cost.	Yes, these will always be an option.
Purchasing Recycled Materials	Material Use	Very effective at reducing material emissions.	Excellent: easy and low cost.	Yes, this will always be an option.
Increased Recycling	Material Use	Very effective at reducing material emissions.	Excellent: easy and low cost.	Yes, this will always be an option.
Increased Parking Prices	Trans.	Effectiveness is difficult to predict.	Poor due to political issues	Poor.
Carbon Neutral Flights	Trans.	Very effective to reduce all air travel emissions.	Good, but not always offered.	Yes, these will likely be offered on more airlines with time.
Offset Purchases	All	Very effective for emissions that are difficult to reduce.	Excellent, easy and medium costs.	Excellent: likely to become cheaper with time.
Forestation	All	Very effective in the long-term.	Poor: lack of Dept. land but low cost with long-term effect.	Good

Appendix C – Summary of Calculations

Line No.	Description	Equation	Calculation	Value
C1	Annual coal consumption by T.B. Simon power plant	M_c		$= 231 \times 10^6$ kg
C2	Annual gas consumption by T.B. Simon power plant	V_g		$= 10.1 \times 10^6$ m^3
C3	T.B. Simon power plant annual electricity production	E		= 319.4 GWh
C4	Steam usage for electricity generation	S_E		$= 1.011\times10^9$ kg
C5	Steam usage for campus HVAC	S_{HVAC}		$= 1.271\times10^9$ kg
C6	T.B. Simon power plant annual steam production	$S_T = S_E + S_{HVAC}$	$= (1.011 + 1.271) \times 10^9$ kg	$= 2.282\times10^9$ kg
C7	Steam required per MWh electricity generated	$S_e = S_E / E$	$= 1.011\times10^9/319.4\times10^3$	= 3169kg/MWh
C8	Coal required to generate 1 kg steam	$m_c = M_c / S_T$	$= 231 \times 10^6 / 2.282 \times 10^9$	= 0.101 kg
C9	Gas required to generate 1 kg steam	$v_g = V_g / S_T$	$= 10.1 \times 10^6 / 2.282\times 10^9$	$= 0.0044$ m^3
C10	Carbon emission per kg of coal burned	c_c		$= 0.715\times10^{-3}$ tC
C11	Carbon emission per m3 of gas burned	c_g		$= 0.527\times10^{-3}$ tC
C12	Carbon emission per MWh electricity	$c_e = S_e [(v_g \times c_g) + (m_c \times c_c)]$	$= 1.011\times10^9[(0.0044\times0.527\times10^{-3}) + (0.101\times10^{-3}\times0.715\times10^{-3})]/ 10^3$	= 0.229 tC
C13	Carbon mission per kg steam used for HVAC	$c_{HVAC} = S_{HVAC} [(v_g \times c_g) + (m_c \times c_c)]$	$= 1.271\times10^9[(0.0044\times0.527\times10^{-3}) + (0.101\times10^{-3}\times0.715\times10^{-3})]/ 10^3$	= 0.075 tC
C14	Annual electricity consumption in all faculty offices	E_f		= 46.7 MWh/yr
C15	Annual electricity consumption in all staff offices	E_s		= 44.3 MWh/yr
C16	Annual power consumption of photocopiers	E_c		= 0.62 MWh/yr
C17	Annual electricity consumption of office space	$E_o = E_f + E_s + E_c$	= 46.7 + 44.3 + 0.623	= 91.6 MWh/yr
C18	Annual electricity consumption of research labs	E_L		= 236 MWh/yr
C19	Annual electricity consumption in classrooms for ME courses	E_{CR}		= 19.6 MWh/yr
C20	Annual electricity consumption in comp/ labs for ME courses	E_{CL}		= 0.95 MWh/yr
C21	Annual electricity consumption in teaching labs for ME courses	E_{TL}		= 7.1 MWh/yr
C22	Annual electricity consumption during ME courses	$E_{MEC} = E_{CR} + E_{CL} + E_{TL}$	= 19.6 + 0.95 + 7.1	= 27.7 MWh/yr
C23	Steam usage by ME for HVAC	S_{ME}		$= 2.8\times10^6$ kg/yr
C24	Carbon emission from ME HVAC	$C_{HVAC} = S_{ME} \times c_{HVAC}$	$= 2.8\times10^6 \times 0.075$	= 237.1 tC/yr
C25	Gas consumption for HVAC at CVRC	V_{CVRC}		$= 64.84\times10^6$ m^3
C26	Carbon emissions from CVRC gas consumption	$C_{CVRCG} = V_{CVRC} \times c_g$	$= 64.84 \times 10^6 \times 0.527 \times 10^{-3}$	= 34 tC/yr
C27	CVRC annual electricity consumption	E_{CVRC}		= 294 MWh
C28	Electricity consumption in seminar rooms	E_{SR}		= 1.2 MWh/yr
C29	Electricity consumption by three racing teams	E_{RT}		= 45 MWh/yr
C30	Annual electricity usage by ME on campus	$E_{ME} = E_o + E_L + E_{MEC} + E_{CVRC} + E_{SR} + E_{RT}$	= 91.6 + 236 + 27.7 + 294 + 1.2 + 45	= 696 MWh/yr
C31	Carbon emissions from electricity consumption	$C_E = E_{ME} \times E_{losses} \times c_e$	$= (696 \times 1.04) \times 0.229$	= 171.3 tC/yr
C32	Departmental total energy footprint	$C_D = C_{HVAC} + C_E + C_{CVRCG}$	= 237 + 171 + 34	= 442 tC/yr
C33	CO_2 emissions from consumable materials	B_{CM}		= 9922 kg/yr
C34	CO_2 emissions from permanent materials	B_{PM}		= 15735 kg/yr
C35	Carbon emissions per ton of CO_2	C_{CO2}		= 0.2729 tC
C36	Carbon emissions from materials	$C_M = (B_{CM} + B_{PM}) \times C_{CO2}$	$= (9922 + 15735) \times 0.2729$	= 7 tC/yr
C37	Emissions from commuting by faculty	C_{CF}		= 34.35 tC/yr

C38	Emissions from commuting by staff	C_{CS}		= 17.37 tC/yr
C39	Emissions from commuting by graduate students	C_{CGS}		= 43.97 tC/yr
C40	Emissions from commuting	$C_{COM} = C_{CF} + C_{CS} + C_{CGS}$	= 35.35 + 17.37 + 43.97	= 95.7 tC/yr
C41	Carbon emissions from reimbursed air travel	C_{AT}		= 6.5 tC/yr
C42	Carbon emissions from reimbursed ground travel	C_{GT}		= 1.5 tC/yr
C43	Carbon emissions from racing team travel	C_{RT}		= 4.1 tC/yr
C44	Carbon emissions from all transportation activities	$C_T = C_{COM} + C_{AT} + C_{GT} + C_{RT}$	= 95.7 + 6.5 + 1.5 + 4.1	= 108 tC/yr
C45	Carbon footprint	$C = C_{HVAC} + C_E + C_M + C_T + C_{CVRCG}$	= 237 + 171 + 7 + 108 + 34	= 557 tC/yr
C46	Cost of carbon capture technologies	P_{CCT}		= 220 $/tC
C47	Cost of carbon capture for all Department energy usage	$P_D = C_D \times P_{CCT}$	= 442 × 220	= $100,000
C48	Cost of Greenwise Power in 250kWh blocks	P_G		= $7.50
C49	Additional cost of Greenwise Power for CVRC	$P_{CVRC} = P_G \times (E_{CVRC} / 250)$	$= 7.5 \times 294 \times 10^3 / 250$	= $8900
C50	Cost of purchase of carbon offset	p_{off}		= 14.77 /tC
C51	Cost of offsets for Department footprint	$P_{off} = p_{off} \times C$	= 14.77 × (557 + 53)	= $25,000
C52	Carbon sequestration per acre of forest	F_C		= 2.4 tC/yr
C53	Cost of planting and maintenance per acre of forest	P_F		= $729 /acre
C54	Acres of forest to offset Department footprint	$F_{ME} = C / F_C$	= (557 + 53) / 2.4	= 260 acres
C55	Cost planting and maintaining ME forest	$P_{ME} = F_{ME} \times P_{ME}$	= 260 × 729	= $190,000