UNIVERSITY 303:

The Impact of CO_2

May 6, 1999

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Executive Summary

This report quantifies the main sources of carbon emissions on Rice University's campus and briefly analyzes a few possible methods of carbon abatement. Carbon emissions contribute to the larger problem of global warming. The Kyoto Protocol, which mandates a 7 reduction of emissions from 1990 levels by the year 2010, is a global agreement that may be ratified by the Senate in the near future. If this is the case, Rice may be required to significantly reduce its carbon emissions. Our calculations find that Rice currently emits 19,900 tons of carbon into the atmosphere. These findings are broken down as follows.

Energy

- Energy emissions include those from the production of air-conditioning, heating, and electricity available at end-use locations.
- By far the largest source of emissions, energy production contributed 15, 700 tons of carbon to the atmosphere in 1998.
- Solutions discussed include department metering and an upgrade of cogeneration.

Transportation

- Transportation emissions include those from commuting students and faculty, campus shuttle buses, and air travel by faculty and student athletes.
- The second largest source of emissions, transportation contributed 3,400 tons of carbon to the atmosphere in 1998.
- Solutions discussed include light rail, electric vehicles, hybrid-electric vehicles, fuel cell vehicles, and alternative fuel sources.

Construction

- Construction emissions include those from the production of concrete, transportation of concrete, and the production of brick.
- The third largest source of emissions, relatively, construction contributed 800 tons of carbon to the atmosphere in 1998.
- Solutions discussed include flyash concrete and concrete masonry units.

Introduction

Emissions of carbon dioxide, a greenhouse gas, pose a major risk to the welfare of the earth. Trapping solar radiation in the atmosphere, it is one of the main contributors to global warming (EPA 1999). According to scientists, global temperatures are rising. This trend correlates with an increase in atmospheric carbon dioxide concentrations, mostly due to anthropogenic sources.

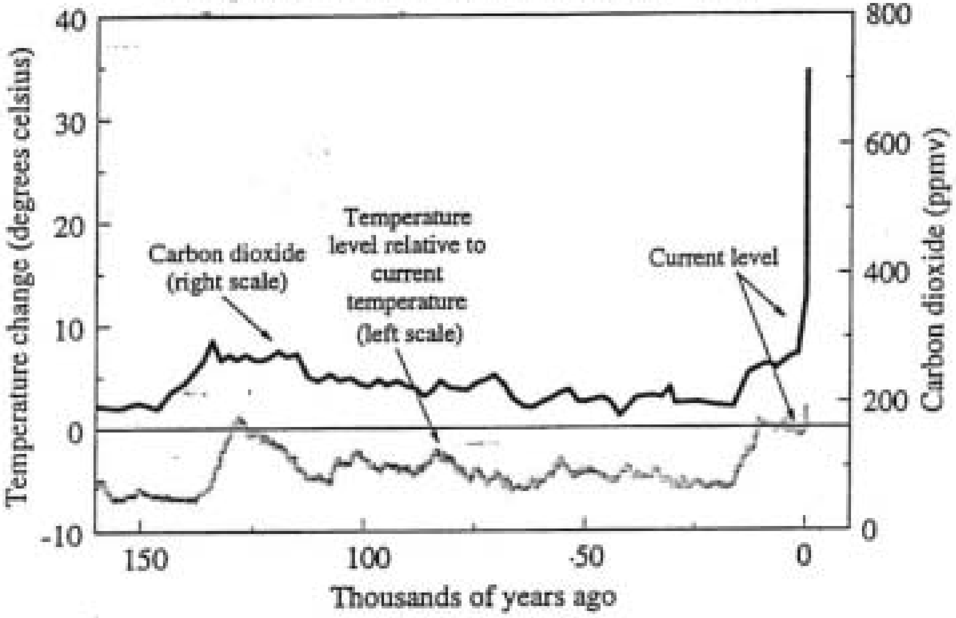

Figure A1. Atmospheric Carbon Dioxide Concentration and Temperature Change over the Past 160,000 Years (EPA 1998).

Climate change caused by increased greenhouse gas emissions may result in catastrophic changes in the biosphere and many ecosystems. A rise in sea level due to melting of the polar ice caps may destroy islands, wetlands, and other coastal areas. Furthermore, the warming of the earth may cause changes in precipitation patterns, altering local climate conditions. Other potential effects include a reduction of crop yields and water supplies that could endanger human health and threaten other species as well (EPA 1999).

The Kyoto Protocol, an international agreement to reduce greenhouse gas emissions, serves as a focal point in the global effort to combat climate change. The Protocol calls for a 7% reduction in U.S. carbon dioxide emissions from 1990 levels by the year 2010. With the deadline for Senate ratification nearing, carbon emissions reduction has come to the forefront of both the national and global policy agenda. Regardless of Senate ratification. Rice should prepare to initiate a plan to reduce University-related CO_2 emissions. By taking precautionary measures, Rice both limits its contribution to the detriment of the environment and steps out as a leader in national policy.

This report provides a beginning to this process. We have quantified Rice-related emissions from energy production, transportation, and construction for 1990,1998, and projected to 2010 (Table Al). According to our calculations. Rice is currently emitting 19,900 tons of carbon into the atmosphere. Although this represents a significant drop from 1990 levels of 22,000 tons, if we continue at current trends, we will not meet the Kyoto-specified 7 reduction by 2010. For this reason, we have also briefly examined solutions to the problem.

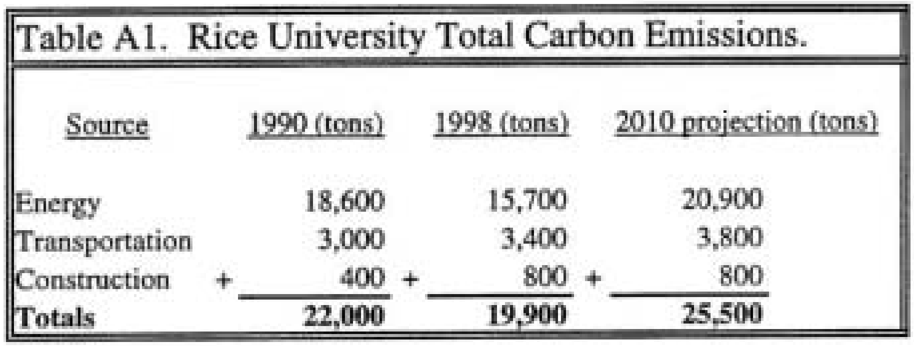

Table A1. Rice University Total Carbon Emissions.

Source	1990 (tons)	1998 (tons)	2010 projection (tons)
Energy	18,600	15,700	20,900
Transportation	3,000	3,400	3,800
Construction	+ 400	+ 800	+ 800
Totals	**22,000**	**19,900**	**25,500**

To put these numbers in perspective, global carbon emissions are currently 6.1 billion tons or about one ton per person. U.S. carbon emissions are 1.4 billion tons or about 5 tons per person (EPA 1999). The University's carbon emissions of 19,900 tons are equivalent to about 3 tons per person due to Rice-related activities only (Rice University 1999).

This report proceeds as follows. Section C details source quantification methods and solutions for energy production. Sections D and E do the same for transportation and construction, respectively. Supporting calculations are shown in the appendices.

Energy

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Abstract

This section presents an overview of carbon emissions due to energy-related activities at Rice University. Rice University's energy system combines energy purchased from Reliant Energy with energy cogenerated on campus. Cogeneration blends the production of electricity, air-conditioning, and heating. We assigned carbon emissions coefficients to each fuel source entering Rice's energy system based on carbon released per unit energy produced. These coefficients were multiplied by energy consumption to give a total carbon emissions of 15,700 English tons for 1998. Carbon emissions per building show that science and research facilities are the highest emitters. Although energy efficient technologies have reduced Rice's emissions, our calculations suggest that carbon emissions will rise in the future due to campus expansion. We looked at department metering and an upgrade of cogeneration as possible carbon abatement techniques.

Source Quantification

Introduction

At the heart of all Rice University operations is electrical energy. It illuminates the room's lights, powers the computers, and cools the buildings. This variety of uses creates many opportunities for reductions in both carbon emissions and money spent. These reductions will become necessary if the Kyoto protocol, which calls for reductions of carbon emissions to 1990 levels by 2010, comes into effect. The generation of electricity, air-conditioning, and heat significantly contribute to global warming and air pollution in general. In fact, fossil fuel power plants produce about sixty percent of all greenhouse gas emissions around the world (Sierra Club 1999).

Rice University's Energy System

Currently, Rice University receives its energy from two sources: Reliant Energy (formerly HL&P) and cogeneration on campus. Rice purchases the majority of its energy from Reliant at night when its prices are cheaper. During Reliant Energy's peak price hours in the middle of the day. Rice combines its purchases with cogeneration to cut cost. Cogeneration produces electricity and air-conditioning or heating at the same time. It works by burning natural gas to operate a jet engine, which turns a turbine to generate electricity. Waste heat from the burning of natural gas is used to make chilled water for air-conditioning or steam for heating, depending on user demand. Boilers also provide additional steam when air-conditioning or heating needs exceed levels provided by cogeneration's waste heat. To simplify. Rice University Energy system combines two inputs-electricity and natural gas-to produce four outputs- electricity, steam, chilled air, and compressed air (Eric Valentine, Rice University Energy Coordinator, personal interview, 2 March 1999). See Appendix, Section A for a more complete diagram of this system.

Purchased Energy

To determine the carbon emissions from purchased energy, fuel sources must be taken into account because each fuel has a different carbon content. Electricity purchased from Reliant Energy comes from 5 different sources of fuel: natural gas (32-39), coal and lignite (40-47), nuclear (9-14), large hydroelectric plants (1), and renewable sources (negligible) (Reliant Energy 1999). Although carbon emissions from these fuels are not released on campus but rather Rice's energy consumption. A fuel's carbon content is used to determine its carbon emissions coefficient, which relates carbon emissions released to energy produced. This coefficient is then multiplied by total energy consumed, taking into account efficiencies within the system, to give the total carbon emissions. See Appendix, Section B for a more detailed description of carbon emissions calculations.

Rice purchased 4.1 x 107 kWh from Reliant in 1998. According to our calculations, the production of this energy released approximately 8,900 English tons of carbon into the atmosphere. The majority of these emissions, about 6,100 tons of carbon, came from energy produced by coal. The other 2,800 tons of carbon came from energy produced by natural gas. See Appendix, Section B for the 1998 campus-wide carbon emissions data.

Cogenerated Energy

Cogeneration relies on one fuel-natural gas. Natural gas emits 42 percent less carbon than standard fossil fuel sources per equivalent energy unit, and, when used in combined-cycle natural gas turbines (like cogeneration), emissions drop another 33 percent (Alliance to Save Energy 1999). In 1998, cogeneration on campus produced 4.3 x 107 kWh, which released about 6,800 tons of carbon. See Appendix, Section B for these calculations.

Total Energy

Adding the contributions from both purchased and cogenerated energy discussed above, Rice's total carbon emissions due to energy production in 1998 were 15,700 tons. Considering the campus population is 6438 people on average, one person in 1998 was responsible for 13.4 pounds per day of carbon emissions due to Rice-related energy activities (Rice University 1999).

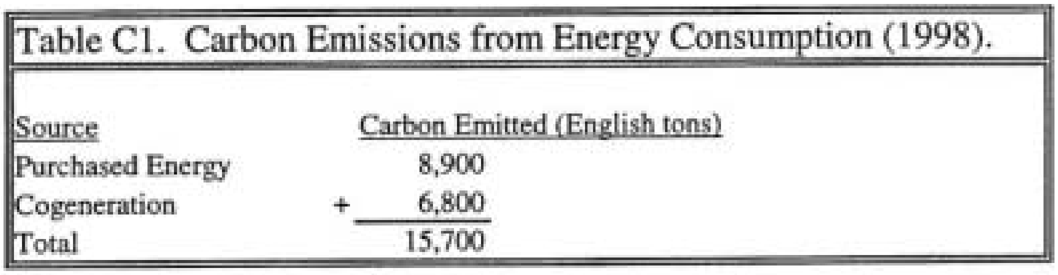


Table C1. Carbon Emissions from Energy Consumption (1998).

Source		Carbon Emitted (English tons)
Purchased Energy		8,900
Cogeneration	+	6,800
Total		15,700

Carbon Emissions by Building

Using building meter data from the University's Department of Facilities and Engineering for 1998, we calculated total carbon emissions per building and per square foot in each building (Valentine, personal interview, 2 March 1999). The meters measure the cooling energy, heating energy, and electrical energy used per building. For our analysis we took the aggregate energy total for each building. Science and research buildings are consistently the largest emitters (Figures Cl and C2). George R. Brown and Anderson Biological Laboratories, both predominantly research facilities, are two of the highest emitters. Additionally, per square foot, six of the top ten emitters are science and research buildings (Figure C2). Dell Butcher and Old Chemistry, low-emitting science buildings, were not operating at full capacity for all of 1998 due to renovation and construction.

There are some deviations from this trend. In total emissions, Fondren Library and Autry Court, high-occupancy buildings that operate beyond normal business hours, are high non-science emitters. In emissions per square foot, smaller buildings, such as Copy Club and the Facilities and Engineering building, also emit high levels of carbon per square foot for non-science buildings. However, in terms of total carbon emissions, these two buildings do not contribute significantly to Rice's total carbon emissions. Also, administrative buildings may seem like seem like high emitters based on average carbon emissions per square foot, but, in terms of totals, their square footage allotment is much lower than any of the other sectors.

To examine this trend further, we devised five building groups based on use: science and research, academic, residential, administrative, and miscellaneous. (See Appendix, Section D for building groups.) In aggregate, total carbon emissions (Figure C3) and average carbon emissions per square foot (Figure C4) by building groups show that science and research facilities consistently emit the most carbon. Why? Federal regulations (OSHA 1999, Chapter 3 Section 3) specify that research facilities must be equipped with a one-pass air system, hi other words, air cannot be recycled within a research building. This significantly increases energy consumption because much more air must be dehumidified and cooled or heated than in other buildings.

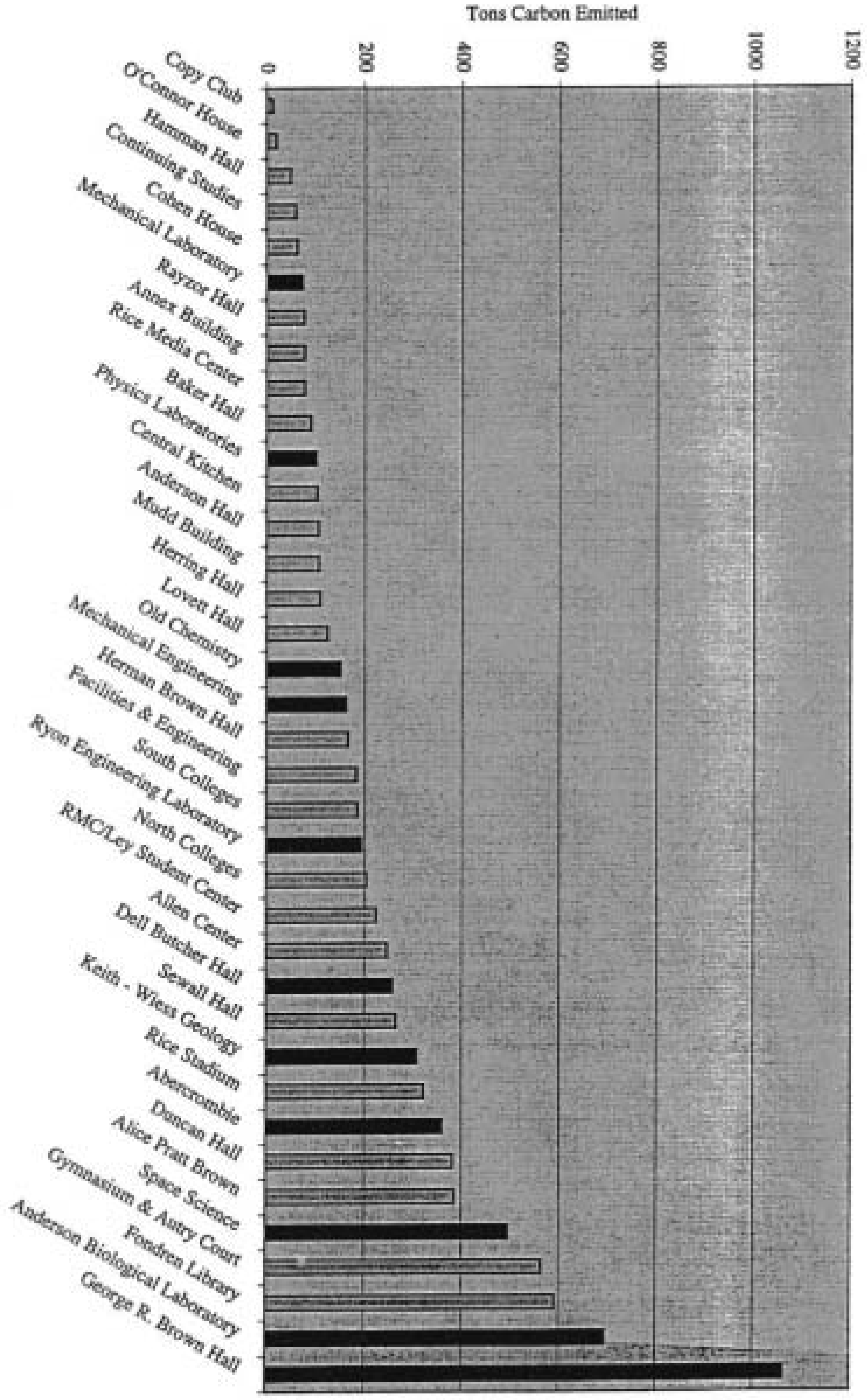


Figure C1. Rice University Carbon Emissions from Energy Consumption by Building (1998).
Solid Bars denote Science Buildings.
Data from Appendix I, Section E.

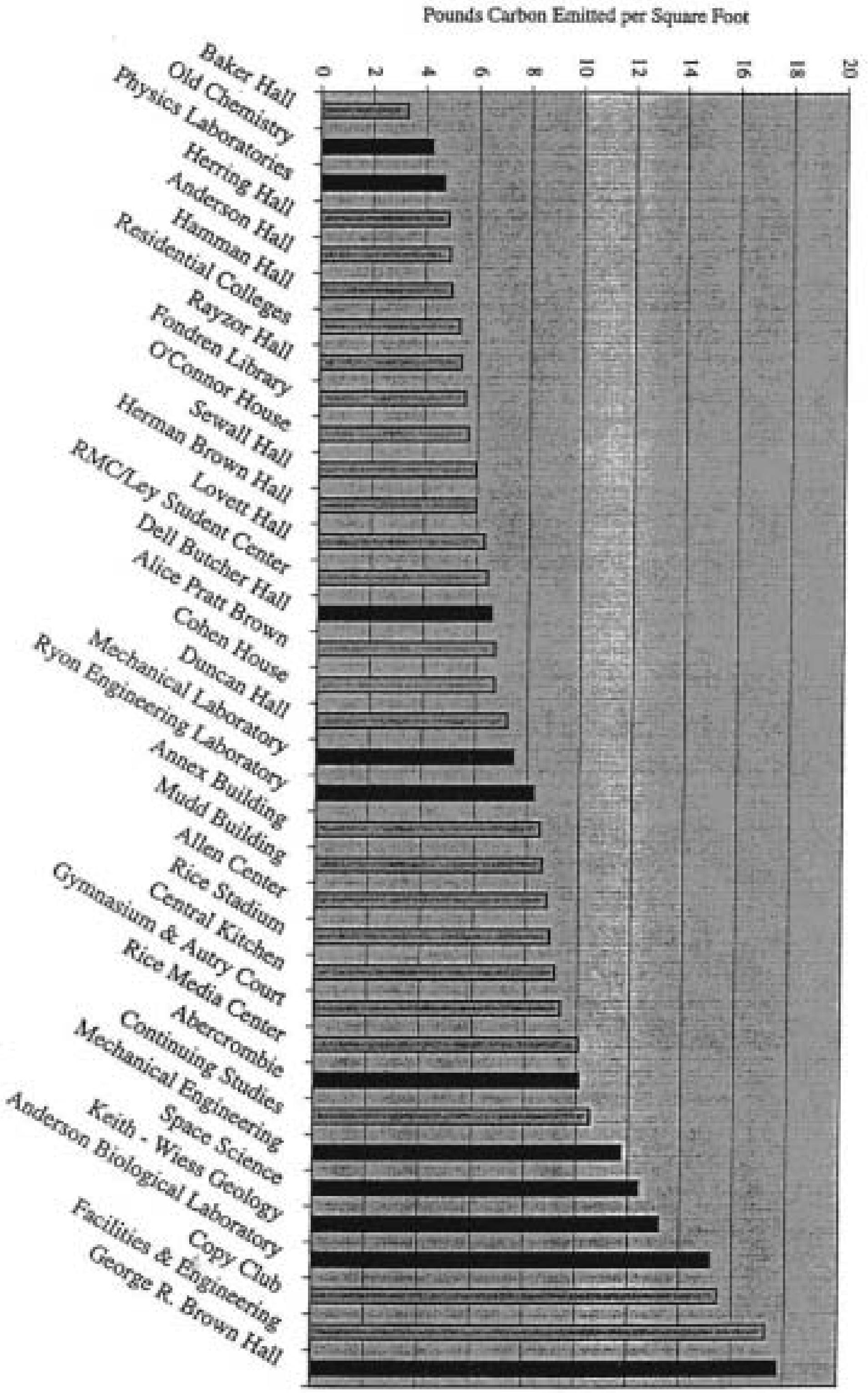


Figure C2. Rice University Carbon Emissions per Square Foot from Energy Consumption by Building (1998).
Solid Bars denote Science Buildings.
Data from Appendix I, Section E.

Figure C3. Rice University Average Carbon Emissions from Energy Consumption by Building Groups (1998). Data from Appendix I, Section G.

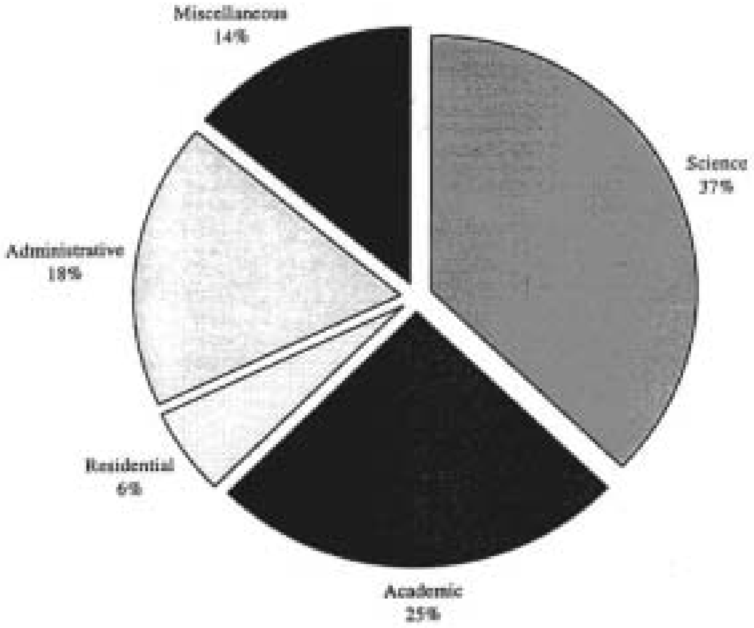
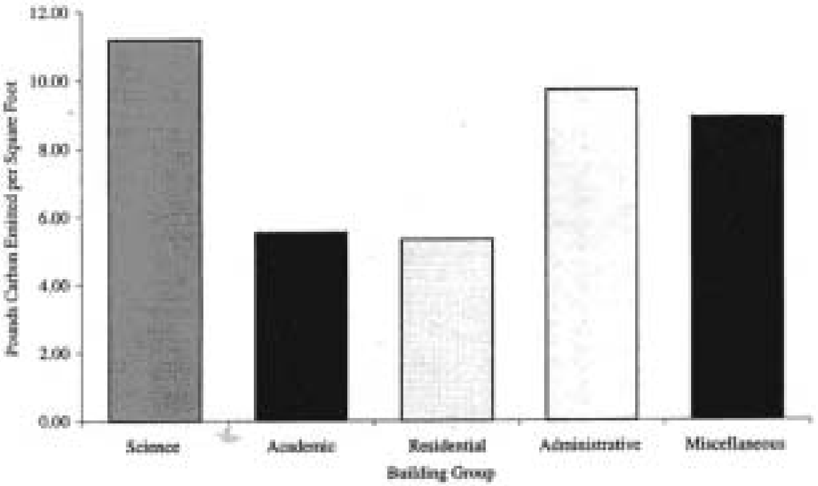


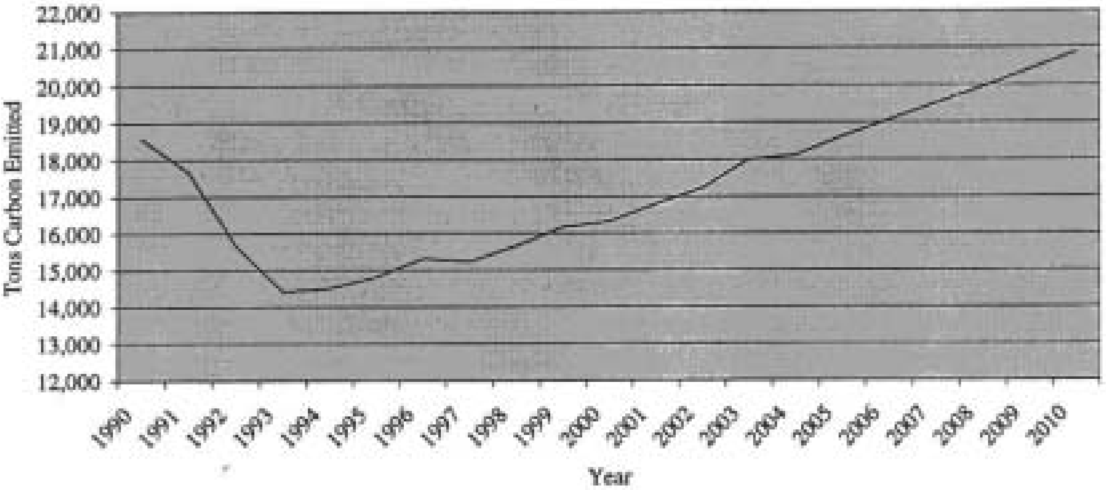
Figure C4. Rice University Average Carbon Emissions from Energy Consumption Per Square Foot by Building Groups (1998). Data From Appendix I, Section G.



Projections

Extrapolating from aggregate data, we can predict future levels of carbon emissions (Figure C5). In 1990, the Rice campus emitted 18,800 tons of carbon, compared to 15,700 tons in 1998. The year 1993 marks the lowest point on the graph. After this year, the University hired a new energy staff, which brought many changes to energy production at Rice. This staff employed new efficiency measures and transitioned the campus to a more efficient cogeneration unit. This transition did slow the increase in energy consumption on campus. However, to implement this transition, the campus had to rely on heavy usage of duct burner units, which increased carbon emissions (Valentine, personal interview, 2 March 1999). Since then, energy consumption has also begun to rise. These upward trends can be attributed to an increased emphasis on scientific research and general campus expansion. Three of the last five major additions to campus have been scientific laboratories: Duncan Hall, Dell Butcher Hall, and George R. Brown. To project the future carbon emissions, we used a forecast function in conjunction with the expected dates of completion for future construction (Appendix, Section H) and trends in fuel usage. Our calculations predict carbon emissions of 20,900 tons in 2010. (See Appendix, Section I for a more detailed explanation of our projections.) To reach Kyoto Protocol targets for 2010, Rice faces the challenge of reducing energy consumption despite campus-wide expansion.

Figure C5. Rice University Carbon Emissions Projections from Energy Consumption. Data from Appendix, Section H.



Limitations

Rice's energy system is complicated. The combined system of purchased and cogenerated energy employs many more pieces of equipment than have been discussed in this paper, including electric chillers, steam turbines, and duct burners. This complexity makes it difficult to quantify carbon emissions.

A natural analysis of energy consumption would include a functional breakdown in terms of air conditioning, heating, and electricity at end-use locations. However, once natural gas or electricity enters Rice's system, no internal mechanism "tracks" its path. Therefore, any attempt to analyze emissions through a functional breakdown would have to include assumptions based on unavailable information about a particular fuel's pathway and would result in a gross misstatement.

The available data limited the scope and depth of our analysis. Metering the buildings is an on-going project for Facilities and Engineering. As a result, data for energy use at nonresidential buildings was only accurate for 1998 and residential colleges are not metered individually.

Conclusion

The energy staff at Rice has taken major steps to increase system efficiency. They view the process holistically, in terms of energy in and energy out (not fuel source in, energy from this fuel source out). According to staff at Facilities and Engineering, Rice has achieved a high level of "holistic efficiency" and can serve as a model of energy use for other college campuses.

This holistic approach to energy production and consumption, combined with the system's complexity, lends itself to carbon-reducing solutions that focus on the amount of energy that goes into and out of the system. In this light, some general approaches to carbon abatement include modifying the technologies that produce energy, limiting the quantity of items that use energy, and converting to items that use less energy. For these reasons, an upgrade of cogeneration, which would make energy production more efficient, and department metering, which would create an incentive structure to reduce energy use, provide areas of further study.

Solutions

Introduction

The production and consumption of energy on campus has been identified as a significant contributor to carbon emissions. What can Rice University do to improve campus energy matters? In this report we chose to focus on two possible solutions, department metering and a cogeneration upgrade. These alternatives seem to be the most promising in terms of feasibility and the promise of future reductions in the academic realm, since they have been implemented in other university settings.

Department Metering/Energy Conservation

Nobel laureate Ronald Coase of the University of Chicago has argued that in order to reduce the negative externalities caused by individuals' actions, a government should simply rearrange property rights. Coase's theorem states that, with property rights appropriately assigned, markets should take care of all externalities without a need for direct government intervention (Stiglitz 1997).

Consider, then, energy use at Rice University. Currently, the Rice Facilities and Engineering (F&E) monitors energy use on campus and pays all energy-related bills directly. As a result, departments on campus are not aware of the fact that the more energy they consume, the more money they spend and the more carbon they emit into the environment. If Rice were to rearrange property rights and grant individual departments the responsibility of monitoring energy-related activities, then departments would have the incentive to use energy more efficiently and the negative externalities associated with energy use would be brought to a minimum.

To implement metering at the department level, the first step is the installation of metering equipment on campus buildings. Currently, energy use is metered on all nonresidential buildings (but not departments) and the residential colleges as North and South, not individually. The purpose of these meters is to verify the amount the University is charged by Reliant Energy, our energy supplier. As each building goes on-line, F&E installs a meter.

Since some departments share buildings, energy use would have to be divided among them. A good start would be to group buildings by energy use (academic, administrative, science, etc.). Then, using a building's total energy consumption, the distributed energy costs could be allocated by square footage, including an energy intensity factor. The energy intensity factor would be defined by the building's energy use (i.e. academic v. science). For example, a science building's energy intensity factor could take into account the quantity of fume hoods and other energy intensive equipment.

Once a department metering system is in place, there are two ways to proceed. Rice could follow Yale University's example and implement a plan that leans toward reducing inefficiencies within the system. Under this plan, each building is subjected to an internal energy audit, under guidelines provided by the US EPA Energy Star Building Program (USEPA 1999). This audit is used to locate and eliminate building inefficiencies. However, only cost centers are billed for energy use; departments level energy costs are paid by the central administration. Yale initiated their program in blocks of campus. Its energy department estimates that it spent three million dollars on metering buildings (personal communication, Tony Bonaffini, Yale University, Manager Power Plants Distribution Systems Utilities). For Rice, F&E estimates a cost of $5,000 to $15,000 per building (personal communication, Greg Dulaney, Rice University Central Plant Engineer). However, because metering is already a project for F&E, these costs should not be considered part of our plan. New costs would be associated with computers for processing data and personnel for operation and maintenance of the system. Because Yale implemented its department metering system fairly recently, no quantifiable results are available yet. The energy department there feels it has been very worthwhile. Thus far, they have received a positive response from faculty and students about the program (personal communication. Tony Bonaffini, Yale University, Manager Power Plants Distribution Systems Utilities).

A second approach would be to use an economic incentive system. Energy costs could be made a part of department budgets, with sizable portions of the money from energy savings retained by the department. Thus, the energy budget becomes a departmental affair, and there is an economic incentive to reduce departmental usage so as to have more money available to use at each department's discretion. Under this approach, initial funds provided to the department for spending on energy would have to be determined, most likely based on previous estimates from department usage data. Department metering would create a sense of responsibility for energy consumption. However, in situations where departments share buildings and an energy intensity factor is employed, a potential for the "tragedy of the commons" exists. This potential problem would create a need for regular evaluations of the energy intensity factor to more accurately assign department funding. One concern is who would mediate department disputes about actual usage versus assigned distributed costs. Depending on the situation, meters could be installed to certain circuits to obtain a more specific energy consumption breakdown, though this strategy should only be employed in cases where the complaints justified the added cost. As a possible solution, departments could be offered meters for individual circuits at a partial cost to the department.

In conclusion, taking into account the current Rice energy monitoring abilities, a move towards a program similar to Yale's would be a good first step. This move, however, would only be in efforts to ultimately have a department monitoring system where each department controls and pays for their energy usage. According to Coase's theorem, changing the property rights of our energy system is essential to reducing carbon emissions, and the most obvious way to create this ownership is through departmental energy budgets.

Cogeneration Upgrade

As Rice University prepares for the 21st century, technological advances, uncertainty over electric utility deregulation, and environmental concerns have made it important for us to reevaluate our system of energy generation and distribution. Currently, Rice University's energy needs are provided through a combination of electricity purchased from the local utility, Reliant Energy, and a cogeneration system on campus. Powered by a natural gas turbine, cogeneration is a "recycling" process in which the excess heat generated by the turbine is used for heating and air-conditioning the campus. This combined process of campus energy production places us in a unique position to have the ability to vary the ratio of purchased and self-generated energy as a means of carbon dioxide reduction.

Rice University's energy system include needs such as electricity and air-conditioning and wants such as environmental friendliness and cost efficiency. Purchasing energy from Reliant could meet all campus needs. However, cogeneration, while also meeting these needs, can offer benefits to the environment and reduced energy costs. The main benefit offered by cogeneration is high efficiency. Although modem technologies have allowed electric utility power plants to reduce emissions and increase overall efficiencies, these plants suffer great amounts of energy losses, in excess of seventy percent, in the form of heat. Cogeneration, however, captures this heat and generates steam or hot water. This built-in efficiency of cogeneration directly results in energy cost savings and reduced emissions.

Often the largest cost in installing a cogeneration system is the vast array of pipes and insulation, but since Rice University already operates a cogeneration system much of this cost is already sunk. If Rice were to stop purchasing electricity and were to employ only Cogeneration in its production of energy next year, then by 2010 we would see a savings of about $4 million (Figure C6) and a carbon reduction of approximately 20 thousand English tons (Figure C7).

In conclusion, Rice University should follow the example of other universities like MIT and Rutgers by increasing the role of cogeneration in campus energy production (University of Rochester 1998). It, unlike purchasing electricity from Reliant Energy, can satisfy all of our expectations from an energy system, both needs and wants.

Figure C6. Rice University Energy Savings from Cogeneration Upgrade (2000-2010).
Data from Appendix I, Section J.

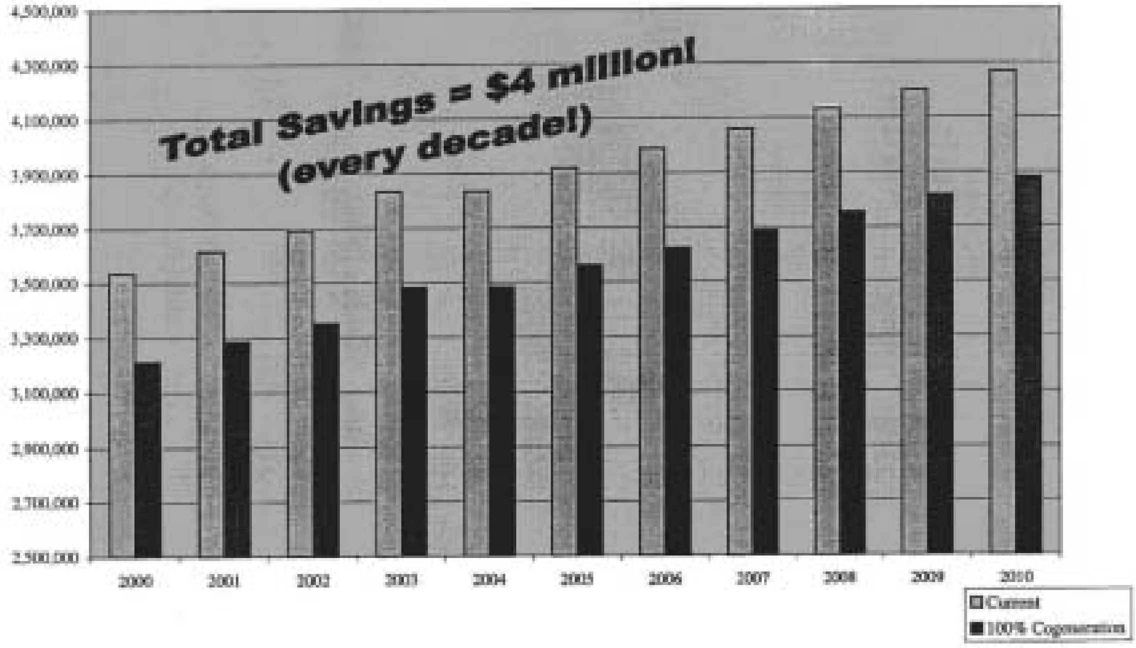
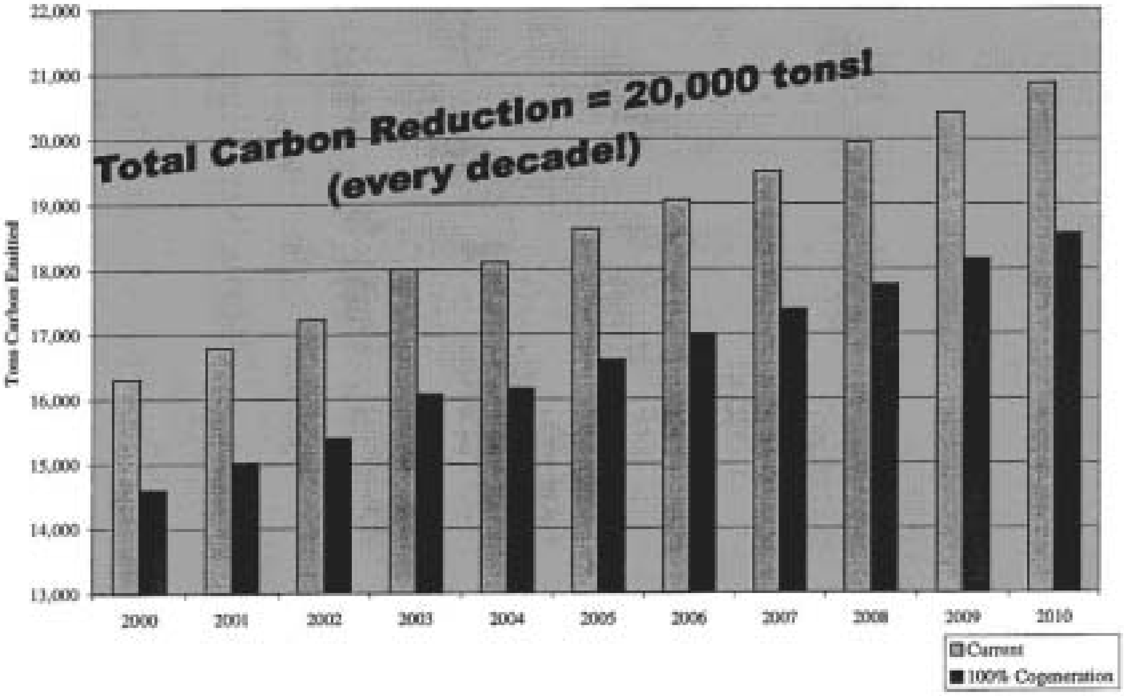


Figure C7. Rice University Carbon Abatement from Cogeneration Upgrade (2000-2010).
Data From Appendix I, Section J.



Conclusion

Energy Consumption at Rice University presents many opportunities for carbon emissions abatement. The two major avenues discussed here include an internal approach - department monitoring and billing - and a system approach - cogeneration expansion. The advantage to these methods is the ability to quantify the amount of carbon emissions abated. Cost center or department budgets can be adjusted to encourage energy conservation. The transition to full cogeneration is also flexible, taking into account instrument efficiency and cost analysis. While only briefly examined, both methods are promising endeavors for the University to investigate for future carbon emissions reductions.

Transportation

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Abstract

This chapter looks specifically at transportation's contribution to Rice's total carbon dioxide emissions budget. Cars commuting to and from the campus, shuttles operating continuously 20 hours a day, and University-related air transportation are the main transportation-related sources of CO_2 *emissions we identified. Multiplying carbon emissions per gallon of fuel consumed by total estimated fuel consumption, we calculated transportation related carbon emissions to be 3,351 tons, which is 17 of Rice's total emissions. As potential solutions to transportation-related carbon emissions, we examined alternative fuels, new vehicle technology, and improved mass transit in Houston.*

Source Quantification

Introduction

The role of transportation is of particular importance as it accounts for over 30 of U.S. CO_2 emissions from fossil fuel combustion (EPA, "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-1996"). In determining Rice's total carbon emissions, it is important examine each source of carbon dioxide as it pertains to transportation. This chapter will investigate emissions from commuting automobiles, shuttle buses, and university-related air transportation.

Obtaining Carbon Conversion Factors

To derive carbon emissions per gallon fuel consumed, we found the carbon coefficients for motor gasoline, distillate fuel oil (also known as diesel fuel), and kerosene-based jet fuel (Department of Energy, "Appendix A: Emissions of Greenhouse Gases in the U.S.," 1998). These coefficients are given in terms of million metric tons of carbon emitted (MMTCE) per quadrillion BTU's (British Thermal Units). Converting these coefficients to pounds of carbon per million BTUs, we calculated 42.80 lb./106 BTU for motor gasoline, 43.98 lb./106 BTU for diesel fuel, and 43.45 lb./106 BTU for jet fuel. In order to convert these values to pounds of carbon per gallon of fuel consumed, we multiplied these values by the BTUs per gallon for each of these fuels. The multiplication yielded 5.35 Lbs. C/gallon for motor gasoline, 6.11 Lbs. C/gallon for diesel fuel, and 5.87 Lbs. C/gallon for jet fuel (Table Dl).

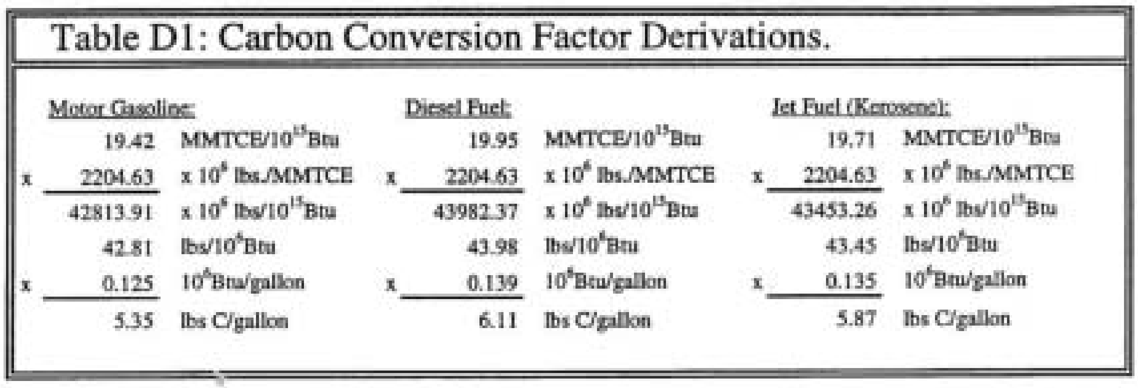


Table D1: Carbon Conversion Factor Derivations.

Motor Gasoline:			Diesel Fuel:			Jet Fuel (Kerosene):		
	19.42	MMTCE/10^{15}Btu		19.95	MMTCE/10^{15}Btu		19.71	MMTCE/10^{15}Btu
x	2204.63	x 10^{6} lbs./MMTCE	x	2204.63	x 10^{6} lbs./MMTCE	x	2204.63	x 10^{6} lbs./MMTCE
	42813.91	x 10^{6} lbs/10^{15}Btu		43982.37	x 10^{6} lbs/10^{15}Btu		43453.26	x 10^{6} lbs/10^{15}Btu
	42.81	lbs/10^{6}Btu		43.98	lbs/10^{6}Btu		43.45	lbs/10^{6}Btu
x	0.125	10^{6}Btu/gallon	x	0.139	10^{6}Btu/gallon	x	0.135	10^{6}Btu/gallon
	5.35	lbs C/gallon		6.11	lbs C/gallon		5.87	lbs C/gallon

Commuting Automobiles

According to the Office of Institutional Research, Rice University employs 2,329 people (Rice University 1999). Based on surveys collected by the ad hoc Committee for Employer Trip Reduction in 1994, the average commute for faculty and staff was estimated to be 10.95 miles. Assuming that faculty and staff members travel to the campus each weekday, this multiplies to 1,020,102 miles per month. Using fuel economies of various types of vehicles, we estimated that commuting automobiles averaged 17 miles per gallon of gas in city conditions (Department of Energy and EPA, "Model Year 1999 Fuel Economy Guide," 1998). Thus, Rice faculty and staff consume 720,072 gallons of gas and emit 1,926 tons of carbon per year (Table D2).

Based on informal student surveys, we estimated the average undergraduate commute to be 3 miles. Assuming that each undergraduate commuted to campus each weekday, we found that the commuting student population emitted 529 tons of carbon per year into the atmosphere (Table D2)

With 10,764 students in Rice's Continuing Education Program, we felt it was necessary to include them in our study of CO_2 source quantification. Continuing Education classes are generally held once a week and are eight weeks in length. Thus, assuming their commute distance is comparable to Rice's commuting faculty and staff, we calculated that the Continuing Studies Students traveled 1,894,464 miles, burned 111,439 gallons of gas, and added 298 tons of carbon annually to Rice's CO_2 budget. Combining all commuting populations at Rice, we found that automobiles traveling to Rice emitted 2,753 tons of carbon annually (Table D2).

Another source of carbon emissions from automobiles we briefly considered is travel related to attendance of athletic events. We made preliminary estimates of attendance to such events and assumed the average distance traveled by spectators was approximately equivalent to the average distance traveled to campus by Rice faculty and staff. These estimates showed that the number of additional trips created by the spectators to athletic events fell below the tonnage created by the continuing education students. As such, we decided not to include visitors to the campus in our estimates of carbon emissions from automobile travel.

Table D2: Annual Carbon Emissions from Commuting Automobiles.

	Faculty/Staff			Graduate/Undergraduate Students			Continuing Education Students	
	2,329	no. of faculty and staff[1]		2,335	no. of commuting students[5]		10,764	no. of participants[7]
x	2	(round trip)	x	2	(round trip)	x	2	(round trip)
	4,658	trips/day		4,670	trips/day		21,528	trips/class
x	20	days/month	x	20	days/month	x	8	classes/year
	93,160	trips/month		93,400	trips/month		172,224	trips/year
x	11.0	miles/trip[2]	x	3.00	miles/trip[6]	x	11.0	miles/trip[8]
	1,020,102	miles/month		280,200	miles/month		1,894,464	miles/month
x	12	months/year	x	12	months/year			
	12,241,224	miles/year		3,362,400	miles/year		1,894,464	miles/year
/	17	miles/gallon[3]	/	17	miles/gallon[3]	/	17	miles/gallon[3]
	720,072	gallons of gas burned/year		197,788	gallons of gas burned/year		111,439	gallons of gas burned/year
x	5.35	lbs of carbon emitted/gal.[4]	x	5.35	lbs of carbon emitted/gal.[4]	x	5.35	lbs of carbon emitted/gal.[4]
	3,852,385	lbs of carbon emitted		1,058,167	lbs of carbon emitted		596,199	lbs of carbon emitted
	1,926	tons of carbon per year		529	tons of carbon per year		298	tons of carbon per year

TOTAL FROM COMMUTING AUTOMOBILES **2,753** tons/year

1 Office of Institutional Research, Rice University,1999.
2 Based on faculty/staff sruveys conducted for the Employer Trip Reduction Plan. Rice University, 1994.
3 Source: USEPA and USDOE. "Model Year 1999 Fuel Economy Guide."
4 Table D1
5 There are 2714 undergraduates, 940 of whom live off campus. This was added to the graduate student poplulation to find total number of commuting students. Office of Institutional Research, Rice University, 1999.
6 Estimate based on an informal survey of undergraduate off-campus population
7 Based on records provided by the School of Continuing Studies. Rice University, 1999.
8 Assumed to be the same as the faculty/staff commute

Shuttle Bus Service

Especially with the new construction emerging at Rice, transportation is beginning to center more and more on a "pedestrian core campus," and perimeter parking (Associate Vice President for Administration Neill Binford, personal interview, 18 February 1999). This will certainly increase the burden on the Rice University shuttle service in the years to come. With the inception of electric bus service, the response of Rice's shuttle service to this increase in demand may be a model for CO_2 abatement across the country by eliminating the direct residuals of gasoline burning (SBETI 1997).

According to 1998 Exxon receipts provided by the Rice Department of Transportation, Rice's seven shuttles consume around 16,500 gallons of diesel per year. This amounts to 50.3 tons of carbon emissions (Table D3).

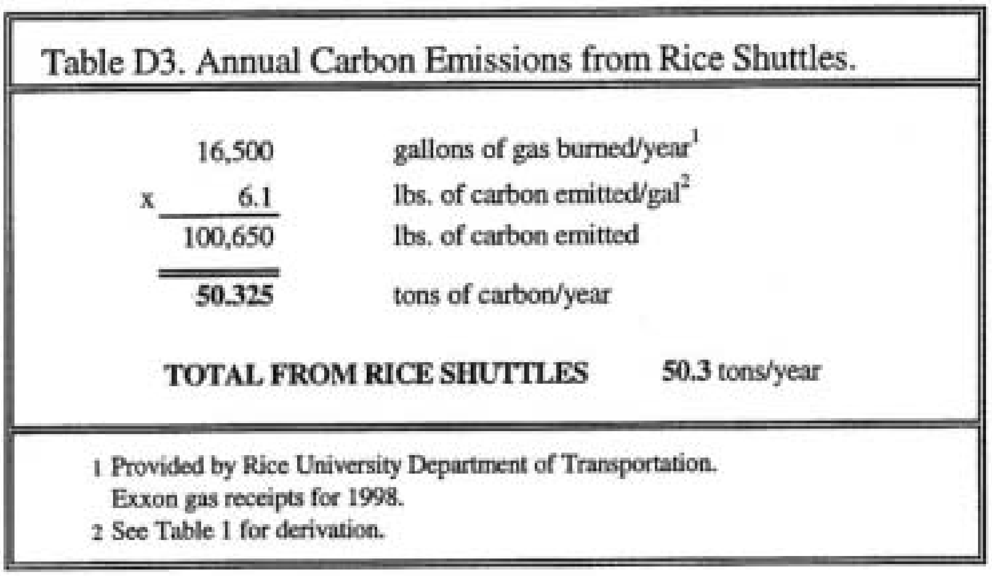


Table D3. Annual Carbon Emissions from Rice Shuttles.

16,500	gallons of gas burned/year[1]
x 6.1	lbs. of carbon emitted/gal[2]
100,650	lbs. of carbon emitted
50.325	tons of carbon/year
TOTAL FROM RICE SHUTTLES	**50.3** tons/year

[1] Provided by Rice University Department of Transportation. Exxon gas receipts for 1998.

[2] See Table 1 for derivation.

Air Travel

To obtain a total number of plane trips taken by the Rice community, several assumptions were made. Vice-Provost Jordan Konisky estimated that the total number of trips taken by administrators in 1998 was approximately 156 (Konisky, personal conversation, March 1999). Additionally, the Rice Department of University Advancement is responsible for approximately 325 trips (Wayne Robinson, personal conversation, March 1999). We guessed that each faculty member took an average of 2.5 trips per year (Paul A. Harcombe, Professor of Ecology & Evolutionary Biology, and Donald H. Ostdiek, Professor of Political Science, personal conversation, March 1999). According to the Office of Institutional Research, there are 774 faculty members, thus indicating that Rice faculty members took approximately 1,935 trips. Finally, varsity athlete trips were estimated by counting the number of members on each team and multiplying that by the number of out of state competitions. As such, we found Rice athletes to make roughly 1,092 trips by plane per year (Appendix A). These together sum to 3,508 trips per year.

To calculate the CO_2 contribution per passenger, several assumptions were necessary. First, we assumed each plane carried an average of 125 passengers per trip. Then, to calculate the fuel economy of a jet plane, we took the average jet plane, a Boeing 737-400, and divided its range of 2,370 miles by its fuel capacity of 6,295 gallons (Boeing 1999). This yielded a fuel economy of 0.376 miles per gallon. Dividing the pounds of carbon per gallon (5.87) by the fuel economy and the number of passengers gave us the result of 0.125 pound of carbon per mile traveled. As a reality check, we compared this figure with a value presented by Infinite Power of Texas, an organization sponsored by the Texas General Services Comission's State Energy Conservation Office. According to the Infinite Power of Texas, approximately 0.14 pounds of

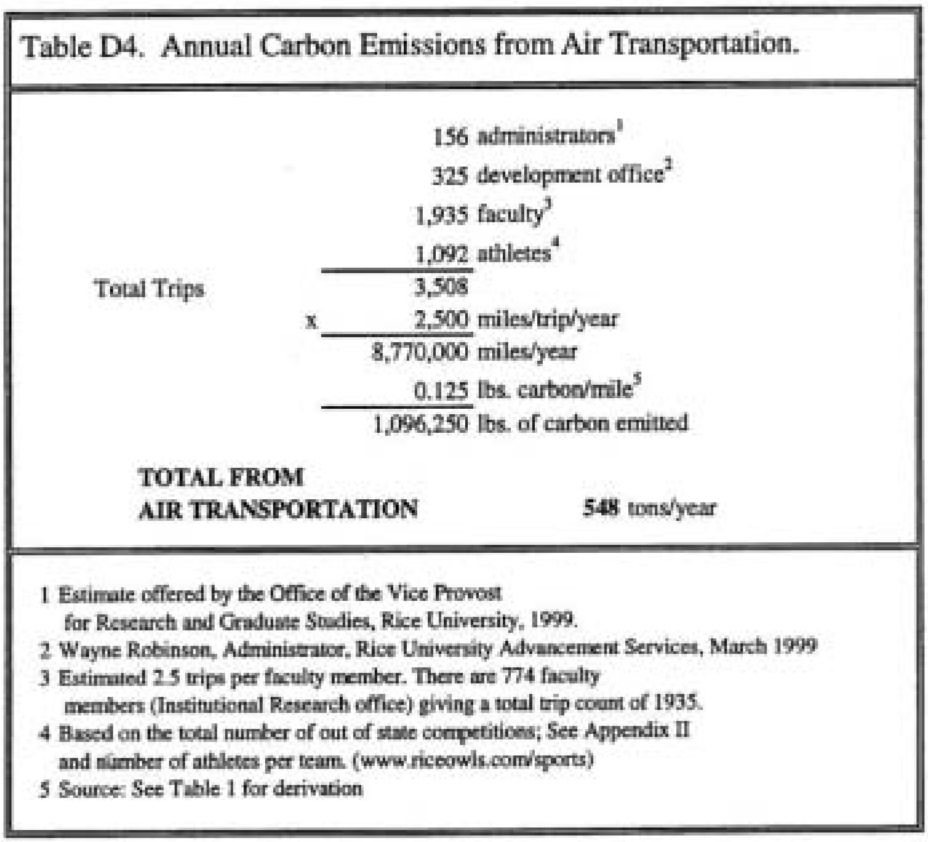


Table D4. Annual Carbon Emissions from Air Transportation.

	156	administrators[1]
	325	development office[2]
	1,935	faculty[3]
	1,092	athletes[4]
Total Trips	3,508	
x	2,500	miles/trip/year
	8,770,000	miles/year
	0.125	lbs. carbon/mile[5]
	1,096,250	lbs. of carbon emitted
TOTAL FROM AIR TRANSPORTATION	**548**	tons/year

1 Estimate offered by the Office of the Vice Provost for Research and Graduate Studies, Rice University, 1999.
2 Wayne Robinson, Administrator, Rice University Advancement Services, March 1999
3 Estimated 2.5 trips per faculty member. There are 774 faculty members (Institutional Research office) giving a total trip count of 1935.
4 Based on the total number of out of state competitions; See Appendix II and number of athletes per team. (www.riceowls.com/sports)
5 Source: See Table 1 for derivation

carbon per mile are added to the atmosphere by the average air traveler (IPC 1999).

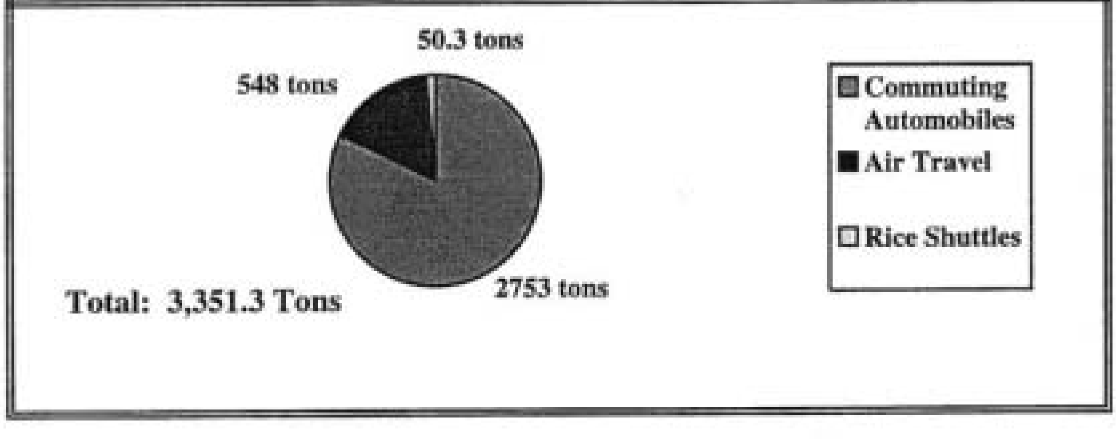
We assumed each plane trip was around 2,500 miles per round trip, and calculated Rice faculty, administrators and athletes to be responsible for approximately 11,457,500 air miles and emitted 716 tons each year (Table D4).

Conclusions

Collectively, Rice's transportation needs are responsible for approximately 3,351 tons of carbon emissions into the atmosphere per year. By looking at trends in population growth, we estimated campus growth to be roughly 10 percent in by the year 2010 (Rice University, Office of Institutional Research). Accordingly, transportation emissions could increase by 10 percent, and Rice may emit approximately 3,800 tons of carbon by the year 2010 (Table Al).

Quantifying the magnitude of transportation's impact on the overall CO_2 budget at Rice helps us recognize where reductions are warranted. Although transportation accounts for a relatively small fraction of all CO_2 emissions, we suggest that initiative in this sector be taken by both the administration and the Rice Community in order to achieve our goals of reducing overall CO_2 emissions for a sustainable environment.

Figure D1. Total Carbon Dioxide Emissions from Transportation.



Solutions

Introduction

Considering significant plans for construction and growth at Rice in the coming years, CO_2 reduction methods in the transportation sector are critical. In terms of commuting automobiles, campus growth will inevitably increase the number of faculty, staff, and students traveling to campus on a daily basis. As such, in accordance with our overall objective to reduce CO_2 emissions, it becomes important to plan for more efficient commuting plans. Support for more efficient mass transit systems, carpools/vanpools, or near-campus housing may help offset the increase in CO_2 emissions expected with Rice population growth.

Furthermore, the shuttle system can find more efficient means of transporting members of the Rice Community throughout the campus. By converting from the use of carbon-heavy diesel gas to the use of alternative fuels, electric buses, or fuel-cell vehicles, we may hope to reduce CO_2 emissions from the Rice Shuttles by as much as 75 to 90 percent (CREST 1996).

Rice wishes to maintain its reputation as both a national and international leader in both academics and athletics; nevertheless we recommend that CO_2 emissions be taken into consideration when using air transportation. With increased use of technological innovations such as internet services, video-conferencing, and other forms of telecommunications, it should be possible to decrease CO_2 emissions by reducing the need for air travel.

We sought to establish preliminary assessments of some of these potential solutions to CO_2 reduction. Specifically, we examined the possibility of replacing Rice's diesel burning shuttles with electric vehicles, hybrid electric vehicles, fuel cell vehicles, or alternative fuel engines. We also examined the possibility of reducing commuter automobile emissions by supporting the Department of Energy's Clean Cities, a program designed to generate support for the increased use of alternative fuels in existing vehicles. Finally, we investigated the concept of light rail for the mass transit system in Houston. This would reduce or eliminate the need for some of Rice University's commuters to travel by automobile.

Electric Vehicles

Electric vehicles (EV's) have come forth as a potential means of reducing auto emissions for both air pollutants and carbon dioxide, the primary greenhouse gas. By replacing the internal combustion engines of today's vehicles with high performance rechargeable lead-acid or nickel-cadmium batteries, local emissions are eliminated since the vehicle no longer relies on the burning of gasoline. In order to maximize energy efficiency, EV technology also uses aerodynamic streamlining in its vehicle design as well as regenerative braking whereby the kinetic energy from braking is transferred to energy used to recharge the battery. The only cost, in terms of carbon dioxide, are the emissions obtained from deriving the energy to recharge the shuttles' batteries. Even with such electricity demands taken into consideration, net carbon dioxide emissions would decline by 75 to 90 percent (CREST 1996). If power plants produce electricity using clean energy sources such as solar or hydropower, emissions are negligible.

These ideas and innovations have also been brought over to the heavy-duty engine market, including large trucks and buses. Rice University owns eight diesel gas-burning shuttle buses, with an estimated total annual carbon emissions of 50.3 tons. According to Rice University Transportation Manager, Eugen Radalescu, Rice has been offered a federal grant to implement EV technology as it plans to replace 2 of its diesel-buming shuttles with EV's. Replacing 2 shuttles with EV's could reduce carbon emissions by 9.4 to 11.3 tons, and replacing the entire fleet with EV's would reduce net annual carbon emissions to 12.8 to 5.03 tons.

There are various types of electric buses, each implementing a slightly different technology. Different cities and institutions offering shuttle services require unique demands on the shuttles of their respective fleets. Aspects such as topography, climate, maximum daily shift mileage, and start/stop frequency are all important considerations in determining the feasibility of EV's and which vehicle to purchase.

Examining the needs of the Rice campus, it is apparent that EV technology can help to reduce CO_2 emissions while maintaining service to the Rice community. Because of the flat terrain and the low speed limit of 20 mph on the inner loop route, acceleration demands on the motor are minimal, so battery power is sufficient in terms of locomotive demands. Rice shuttles have a maximum daily shift mileage of 70 to 75 miles, which is within the single-charge performance capabilities of existing EV's. Furthermore, the moderate start/stop frequency of 7 events per mile compares favorably with other successful electric bus operations, which may experience a start/stop frequency up to 13 events per mile (SBETI 1997).

The largest obstacle to implementing EV technology at Rice is the climate of Houston. With the temperature ranging from 30°F to 105°F, the energy required to heat and provide air-conditioning to the passenger compartment is substantial. Use of battery powered heating and cooling systems can increase the energy load by as much as 30. The wide climate range also poses a potential problem to the batteries themselves, as they lose charging ability in high ambient temperatures (SBETI 1997). Since the technology behind rechargeable vehicle batteries is not advanced enough to withstand such conditions, long-term use of the battery is hindered in all cases. Frequent purchase of new batteries will result in a large amount of battery waste, which may pose other, more detrimental environmental harms.

Hybrid-Electric Vehicles

Because of the limitations of EV's, it is important to consider other technological alternatives. Many companies are integrating hybrid vehicles (HEV's) into their lines of energy efficient models. HEV's combine electric vehicle technology with a gasoline powered motor. Depending on the driving conditions, the vehicle chooses the most efficient source of power, gasoline or electricity. Running on the battery alone, the vehicle achieves zero local emissions, and when stored energy levels fall, the combustion engine takes over to provide wheel power (Hitachi 1999). The internal combustion engine has twice the fuel economy of conventional gasoline engines, thus resulting in a net CO_2 reduction of 50, and its batteries are recharged entirely by the kinetic energy obtained from regenerative braking, so no outside charging source is needed (Toyota 1999).

Although CO_2 emissions are not entirely eliminated, HEV's may be more suitable for Rice University. By using hybrid technology, the energy needed to heat and cool the passenger compartment during temperature extremes may be provided by a combustion engine and the energy needed for locomotive purposes can be served by electricity. HEV technology is in its incipient stages with respect to heavy-duty engines, but further research into the feasibility of incorporating HEV's into the shuttle system at Rice is recommended.

Fuel Cells

Another new innovation in automobiles is fuel cell technology. Initially developed by NASA in the Apollo spacecrafts, fuel cells have been used to power automobiles. Fuel cells transform hydrogen and oxygen into electricity. In an automobile, a fuel cell's power train would consist of a storage tank holding hydrogen (or another hydrogen-carrying fuel such as methanol), a fuel cell system that converts the fuel into electricity, and an electric motor (CREST 1996). Advantages of such a system include zero emissions, quiet operation, long range ability, and high energy efficiency. Since fuel cells run on hydrogen-rich fuels such as methanol, natural gas, or petroleum, CO_2 emissions may be reduced by over 50.

Rice can look to Georgetown University as a model for implementation of fuel cell buses. They obtained three fuel-cell buses with funding from the Department of Energy. All three are powered by methanol, a phosphoric-acid fuel cell, and a nickel-cadmium battery available for peak-power needs, such as climbing steep hills and strong accelerations (CREST 1996). Although the campus of Rice is relatively flat and does not require such hard accelerations, a model like the one at Georgetown may be of use as we seek emissions-friendly technology that simultaneously supports the high energy demand of interior heating and cooling. Although fuel cell vehicles are not widely manufactured, continued research into the feasibility of implementing such vehicles into the shuttle system is recommended as well.

Alternative Fuels

In spite of the ever-changing face of automobile technology, the implementation of such innovations is a slow process. For example, widespread usage of new vehicle technology may be hindered by the need for infrastructural changes, such as the establishment of recharging stations for EV owners and technology educated repair services. Thus, the environmentally friendly concepts behind the new technology may never be accepted, thus eliminating the market for EV's, HEV's, and fuel cell vehicles. Without a consumer market, companies will cease to produce such automobiles and buses. However, it is still possible to reduce CO_2 emissions using current technology. By using alternative fuels instead of diesel and standard unleaded gasoline, we may reduce our contributions to greenhouse gas emissions (Table D5). Standard gasoline releases 5.35 pounds of carbon per gallon, and diesel gas emits 6.11 pounds per gallon (Table Dl).

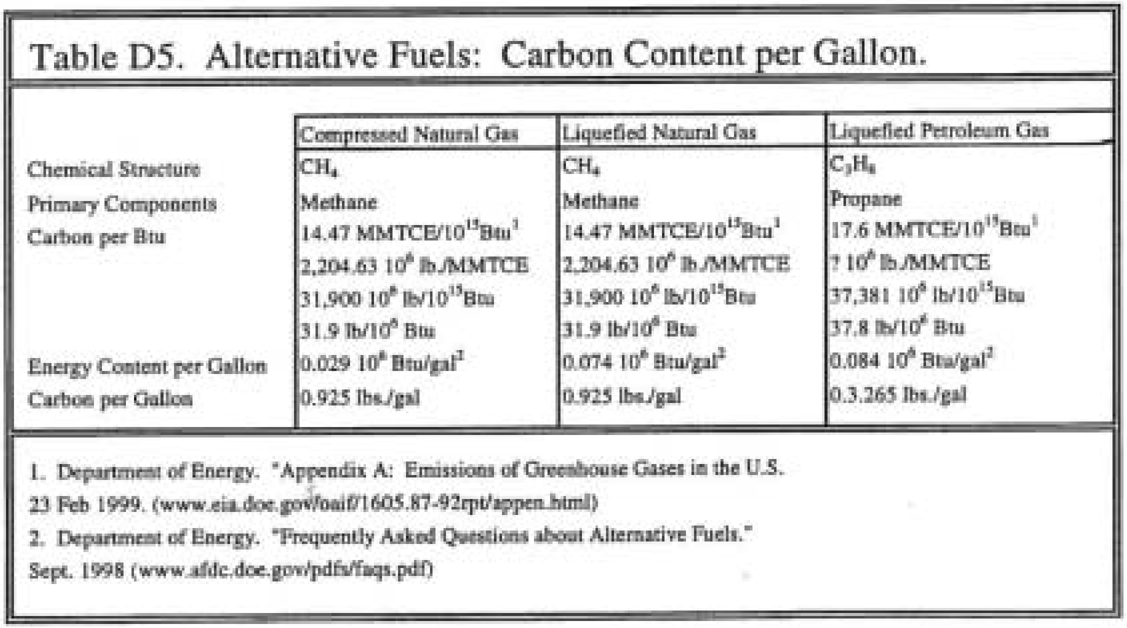


Table D5. Alternative Fuels: Carbon Content per Gallon.

	Compressed Natural Gas	Liquefied Natural Gas	Liquefied Petroleum Gas
Chemical Structure	CH_4	CH_4	C_3H_8
Primary Components	Methane	Methane	Propane
Carbon per Btu	14.47 MMTCE/10^{15}Btu[1] 2,204.63 10^6 lb./MMTCE 31,900 10^6 lb/10^{15}Btu 31.9 lb/10^6 Btu	14.47 MMTCE/10^{15}Btu[1] 2,204.63 10^6 lb./MMTCE 31,900 10^6 lb/10^{15}Btu 31.9 lb/10^6 Btu	17.6 MMTCE/10^{15}Btu[1] ? 10^6 lb./MMTCE 37,381 10^6 lb/10^{15}Btu 37.8 lb/10^6 Btu
Energy Content per Gallon	0.029 10^6 Btu/gal[2]	0.074 10^6 Btu/gal[2]	0.084 10^6 Btu/gal[2]
Carbon per Gallon	0.925 lbs./gal	0.925 lbs./gal	0.3.265 lbs./gal

1. Department of Energy. "Appendix A: Emissions of Greenhouse Gases in the U.S. 23 Feb 1999. (www.eia.doe.gov/oaif/1605.87-92rpt/appen.html)
2. Department of Energy. "Frequently Asked Questions about Alternative Fuels." Sept. 1998 (www.afdc.doe.gov/pdfs/faqs.pdf)

In addition to the benefits offered by reducing carbon dioxide emissions, a co-benefit of alternative fuels is the reduction of ozone-forming tailpipe emissions, such as carbon monoxide and NOx. Compressed Natural Gas (CNG) may reduce emissions of air pollutants by 80 (DOE 1999). For that reason we recommend immediate conversion to alternative fuels in the Rice University shuttle system. While EV's, HEV's and fuel cells may offer greater reductions in CO_2, alternative fuel usage remains a viable option that should be considered.

Clean Cities

Rice can take an active role in supporting alternative fuel vehicle (AFV) use among commuters by participating in the Clean Cities program (Clean Cities 1999). Clean Cities is a voluntary program that brings together stakeholders in a community to develop their own strategy, focusing on the support of alternative fuel vehicles and their associated infrastructure, to combat air pollution. Although sponsored by the U.S. Department of Energy, it is not government mandated, so local businesses and government have the flexibility and the opportunity to take their own initiative. Some of the main objectives of Clean Cities (1999) are:

1) Creating new jobs and markets through the development of AFV technology;

2) Expanding the refueling infrastructure;

3) Developing "Clean Corridors"—linking local with regional and national infrastructure;

4) Increasing public awareness;

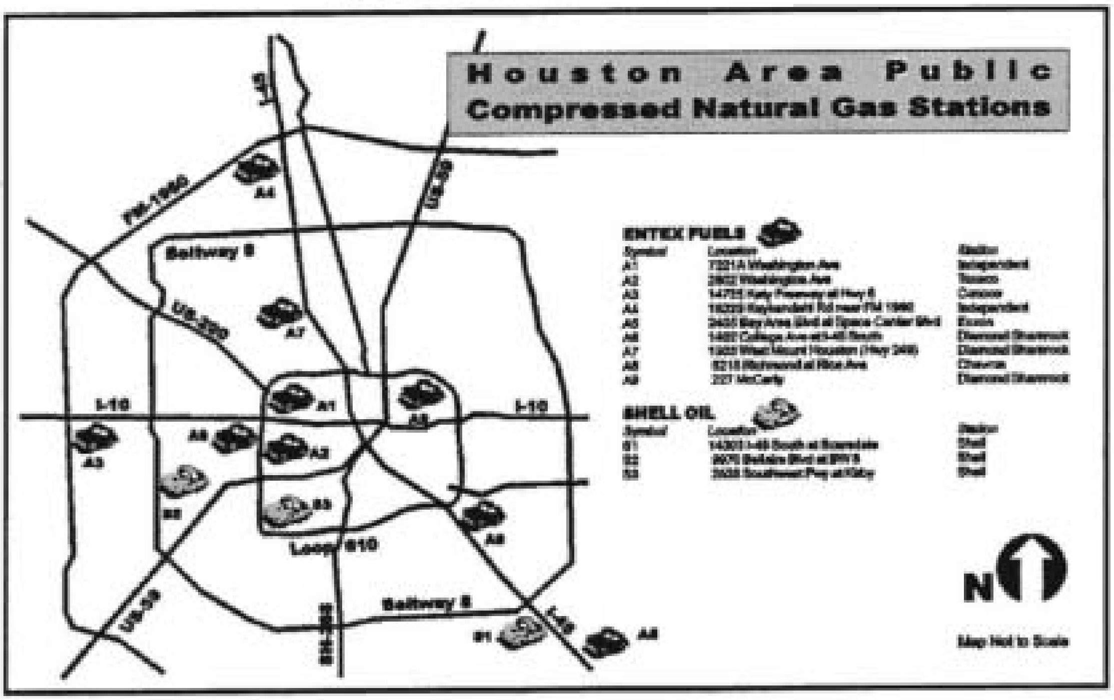
5) Fleet conversion; and

6) Meeting national clean air standards.

Houston has been a Clean Cities member since September 1997. The Greater Houston Regional Clean Cities Coalition looks at ways alternative fuels and vehicles can be used to bring the city closer to meeting national ozone standards—primarily by being a resource to its stakeholders. The organization provides area managers with information regarding federal mandates for alternative fuels as specified in the 1990 Clean Air Act and Energy Policy Act of 1992. It also hosts events that inform the community about alternative fuels. One of its more recent projects has been converting two of Humble ISD's school buses to electricity. This project —which brought together the school district with private industry. Reliant Energy-Entex and Reliant Energy-HL&P—demonstrates the sense of partnership within Clean Cities (Houston Clean Cities 1999).

Rice, too, can tap into the resources provided by Clean Cities to offer its faculty, staff and students a cleaner way to the campus. There are compressed natural gas stations throughout the city and one just at the comer of 1-59 and Kirby, only four blocks from the Rice campus (Figure D2). Thus, although the options for gasoline substitutes are many, with varying degrees of market accessibility, the infrastructure to support some of these alternative fuels is already in place for Rice to use.

Figure D2. Houston Public CNG Stations



source: www.houston-cleancities.org/cng_map.gif

If Rice were to become a Clean Cities stakeholder, it would have access to funds for Clean Cities projects. The Houston-Galveston Area Council has Congestion Mitigation and Air Quality funds specifically set aside to help offset up to 80 of the cost of purchasing or converting vehicles to alternative fuels (Houston Clean Cities, "Funding Opportunities", 1999).

Existing corporate programs that subsidize the leasing of alternative fuel vehicles have shown great promise. Southern Company an electric power company in Georgia, for example, has the largest corporate electric lease program in the nation. By 2003, 600 electric vehicles will be available to its employees for lease—a Ford Ranger truck runs about $150 a month and a GM EV 1 sports car is leased for $200 a month (Southern Company 1999). If Rice adopted a program such as this one, we could begin to significantly reduce our carbon emissions caused by commuting automobiles.

According to Dan Deaton, Clean Cities Regional Director, becoming a stakeholder is as simple as a phone call to the local Clean Cities representative. There are no costs or fees associated with membership. As a Greater Houston Regional Clean Cities Coalition participant, Rice would be represented at the regular stakeholder meetings. (Dan Deaton, April 21,1999). From this position, Rice would be able to meet with other local community members to develop infrastructure plans that are beneficial to Rice's commuters. Given that carbon emissions are a Houston-wide problem, it would be beneficial for Rice to join the Clean Cities program.

Light Rail Transit

If significant steps are taken now to implement a light rail system in Houston, it could serve as an effective long-term solution for carbon abatement. Light rail may not appear to most policymakers as a cost-effective solution to congestion and pollution problems due to the large initial investment required, especially when compared to the alternatives like the expansion of existing highways and METRO bus service. However, when all of the benefits are collectively considered, the true value of this type of system can be substantial. With benefits reaching far beyond carbon emission reductions, light rail "allows you to travel about town smoothly, comfortably, quietly, looks great, doesn't spew out noxious fumes over pedestrians, reaches right into the city center..., doesn't need parking, is economical to use, [and] runs so frequently you don't need a timetable." (LRTA, "What is Light Rail?")

(Source: LRTA., www.lrta.org/explain.htm)

Downtown to Dome Route

The Major Investment Study (MIS) undertaken by METRO is investigating a light rail alternative in Houston's downtown to Astrodome corridor and would include a station in the Rice University area. One might ask how this would help reduce Rice's carbon emissions. The truth is that Rice-related use of light rail in this corridor would be small, making carbon abatement from this first phase minimal. The potential for reductions, however, could be very significant if light rail becomes a real alternative for commuters in the long run. Given that Rice's commuting automobiles emit 2,753 tons of carbon into the atmosphere per year - some 82 of transportation related emissions - a light rail system with a stop at Rice University could lead to significant changes in this percentage over time. If one in ten commuters decided to become a regular commuter on an expanded light rail service, thus leaving their cars at home, the seven percent reduction in carbon emissions prescribed by the Kyoto Protocol could conceivably be achieved for the Rice transportation sector. This would include commuters leaving their cars at transit centers outside of the center city and taking the rail system in to the University.

When considering light rail in the downtown to Astrodome corridor, it would be useful to assess the impact in terms of number of Rice-related vehicles taken off of Houston roadways. Such an analysis was beyond the scope of this project; nevertheless, the experiences of other major cities provide some insight as to what Houston can expect. In Los Angeles, for example, estimates overstated the amount of riders that their system would take on when it opened in 1990, and the result has been a light rail system that has not proven to be a cost-effective solution in the minds of many politicians. On the other hand, Portland's light rail system was an immediate success with ridership 40 greater than initial expectations (LRTA, "Light Rail Successes Despite Opposition"). The most useful reference for our purposes is the light rail system launched in 1996 by Dallas Area Rapid Transit (DART). A careful analysis of DART will continue to give Houston some insight into the feasibility of a similar system.

One unique fact about Houston that has dissuaded policy makers from implementing light rail has been the expansion of the major highways and the apparent success of HOV lanes that has been unparalleled in any other major city. In fact, Houston has been the largest major city to see reductions in traffic congestion over the last decade (DeLay 1998). Still, our benchmark is not congestion abatement; it is carbon abatement. And expanding the highways will only promote the addition of more carbon polluting automobiles on the road.

The South Main Association

The South Main Association is a coalition of the major stakeholders in the South Main Corridor, including downtown, midtown, the Museum District, Hermann Park, the Texas Medical Center, Rice University, and the Astrodome complex. The association holds regular meetings to hear the positions of all of these stakeholders with respect to development in the corridor, especially with respect to the Major Investment Study being undertaken by METRO. As a member of the South Main Association, Rice University has potential lobbying power on the course of action taken by the city with respect to light rail. Both Associate Vice President Neill Binford and Manager of Transportation Eugen Radulescu regularly attend these meetings. Currently, the South Main Association will not put forward a specific stance on the issue (either in favor or against the implementation of light rail). Instead, it serves as a forum for the various stakeholders in the development of the South Main Corridor.

Co-benefits

As we begin to look further into the future of transportation in Houston, we see that implementing a light rail program could have many additional benefits beyond possible carbon reductions with respect to pollution and congestion in the city. First, the light rail service will help alleviate the existing traffic congestion on highways by providing a fast, convenient alternative. Another major co-benefit of taking fossil fuel powered vehicles off of the road is the reduction of urban smog and other dangerous pollutants in the metropolitan area. Emissions of air pollutants such as nitrogen oxides, sulfur oxides, ozone, and volatile organic compounds, would all be reduced and decentralized. Instead of coming out of tailpipes, the emissions necessary for many of the transportation needs of the city would take place at power plants outside of the city. This co-benefit would have an immediate impact when the downtown to dome light rail segment allows for the removal of many of the high-polluting diesel METRO buses that currently serve this corridor. This change certainly benefits Rice, which is situated in this corridor. Considering that Houston is a non-attainment zone for ozone and at risk of losing federal funding if this state of affairs is not remedied, the light rail option becomes all the more attractive. Although the prospects for carbon abatement from light rail are certainly long-term, Houston must begin implementing such a system now if it wishes to reach these goals in the future.

Construction

Shalini Jain
Cameron Naficy
Casey Roberts

Abstract

To reduce CO_2 *emissions on the Rice University campus, we must examine both the history and future of on-campus construction, since concrete and brick, the main components of buildings, are significant sources of* CO_2*. A chronology of past and future projects indicates that Rice is in a period of substantial growth. Based on information obtained regarding the basics of building material and construction, we calculated the amount of* CO_2 *associated with a typical low-rise building for both of these materials. The total carbon emitted annually due to the production and transport of concrete is 567 Tons C. Estimated total annual carbon emissions related to the use of brick is 263 Tons C. Combined, the two largest components of buildings, concrete and brick, account for 830.9 Tons C annually. After calculating* CO_2 *emissions associated with basic construction, it is clear that construction plays a significant role in the campus' total* CO_2 *output. Some possible ways to reduce carbon emissions from construction are the use of alternative materials such as flyash concrete and concrete masonry units in place of traditional concrete and brick, respectively. By recognizing this as an area for improvement, Rice can continue to lower its* CO_2 *emissions and set a precedent for environmentally thoughtful construction.*

Source Quantification

By examining Rice's past and future construction, we can begin to see the significant presence of construction on campus from 1991 - 2004 (Table El). This information sets the stage to examine the impact of construction on Rice's CO_2 emissions.

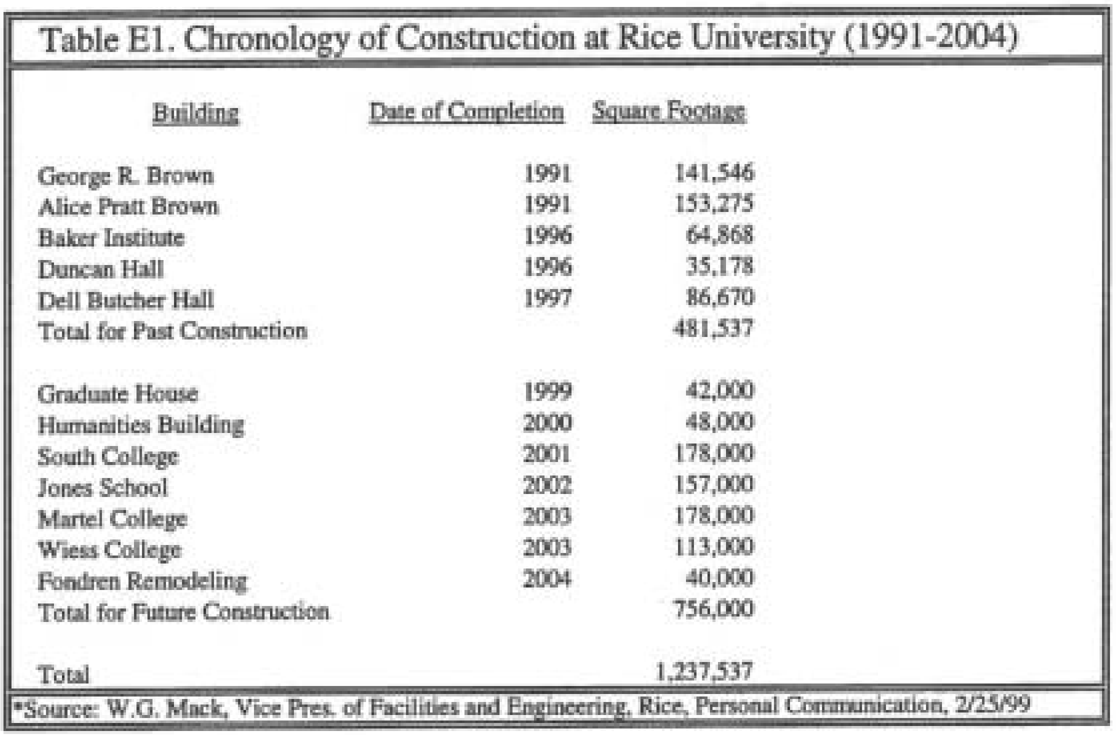


Table E1. Chronology of Construction at Rice University (1991-2004)

Building	Date of Completion	Square Footage
George R. Brown	1991	141,546
Alice Pratt Brown	1991	153,275
Baker Institute	1996	64,868
Duncan Hall	1996	35,178
Dell Butcher Hall	1997	86,670
Total for Past Construction		481,537
Graduate House	1999	42,000
Humanities Building	2000	48,000
South College	2001	178,000
Jones School	2002	157,000
Martel College	2003	178,000
Wiess College	2003	113,000
Fondren Remodeling	2004	40,000
Total for Future Construction		756,000
Total		1,237,537

*Source: W.G. Mack, Vice Pres. of Facilities and Engineering, Rice, Personal Communication, 2/25/99

To estimate the impact of campus development on CO_2 emissions we developed an algorithm to calculate the carbon emissions per square foot of building. Since concrete is a building's primary material, we investigated its basic composition and the embodied energy of each of component. Next, we used a weighted average of the components to find the total energy required to produce concrete. These figures are presented in Calculations A and B, following.

Concrete

Calculations of Carbon Released from the Formation of Concrete

There are two aspects of concrete manufacturing that release carbon dioxide: the chemical reaction forming cement and the energy needed to produce the components of concrete.

A. Calculation of Carbon Released during Reaction $CaCO_3(s) \rightarrow CaO(s) + CO_2\ (g)$

The actual reaction that forms cement (CaO) from calcium carbonate releases carbon dioxide as a product. The amount of carbon dioxide released can be calculated by first finding the number of moles of CaO in a kilogram of cement. The number of moles CaO is equal to the number of moles of CO_2, so we can convert this number back to mass of carbon per kilogram of cement formed. The calculations are as follows:

Step #1

Composition of Cement

Typical construction cement is: 95% Ordinary Portland Cement (OPC), which is 66.8% lime (CaO) (Chen 1997).

So, 1 kg cement = 0.95 * 0.668 = 0.635 kg CaO

Step #2

Conversion of mass CaO to moles CaO

Molar Mass of CaO = 0.056 kg (Gillespie et al. 1994)

0.635 kg CaO * 1 moVO.056 kg =11.34 mol CaO / kg cement

The stoichiometric ratio of the above reaction is 1:1. Therefore, the moles of C produced must be equal to the moles of CaO consumed since the molar mass of C is 0.012 kg (Gillespie et al. 1994).

Step #3

Total C Released During Reaction

11.34 mol C * 1 mol/0.012 kg = 0.136 kg C released / kg cement produced

Cement makes up 12% of concrete by mass (Wilson 1993), so we can calculate the amount of carbon released per kg of concrete by multiplying by that factor, as follows:

*0.136 kg C/kg cement * 0.12 (kg cement/kg concrete) = 0.016 kg C / kg concrete*

= 0.016 lbs. C / lb. concrete

= 32.7 lbs. C / T concrete

B. Energy Consumed in Concrete Manufacturing

The manufacture of concrete requires energy input to produce cement and the other aggregates, sand and crushed stone. Table E2 describes the composition of concrete by mass and the amount of energy required to produce a ton of each of the components. The fourth column gives the amount of energy needed to produce the amount of a given aggregate that is used in one ton of concrete. The total at the bottom of that column, while interesting, cannot be used in further calculations because the production energy of each aggregate comes from different sources. Tables E3 and E4 present the carbon emissions from each of these components.

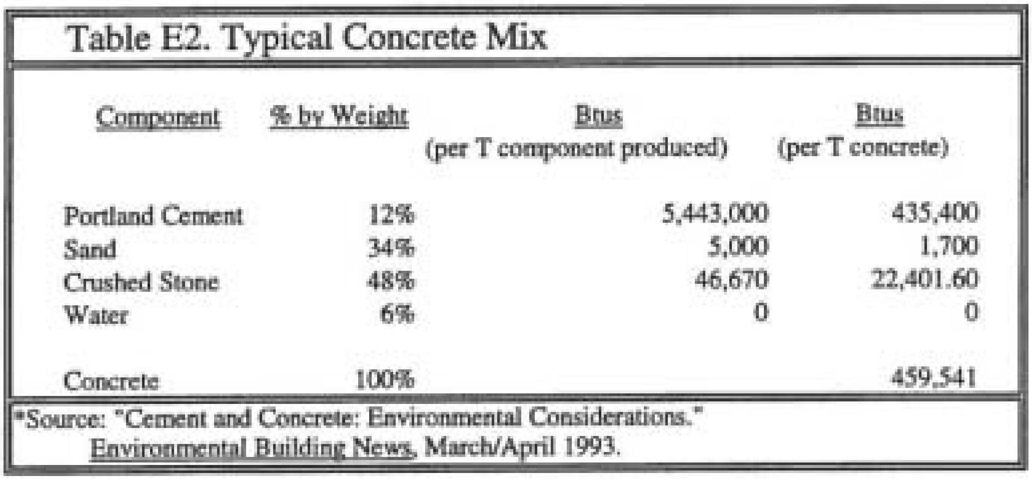


Table E2. Typical Concrete Mix

Component	% by Weight	Btus (per T component produced)	Btus (per T concrete)
Portland Cement	12%	5,443,000	435,400
Sand	34%	5,000	1,700
Crushed Stone	48%	46,670	22,401.60
Water	6%	0	0
Concrete	100%		459,541

*Source: "Cement and Concrete: Environmental Considerations." Environmental Building News, March/April 1993.

The production of cement uses a large amount of energy that is provided by natural gas, coal and electricity jointly. A certain amount of Btus is needed from each source to produce each ton of cement: natural gas (476,000 Btu), coal and coke (3,524,000 Btu) and electricity (1,443,000 Btu). We know that the combustion of these fuels is not completely efficient. In fact, it is only 30% efficient at most (Watson 1996), meaning that we must combust three times as much fuel as we would need if combustion was 100% efficient. Therefore, we multiply the required Btu amounts by a factor of three, in order to gain a better sense of how much fuel is actually used. The carbon coefficients are a measurement of how much carbon is released by the combustion of a given fuel, expressed here in pounds C per quadrillion Btu. So, the amount of fuel combusted is multiplied by the carbon coefficient for that fuel, resulting in the amount of carbon produced by each fuel source.

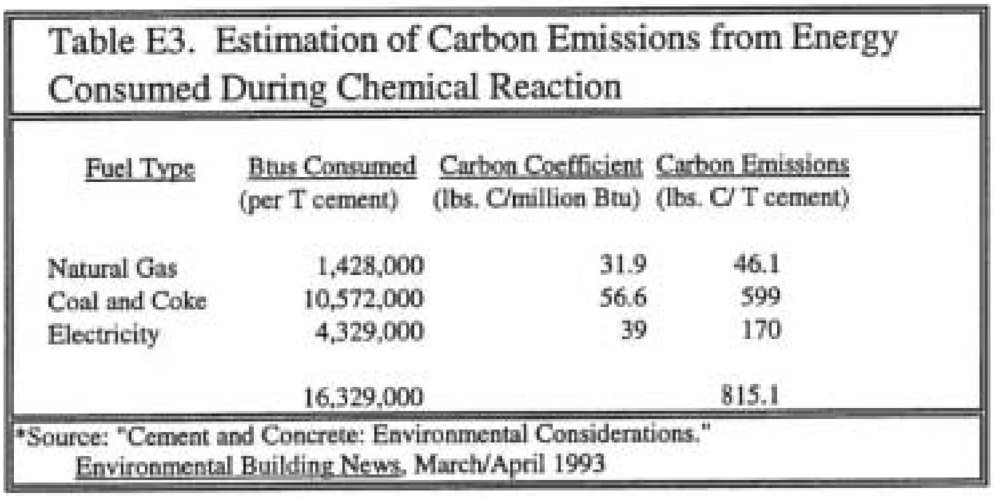


Table E3. Estimation of Carbon Emissions from Energy Consumed During Chemical Reaction

Fuel Type	Btus Consumed (per T cement)	Carbon Coefficient (lbs. C/million Btu)	Carbon Emissions (lbs. C/ T cement)
Natural Gas	1,428,000	31.9	46.1
Coal and Coke	10,572,000	56.6	599
Electricity	4,329,000	39	170
	16,329,000		815.1

*Source: "Cement and Concrete: Environmental Considerations." Environmental Building News, March/April 1993

Table E4 carries out the calculations from Table E3 for the additional components of concrete, crushed sand and stone; this time the only energy source is electricity.

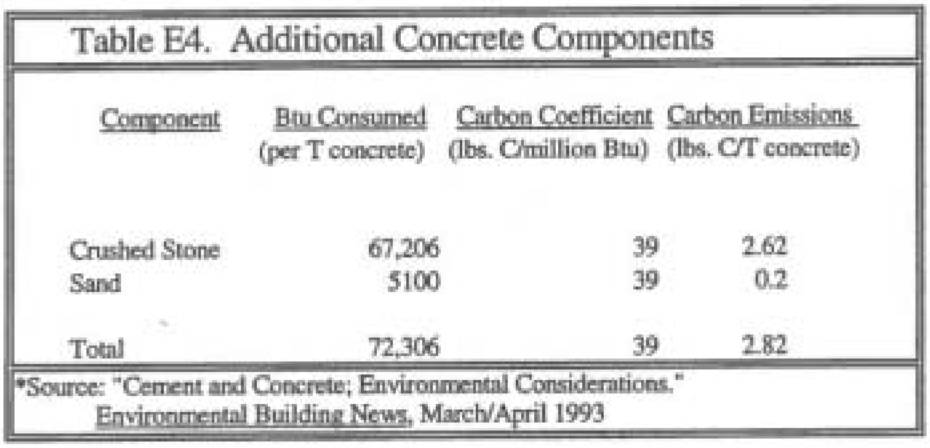


Table E4. Additional Concrete Components

Component	Btu Consumed (per T concrete)	Carbon Coefficient (lbs. C/million Btu)	Carbon Emissions (lbs. C/T concrete)
Crushed Stone	67,206	39	2.62
Sand	5100	39	0.2
Total	72,306	39	2.82

*Source: "Cement and Concrete; Environmental Considerations." Environmental Building News, March/April 1993

Step #1

Energy Use Carbon Emissions for Concrete (T)

= emissions from cement + emissions from other components

= 815.1 Lbs. C/ T cement * 12% (amount cement in concrete) + 2.82 Lbs. C/ T concrete

= 100.6 Lbs. C/ T concrete

Step #2

Total Carbon Emissions from Concrete Manufacturing

= emissions from chemical reaction + emissions from energy use

= 32.7 Lbs. + 100.6 Lbs.

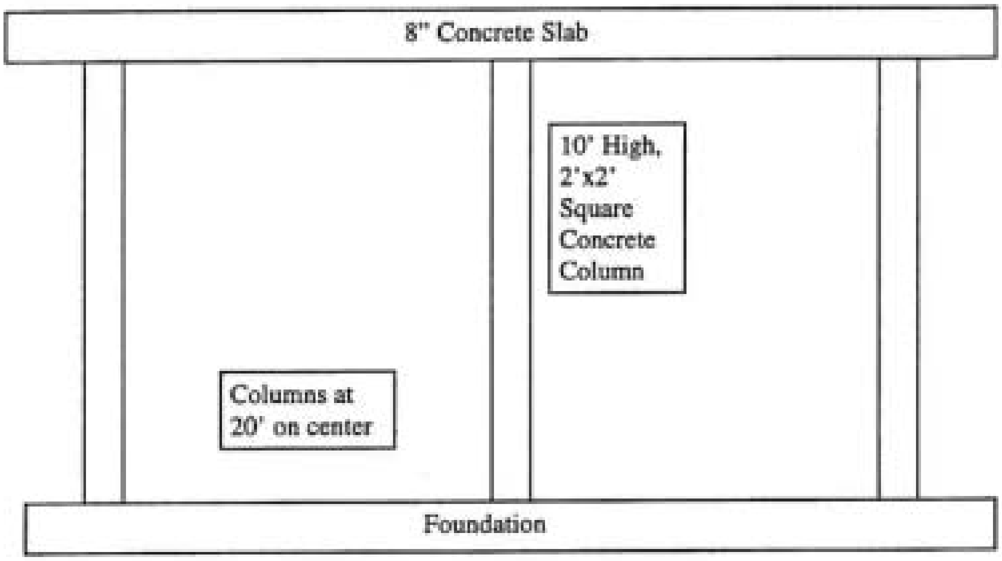
= 133.3 Lbs. C / T concrete

Method of Estimation of Concrete Used per Sq. Ft. of Building Space

With the assistance of Ahmad Durrani, Professor of Civil Engineering at Rice University, we developed a method for calculating the amount of concrete used in an average building at Rice. When transportation and concrete manufacturing emissions were consolidated, we found that 3.38 Lbs. of carbon are emitted for each square foot of construction.

A typical low-rise apartment or office building has an 8" thick concrete floor slab supported by 2'x2' square concrete columns at 20' on center in each direction.

Figure E1. Typical Low Rise Building.



For a 10' column, this averages as follows:

*Floor Slab: 1' * 1' * 8/12 = 0.67 cu ft./sq. ft.*
*Columns: 2' * 2 '* 10'/(20' * 20') = 0.10 cu ft./sq. ft.*
Total Unit Volume = 0.77 cu ft./sq. ft.

Once we have this approximation of volume of concrete used per square foot, we must convert this to mass of concrete. The normal weight of plain concrete is 145 Lbs. / cu. ft (Kosmatcka, Panarefe, 1994).

0.77 cu. ft./sq. ft.* 145 Lbs. concrete / sq. ft. of building space =

111.65 Lbs. = 0.05 T concrete/ sq.ft. of building space

Calculation of the Transportation Costs of Concrete

The costs of transporting materials to the point of construction must be taken into account when calculating total carbon emissions related to construction. We calculated the delivery of concrete to the campus to cost an estimated 0.81 Lbs. of carbon per ton of concrete delivered. Our calculations are as follows:

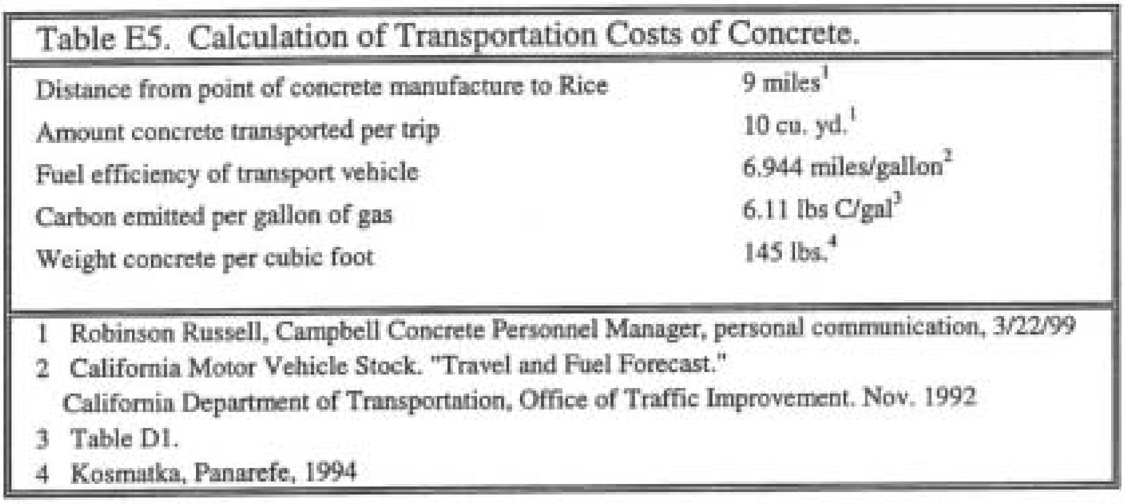


Table E5. Calculation of Transportation Costs of Concrete.

Distance from point of concrete manufacture to Rice	9 miles[1]
Amount concrete transported per trip	10 cu. yd.[1]
Fuel efficiency of transport vehicle	6.944 miles/gallon[2]
Carbon emitted per gallon of gas	6.11 lbs C/gal[3]
Weight concrete per cubic foot	145 lbs.[4]

1 Robinson Russell, Campbell Concrete Personnel Manager, personal communication, 3/22/99
2 California Motor Vehicle Stock. "Travel and Fuel Forecast."
California Department of Transportation, Office of Traffic Improvement. Nov. 1992
3 Table D1.
4 Kosmatka, Panarefe, 1994

Step #1

<u>Calculation of Amount of Concrete Transported in One Trip:</u>

10 cu. yd. * 27 cu. ft. / cu. yd. * 145 Lbs. / cu. ft. = 39150 Lbs. concrete / trip
= 19.6 T concrete / trip

Step #2

<u>Amount of Carbon Emitted in One Trip:</u>

9 miles * 1 gallon gas/6.94 miles * 6.11322 Lbs. C/ gallon gas = 7.92 Lbs. C/ trip
Amount of Carbon/Round Trip = 15.85 Lbs. C/ trip

Step #3

<u>Amount of C Emitted per T of Concrete in One Trip</u>

15.85 Lbs C/trip * trip/19.6 T concrete = 0.81 Lbs C/ T concrete

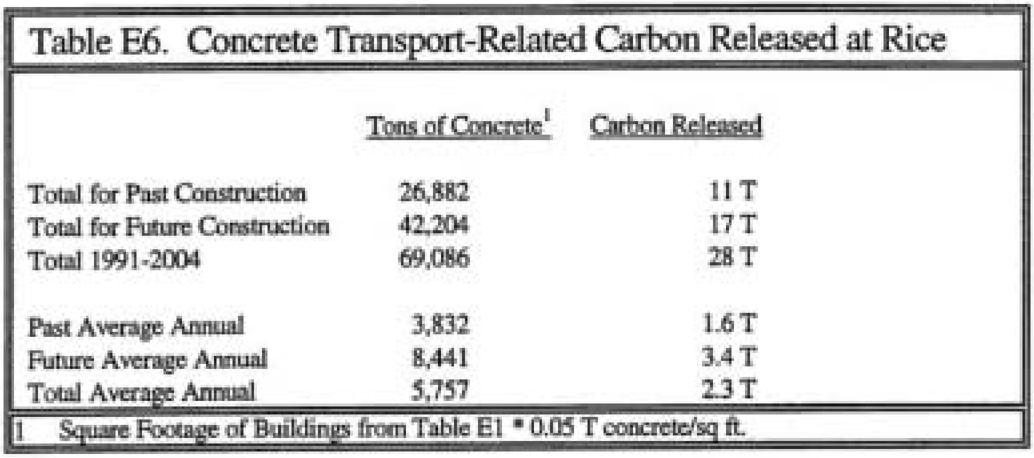


Table E6. Concrete Transport-Related Carbon Released at Rice

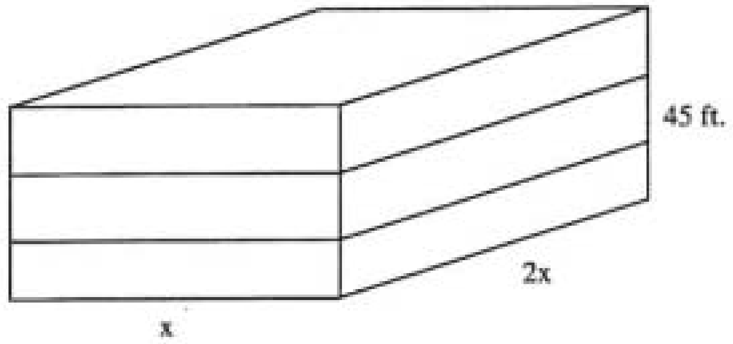
	Tons of Concrete[1]	Carbon Released
Total for Past Construction	26,882	11 T
Total for Future Construction	42,204	17 T
Total 1991-2004	69,086	28 T
Past Average Annual	3,832	1.6 T
Future Average Annual	8,441	3.4 T
Total Average Annual	5,757	2.3 T

[1] Square Footage of Buildings from Table E1 * 0.05 T concrete/sq ft.

Brick

To calculate the amount of brick used in an average Rice University building, we developed a conceptualization of an exterior that expands on the typical low rise building (Figure El) developed by Dr. Durrani. We assume that future buildings will be approximately rectangular, with length twice as long as the width. We also assumed that the buildings would be three stories tall, each story fifteen feet tall, totaling a 45-foot tall building.

Figure E2. Average Rice University Building.



Step #1

<u>Area of One Level</u>

Floor Area of One Level = Total Square Footage/3 (1)
Area of one level = width * length:
$2x * x$ = level area
$x = \sqrt{(\text{level area}/2)}$ (2)

Step #2
<u>Lateral Area</u> (LA. (sq. ft.)) = (width(x) * height(45 ft.) * 2) + (length(2x) * height(45 ft.) * 2)
$= 90x + 180x$
$\mathbf{=270x}$ (3)
Combining Calculations 1, 2 & 3 yields:
$LA(sq.ft.) = 270 * (\sqrt{(\text{total square footage}/6)})$

By counting the number of bricks in a square foot area on recent buildings around campus and averaging these counts, we obtained an average number of bricks, 6.8, per square foot of wall space

No. bricks $= 6.8 * 270 * (\sqrt{(\text{square footage}/6)}) = 1836 * (\sqrt{(\text{square footage}/6)})$

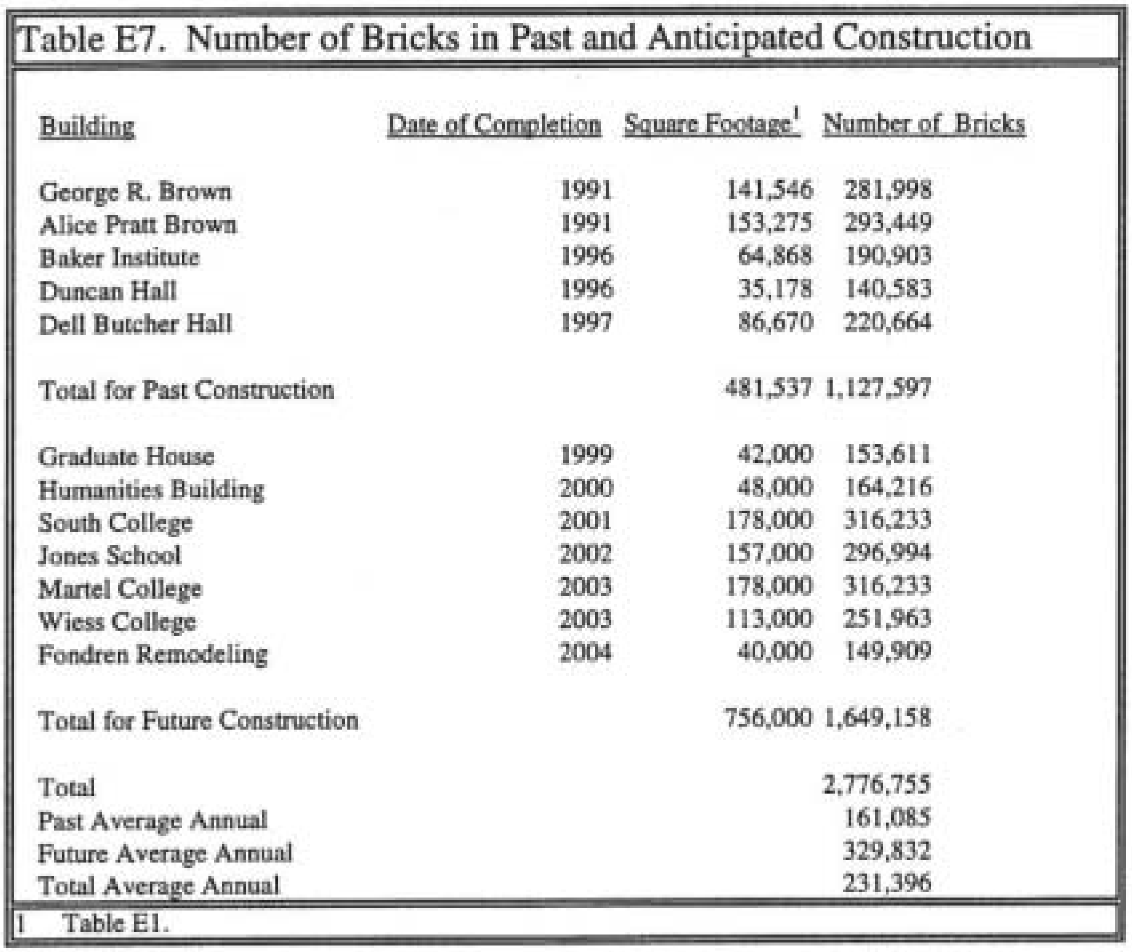


Table E7. Number of Bricks in Past and Anticipated Construction

Building	Date of Completion	Square Footage[1]	Number of Bricks
George R. Brown	1991	141,546	281,998
Alice Pratt Brown	1991	153,275	293,449
Baker Institute	1996	64,868	190,903
Duncan Hall	1996	35,178	140,583
Dell Butcher Hall	1997	86,670	220,664
Total for Past Construction		481,537	1,127,597
Graduate House	1999	42,000	153,611
Humanities Building	2000	48,000	164,216
South College	2001	178,000	316,233
Jones School	2002	157,000	296,994
Martel College	2003	178,000	316,233
Wiess College	2003	113,000	251,963
Fondren Remodeling	2004	40,000	149,909
Total for Future Construction		756,000	1,649,158
Total			2,776,755
Past Average Annual			161,085
Future Average Annual			329,832
Total Average Annual			231,396

[1] Table E1.

Calculating the Carbon Released from Brick Construction

Clay bricks must be fired in a coal-burning kiln, operating at 30% efficiency, at over 2000°F for 24 hours to harden properly. Clearly, this represents a tremendous amount of energy and thus considerable carbon emissions.

Coal combustion releases 56.6 Lbs C/ million Btus (EPA 1992).

Energy needed for one brick = 14,291 Btus (Wittenburg 1999)

A. Carbon Released per Brick

14,291 Btu * 3 (efficiency multiple) * 56.6 Lbs C/ million Btu

= 2.4 Lbs C per brick

B. Brick-related Carbon per sq. ft. of building space=

= 2.4 Lbs C/brick * number of bricks per building

= 2.4 Lbs C/ brick *[1836 * (√(square footage/6))]

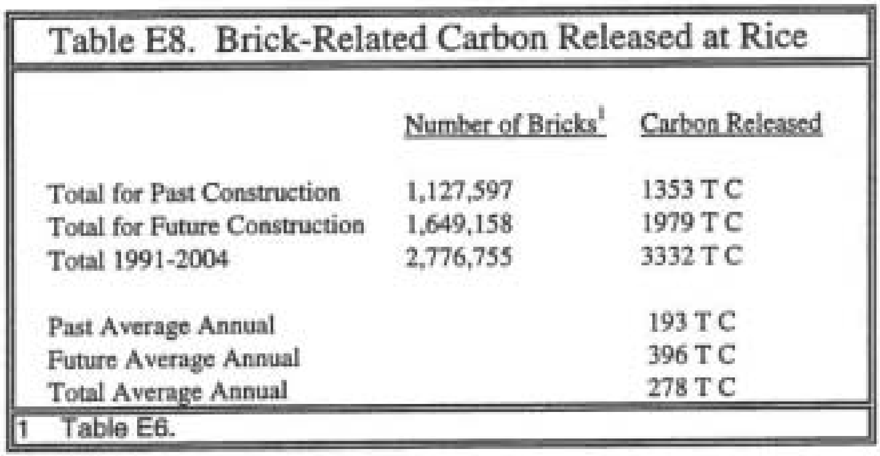


Table E8. Brick-Related Carbon Released at Rice

	Number of Bricks[1]	Carbon Released
Total for Past Construction	1,127,597	1353 T C
Total for Future Construction	1,649,158	1979 T C
Total 1991-2004	2,776,755	3332 T C
Past Average Annual		193 T C
Future Average Annual		396 T C
Total Average Annual		278 T C

[1] Table E6.

Conclusion

The impact of construction on carbon emissions is considerable and must be accounted for in future projects. We suggest examining solutions, such as the use of alternative materials, which can effectively contribute to the lowering of CO_2 emissions.

Total Concrete-Related Carbon Emissions

Concrete Manufacture:	133.3 Lbs. C /T concrete
Transportation of Concrete:	0.81 Lb C /T concrete
Total:	**134.11 Lbs. C / T concrete**

134.11 Lbs. C/Ton concrete * 1 Ton concrete/2000 Lbs. * 111.65 Lbs. concrete/sq. ft. =

= 7.5 Lbs. C/ sq. ft. of building space

Total Brick-Related Carbon Emissions

The brick-related carbon emissions must be calculated individually for each building, and therefore cannot be expressed as a simple function of total square footage for a given time period.

Brick-Related Carbon Emitted per building = 2.4 Lbs C *[1836 * (√(square footage/6))]

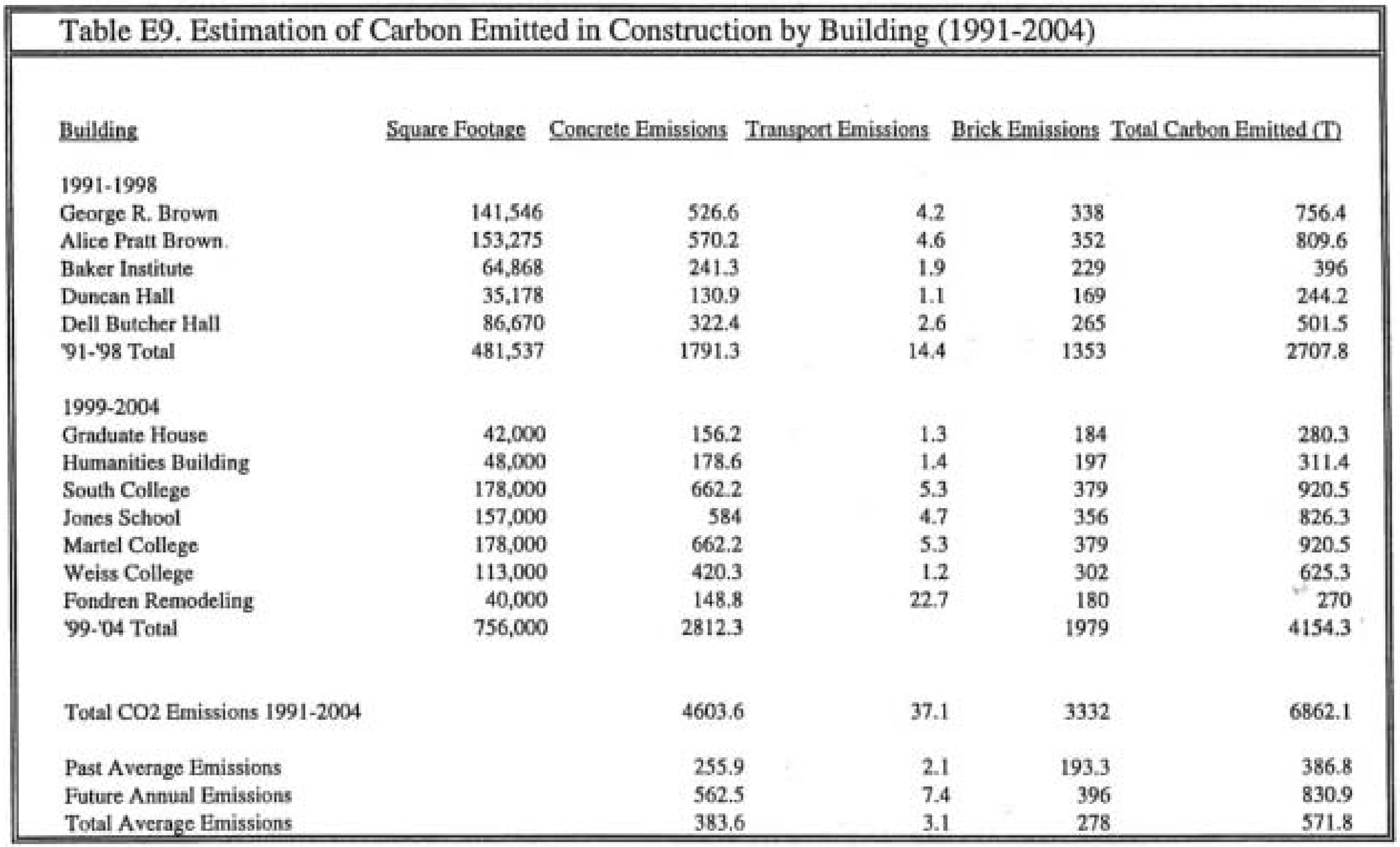
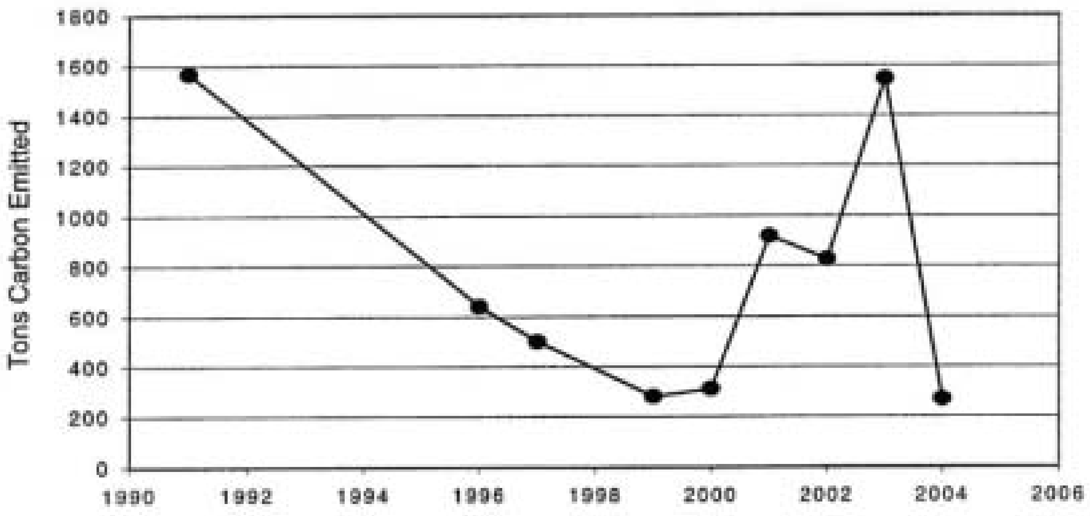


Table E9. Estimation of Carbon Emitted in Construction by Building (1991-2004)

Building	Square Footage	Concrete Emissions	Transport Emissions	Brick Emissions	Total Carbon Emitted (T)
1991-1998					
George R. Brown	141,546	526.6	4.2	338	756.4
Alice Pratt Brown	153,275	570.2	4.6	352	809.6
Baker Institute	64,868	241.3	1.9	229	396
Duncan Hall	35,178	130.9	1.1	169	244.2
Dell Butcher Hall	86,670	322.4	2.6	265	501.5
'91-'98 Total	481,537	1791.3	14.4	1353	2707.8
1999-2004					
Graduate House	42,000	156.2	1.3	184	280.3
Humanities Building	48,000	178.6	1.4	197	311.4
South College	178,000	662.2	5.3	379	920.5
Jones School	157,000	584	4.7	356	826.3
Martel College	178,000	662.2	5.3	379	920.5
Weiss College	113,000	420.3	1.2	302	625.3
Fondren Remodeling	40,000	148.8	22.7	180	270
'99-'04 Total	756,000	2812.3		1979	4154.3
Total CO2 Emissions 1991-2004		4603.6	37.1	3332	6862.1
Past Average Emissions		255.9	2.1	193.3	386.8
Future Annual Emissions		562.5	7.4	396	830.9
Total Average Emissions		383.6	3.1	278	571.8

To understand these numbers in relation to the Kyoto Protocol, we regard the Past Average Annual Emissions as our approximate 1990 levels. Similarly, the Future Average Annual Emissions, the average of emissions over the next five years, is treated as our current annual emissions. Predicting the emissions levels for 2010 is more difficult, because construction plans are not well defined so far in advance. So on this point we make the reasonable assumption that Rice will continue on its present rate of growth, and thus 2010 carbon emission levels due to construction will be approximately the same as emission levels over the next five years.

Figure E1. Construction-Related Carbon Emissions 1991-2004.



Solutions

Introduction

The area of construction represents enormous potential for reducing carbon emissions at Rice. The solutions can be grouped into three general areas: concrete, exteriors and sustainable architecture. For each of these groups we propose a list of solutions that we feel merit further discussion and research, and we also looked more in depth at two very promising alternative materials, flyash concrete and concrete masonry units

Our primary recommendation is to specify that flyash concrete and concrete masonry units be used in building construction at Rice. These materials provide the same service as traditional concrete and brick, yet their production emits less CO_2 and their use can therefore reduce Rice's emissions by a significant amount.

Recommended Solutions for Concrete

- Substituting flyash concrete for standard concrete when applicable.
- Incorporate recycled materials such as ground blast furnace slag.
- Used concrete can be pulverized and used as aggregate for fresh concrete.

Flyash (Cote, 1997):

Flyash, also known as coal ash, is produced as a byproduct in the combustion of coal. Thirteen million tons of coal ash are produced in Texas each year and about 38% of this is of sufficient quality for use in concrete products. Still, only 4.2% is actually reused, which is well below the national average of 11.4%. Because flyash is produced as a byproduct of coal combustion, many people may have concerns about the safety and health issues associated with its use. However, according to the EPA's "Study of Waste from Combustion of Coal by Electric Utility Plants" (1988), coal combustion by-products (CCBP) do not exhibit hazardous characteristics and therefore will not be regulated. Furthermore, in 1993 the EPA released a final ruling that specifically exempted coal ash from regulation.

Flyash is incorporated into concrete products by substituting it for about 20-35% of Portland cement, depending on the application. Since the reaction creating cement releases so much carbon, and because this reaction consumes a significant amount of fossil fuels, substituting flyash for Portland cement would result in huge carbon savings. In addition to its benefits to carbon emissions, using flyash alleviates the economic cost of its own disposal.

Properties of Flyash

Flyash consists of many of the mineral components of coal that remain after combustion. Class C flyash, which is the grade recommended by the American Society for Testing and Materials, is about 40% silicon oxide, 25% lime, 17% aluminum oxide, and contains smaller amounts of iron oxide, magnesium oxide, and sulfates. These materials react with water and lime to form a cementitous material. Flyash varies greatly between coal plants and even within the same plant; these variations can make a significant difference in the properties of cement containing flyash. This is why not all flyash can be used in construction.

Properties of Flyash Concrete

The workability of flyash concrete is improved over ordinary concrete because of the small size and spherical shape of flyash particles. Improved workability ensures that the concrete will flow to completely fill forms, the concrete will self-compact, and it will not segregate during placement. Aggregate attack occurs in concrete when potassium and sodium alkalis released from the cement combine with siliceous aggregates in the concrete, causing expansion and cracking. When flyash is present, these alkalis will react with the high concentration of silicon oxide(40%) in the flyash more quickly, reducing problems of expansion after the concrete sets.

In addition, flyash reacts with the free lime present in concrete, creating extra cementious materials. This both strengthens the concrete and reduces permeability. Reduced concrete permeability blocks concrete 'bleed channels,' making the forms more resistant to invading chemicals that can compromise the strength and durability of the concrete.

One of the disadvantages of flyash concrete is its low strength in the early stage of setting. Its very early strength is lower than that of traditional concrete, but by 28 days, the compressive strength is usually comparable or better. Still, several contractors stated they primarily use flyash concrete for foundations and similar slab surfaces, as opposed to using this material throughout a building for support and vertical construction. Dr. Ahmad Durrani, Professor of Civil Engineering at Rice University, also stated that flyash could be less durable in the long term. Despite these views, the use of flyash concrete is approved under Texas building codes, and it use accounts for a substantial portion of the concrete sales of several contractors we interviewed.

Current Use of Flyash

Thirty percent of flyash is recycled for use in concrete products in the United States. Besides private use, both the Colorado Department of Highways and the Iowa Department of Transportation recommend flyash concrete for construction. In Houston, representatives from

Campbell Concrete and Houston Shell and Concrete state that 50 of their concrete orders are for flyash concrete, indicating its wide local use and availability.

Flyash Cost

Communication with several Houston area concrete contractors (Russell Robinson, Plant Manager, Campbell Concrete, Robert Barkley, Manager, Houston Shell and Concrete, Personal Communication 3/22/99) indicate that the cost of flyash concrete is less than that of traditional concrete. The cost of substituted concrete is $62/ cu yd, compared to $64/ cu yd for traditional concrete. Considering that Rice University will use an estimated 23,000 cu yds of cement in the next five years (Table E6), this would represent savings of at least $46,000.

Calculation of Carbon Emitted by Use of Flyash Concrete

Local contractors recommend that flyash substitute 30 of the cement present in concrete. Thus, we can reduce the use of cement, the major contributor to concrete carbon emissions by 30%. So, whereas cement now comprises 12% of concrete, it can be reduced to 8%. Flyash constitutes 4% of concrete and because it is the waste product of another industrial process, it effectively requires no energy to produce.

If we change the percentage of cement in our calculations from 12% to 8%, the amount of carbon emitted per ton of concrete drops to **88 Lbs. or 0.044 T**. For a complete understanding of the calculations please see the Construction Source Quantification Report.

This total was 133.3 Lbs C / T concrete. Through the use of flyash concrete this number is reduced to 88 Lbs. C, creating a **34% decrease in carbon emissions** from standard construction concrete by using flyash concrete. This reduction is dramatic because cement is by far the most energy-intensive component of concrete; reducing its mass by only 30%, reduces the carbon emissions significantly.

Area contractors suggest that flyash only be used in floor slabs, not in vertical construction. Therefore, to obtain true estimates of carbon emissions reductions we must modify our approximation of concrete used in buildings. For the floor slabs, we may use flyash concrete, but for the columns we will retain the use of standard concrete.

Floor Slab: 1' * 1' * 8/12 = 0.67 cu ft/sq ft
Columns: 2'* 2'* 10'/(20'*20') = 0.10 cu ft/sq ft
Total Unit Volume = 0.77 cu ft/sq ft[4]
(Concrete weighs 145 Lbs/cu ft) (Kosmatka, Panarefe, 1994)

Pounds of Carbon per Sq. Ft. of Building Space

Because floor slabs and columns cannot both be composed of flyash concrete, we must calculate the carbon emitted per square foot of floor space separately for each of these components.

Step #1
<u>Floor Slabs</u>
0.67 cu ft /sq ft * 145 Lbs/ cu ft = 97.15 Lbs concrete / sq ft of building space
97.15 Lbs concrete /2000 Lbs/T = *0.05 T/sq ft of building space*

We are using flyash concrete for the floor slabs. Therefore, we attribute 88 Lbs C for every ton of concrete used.
Subtotal: 0.05 T concrete/ sq. ft. * 88 Lbs C/ T concrete = *4.4 Lbs of carbon / sq. ft*

Step #2
<u>Columns</u>
0.10 cu ft/ sq ft * 145 Lbs/ cu ft = 14.5 Lbs concrete/ sq ft of building space
14.5 Lbs concrete /20001bs /T = *.007Tconcrete/sq ft of building space*
We are using standard concrete for the columns. Therefore, we attribute 133.3 Lbs C for every ton of concrete used in the columns.
Subtotal: 0.007 T concrete/ sq ft * 133.3 Lbs C/ T concrete = *0.9 Lbs of Carbon/sq ft*

Total (Floor Slabs + Columns): 5.3 Lbs. C/ sq ft of building space.

Our previous calculation, using all standard concrete, estimated carbon emissions at *7.5 Lbs C/ sq ft*. The new value represents a **29.3%** decrease in carbon emissions from concrete used in construction.

From Table E10, we can see that incorporating flyash concrete into building construction reduces carbon emissions significantly.

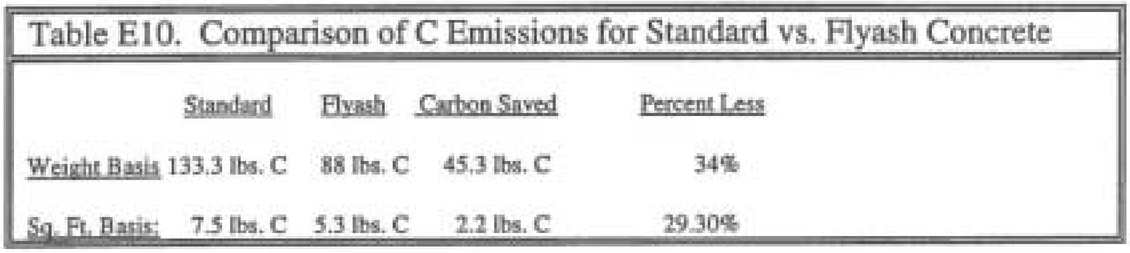


Table E10. Comparison of C Emissions for Standard vs. Flyash Concrete

	Standard	Flyash	Carbon Saved	Percent Less
Weight Basis	133.3 lbs. C	88 lbs. C	45.3 lbs. C	34%
Sq. Ft. Basis:	7.5 lbs. C	5.3 lbs. C	2.2 lbs. C	29.30%

In Table El 1, carbon emissions per building are determined by multiplying the square footage of each building by the carbon emitted per square foot (5.3 Lbs. C).

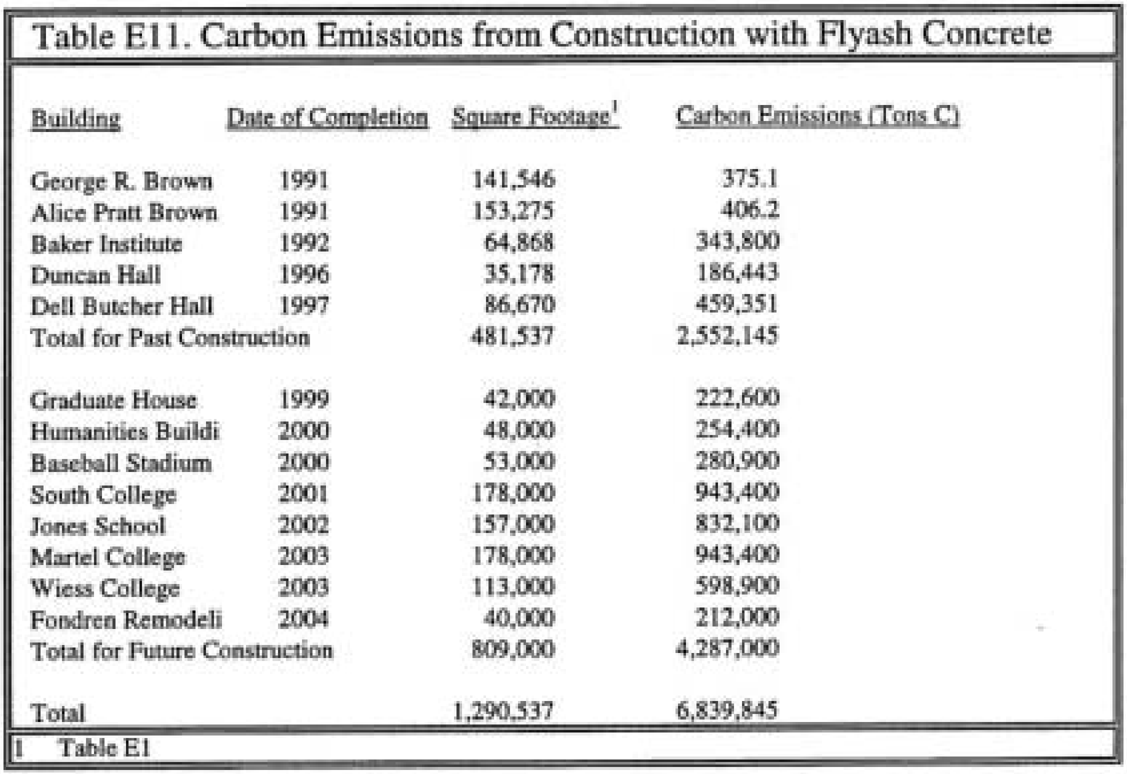


Table E11. Carbon Emissions from Construction with Flyash Concrete

Building	Date of Completion	Square Footage[1]	Carbon Emissions (Tons C)
George R. Brown	1991	141,546	375.1
Alice Pratt Brown	1991	153,275	406.2
Baker Institute	1992	64,868	343,800
Duncan Hall	1996	35,178	186,443
Dell Butcher Hall	1997	86,670	459,351
Total for Past Construction		481,537	2,552,145
Graduate House	1999	42,000	222,600
Humanities Buildi	2000	48,000	254,400
Baseball Stadium	2000	53,000	280,900
South College	2001	178,000	943,400
Jones School	2002	157,000	832,100
Martel College	2003	178,000	943,400
Wiess College	2003	113,000	598,900
Fondren Remodeli	2004	40,000	212,000
Total for Future Construction		809,000	4,287,000
Total		1,290,537	6,839,845

[1] Table E1

Recommended Solutions for Sustainable Architecture

There are many potential solutions for reducing construction-related carbon emissions that involve the design of buildings that are compatible with the intended purpose of the building and its energy needs. Buildings can also be designed to minimize the use of construction materials, and to use construction materials that help reduce the energy use of the building.

- Landscaping can be designed to reduce the energy needs of a building. For example, planting deciduous trees near windows shades the window during the hot summer, but allows light and heat in during the winter.
- The albedo, or reflectivity of surfaces, can greatly affect the energy demands of a building. For example, light colored roofs do not absorb as much heat as do dark ones, reducing the strain on cooling mechanisms (Robert Harriss, Professor of Environmental Science, Texas A&M University, 4/8/99).

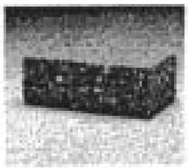
Recommended Solutions for Exteriors

- Incorporate recycled materials in brick, such as concrete, ground glass, ground granulated blast furnace slag, or flyash
- Use sun-dried adobe rather than clay-fired brick because sun-drying incures much less embodied energy costs. This solution is not feasible for Rice University due to the humidity of Houston's climate and the unsuitability of less-durable adobe bricks for large buildings

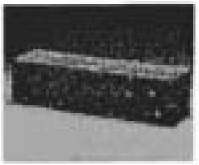
Concrete Masonry Units (CMUs)

Concrete masonry units have been offered as an effective substitute for brick. CMUs can be used as load-bearing structural supports or as a substitute for brick in exterior walls. Our focus is on the latter use of CMUs as units in exterior walls. They are generally hollow and are composed mostly of cement. Their size, color, shape and design may vary in accordance with aesthetic purposes. Various examples of different CMU types are provided below (Beavertown Block Co., me, 1999.)

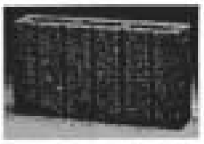
Figure E4: CMU Types



Split Brick
3x4x8
Sage Green

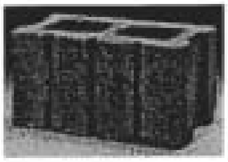


Split Veneer
4x4x16
Rustic Brown

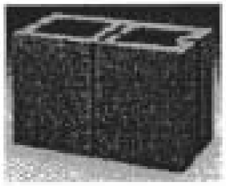


Textured 5-Score
4x8x16
Rustic Brown

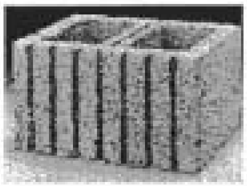
Split 6-Rib
4x8x16
Rustic Brown



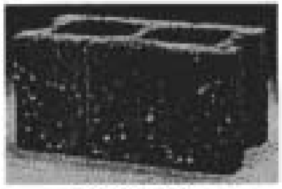
Split 4-Rib
Special
8x8x16
Dark Sea Shell



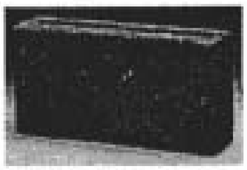
Textured Single Score
Corner Sash
8x8x16
Terra Cotta



Split 8-Rib
Corner Sash
12x8x16
Sand Stone Beige



Split 3-Rib
8x8x16
Bermuda Brown



Split Face
4x8x16
Medium Terra Cotta

Production of CMUs

Recycled concrete, sand and up to 30% flyash can be employed as a substitute for virgin materials currently used in CMUs. Due to its potential for incorporating recycled material and its lower volume, compared to brick, CMUs are more efficient. When the energy used to fire a clay brick is compared to the formation process for CMUs, further differences are manifest. Clay bricks are fired at temperatures around 2000 °F, requiring large amounts of fuel, usually coal. CMUs, however, are formed through a different process. First, Portland cement, lime and sand are mixed and poured into molds. Next, these molds are placed into large kilns where they are steam cured at temperatures ranging from 120°C-130°C. The steam used for the curing process can be acquired by means of co-generation or by the use of natural gas (Keith Brady, Operations Manager, Eagle Concrete Products, Personal communication, 4/19/99). Thus, CMUs are more efficient both in their energy consumption and also from a composition materials standpoint.

Calculation of Carbon Emitted by the Use of Concrete Masonry Units

I. Calculation of Lateral Area from Square Footage

Using the lateral area algorithm described on page 49 we can calculate the lateral area of a building from its square feet.

Lateral Area of a Building (sq. ft.) = 270 * (sq. ft./ 6)^ 1/2
We obtained the lateral areas shown in Table 5 for all of the buildings constructed from 1991-2004 using this algorithm.

II. Calculation of Carbon Emitted Based on Lateral Area

Step #1
Pounds of CMU per Sq. Ft. of Building Space
There are approximately 1.125 CMUs per sq. ft.
(Edward Witt, Sales Manager, Eagle Concrete Products, 4/12/99)
A typical CMU weighs 26.8 Lbs.
(Teal Johnson, Architectural Representative, Eagle Concrete Products, 4/12/99)
So, 1.125 CMU/ sq. ft. * 26.8 Lbs./ CMU = 30.15 Lbs./ sq. ft.

Step #2
Pounds of C Emitted per Pound of CMU
Each pound of CMU produced uses 603 BTUs
(American Institute of Architects, 1997)
For every million (10^6) BTUs emitted 56.6 Lbs. of Carbon are released.[12]
So, 603 BTU/ 1 Lb. of CMU * 56.6 Lbs. C/ 10^6 BTU = .0341 Lbs. C/ Lb. CMU

Step #3
Pounds of C Released per Sq. Ft. of Building Space
30.15 lbs./sq. ft. * .0341 Lbs. C/ Lb. CMU= 1.03 Lbs. C/ sq. ft.

Step #4
Efficiency Factor
This figure does not account for the inefficiency of coal used as a power source in forming the CMUs. We must therefore include a efficiency factor of 3 to compensate for this.
3 * 1.03 Lbs. C/ sq. ft.= 3.09 Lbs. C/ sq. ft.

We convert this into tons of C as follows:
3.09 Lbs. C/ sq. ft. * Iton C/ 2000 Lbs. C= .00155 tons C/ sq. ft.

Finally, we multiply this figure by the lateral area (sq. ft.) of each building (see Table E10) to get tons of Carbon produced per square foot of building due to CMUs.
0.00155 tons C/ sq. ft.* L.A. (sq. ft.) of building = tons of C

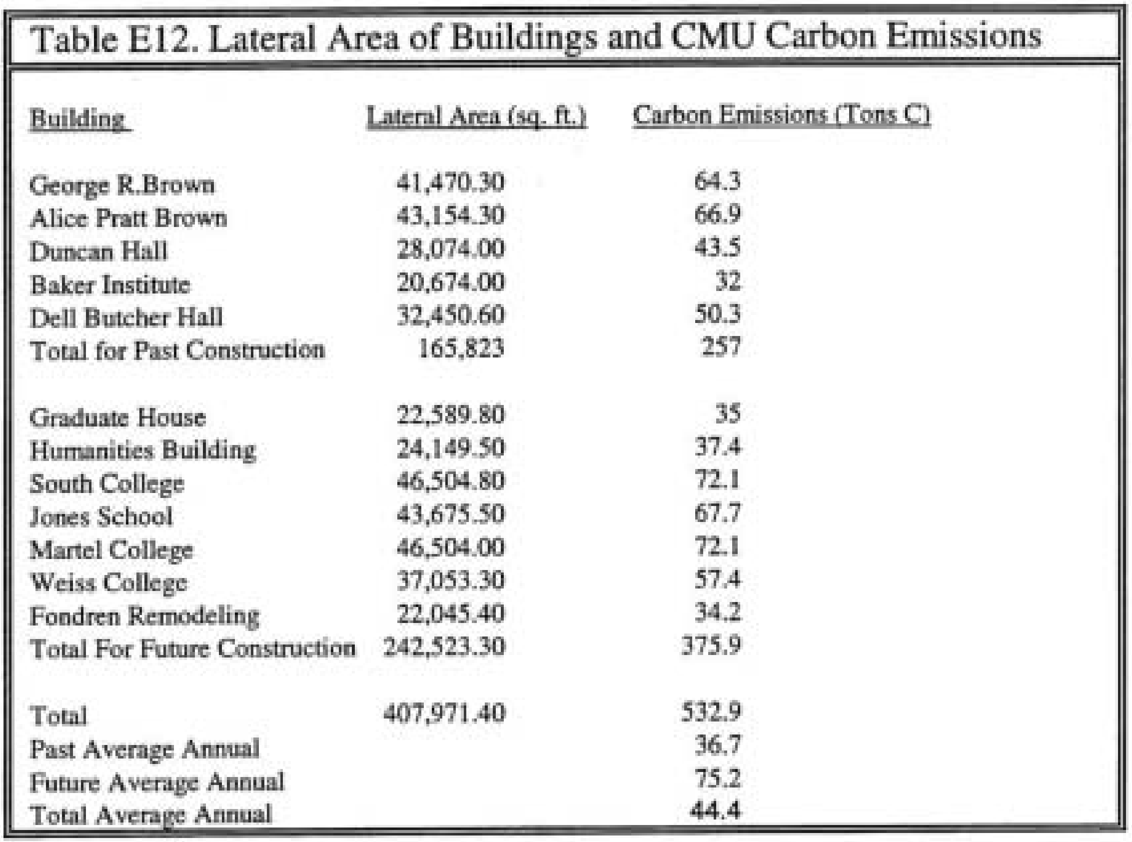


Table E12. Lateral Area of Buildings and CMU Carbon Emissions

Building	Lateral Area (sq. ft.)	Carbon Emissions (Tons C)
George R.Brown	41,470.30	64.3
Alice Pratt Brown	43,154.30	66.9
Duncan Hall	28,074.00	43.5
Baker Institute	20,674.00	32
Dell Butcher Hall	32,450.60	50.3
Total for Past Construction	165,823	257
Graduate House	22,589.80	35
Humanities Building	24,149.50	37.4
South College	46,504.80	72.1
Jones School	43,675.50	67.7
Martel College	46,504.00	72.1
Weiss College	37,053.30	57.4
Fondren Remodeling	22,045.40	34.2
Total For Future Construction	242,523.30	375.9
Total	407,971.40	532.9
Past Average Annual		36.7
Future Average Annual		75.2
Total Average Annual		44.4

From Table E9, we know that 1,979 T of C are predicted to be emitted due to the use of brick exteriors on campus. The use of CMUs reduces this figure to 375.9 T of C. **This represents an *81% savings in carbon emissions.***

Comparison of Cost and CO_2; Emissions of Brick to CMUs

When constructing a new building, reduced CO_2 emissions are not the only factor to consider. Economic feasibility is of primary importance. If we compare the cost of CMUs to the cost of brick we find that 1 CMU costs $0.99 and 1 brick costs $0.35 (Teal Johnson, 4/13/99) These numbers, though, are misleading because they do not take into account the size or volume of either material. To do this, we must know the cost of brick per unit area versus the cost of CMUs per unit area. We know the cost per brick and we know the number of bricks per square foot.

$0.35/brick * 6.8 bricks/sq. ft. = **$2.38/sq. ft.**

We also know the cost per CMU and the number of CMUs per square foot.

$0.99/CMU * 1.125 CMUs/sq. ft. = **$1.11/sq. ft.**

Obviously, using CMUs as a substitute for brick in exterior walls can yield substantial economic benefits. The difference amounts to $1.27 for every square foot of building. We can use this to find the difference in costs of total future construction (L.A.=242,523.3 sq. ft.) using CMUs as a substitute for brick.

Multiplying 242,523.30 sq. ft by. * $1.27/sq. ft. gives a **$308,004.59** savings for total future construction over the next five years

Thus, we can see that CMUs can provide both an economically profitable and an energy efficient alternative to brick without sacrificing aesthetics.

Conclusion

This report shows that the use of alternate materials such as flyash concrete and concrete masonry units can substantially reduce Rice University's construction-related carbon emissions. The use of flyash concrete would result in a carbon savings of 29.3%. Utilizing CMUs rather than brick results in 79% carbon savings. Overall, using these alternative materials in construction could reduce the university's construction related emissions by an estimated 45%.

The use of the proposed alternative materials benefits Rice in two ways. First, it allows Rice to be an innovative leader in the movement towards reducing carbon emissions. Second, alternative materials decrease the overall cost of construction. With the large amount of growth on campus, Rice now has the opportunity to use alternative materials and make a significant difference in the amount of carbon emitted.

Appendices and References

Appendix I

A. Schematic Diagram of Rice University's Energy System.

B. Methodology Used to Determine Carbon Emissions from Energy Consumption.

C. Carbon Coefficient Methodology Reality Check.

D. Building Groups by Use.

E. Rice University Carbon Emissions by Building from Energy Consumption in 1998.

F. Rice University Carbon Emissions per Square Foot by Building from Energy Consumption in 1998.

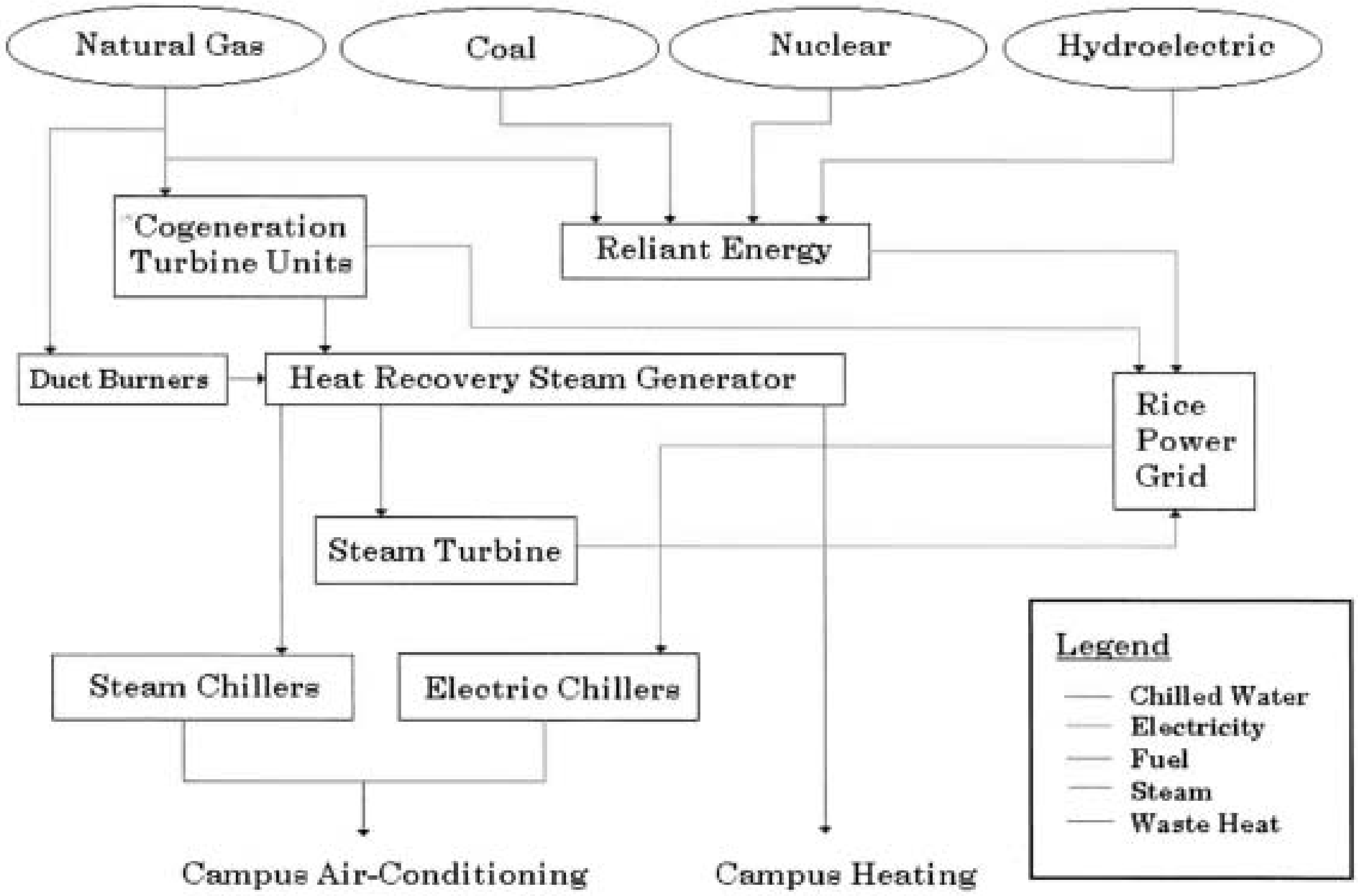
G. Rice University Carbon Emissions by Building Group from Energy Consumption in 1998.

H. Projected Rice University Carbon Emissions due to Increased Energy Consumption from Future Construction 1999-2004.

I. Projected Rice University Carbon Emissions due to Increased Energy Consumption 1990 -2010.

J. Rice University Cogeneration Upgrade Projection 2000-2010.

Appendix A. Schematic Diagram of Rice University's Energy System.



B. Methodology Used to Determine Carbon Emissions from Energy Consumption.

In our determination of Rice University's carbon dioxide production, we followed the procedure recommended by the United States Environmental Protection Agency State Workbook: Methodologies for Estimating Greenhouse Gas Emissions (USEPA 1998). See Section E for applied calculations.

I. Carbon Calculation

Step #1

Energy Consumed (Fuel Identification)

Convert amounts of major combustion fuels consumed to BTU values.

Step #2

Energy Produced (Overall Efficiency Correction)

In the conversion of energy from its primary source to useful energy, there are many different places where inefficiencies can occur. Therefore, the overall efficiency reported often spans a wide range. For the purposes of this report, we have assumed a 30% overall efficiency (Watson 1996).

Step #3

Carbon Coefficient/ Total Carbon (Carbon Conversion)

Multiply BTU values from step 2 by fuel-specific BTU-to-carbon conversion factor (Carbon Emissions Coefficient) to get tons of carbon released to the air if 100% of the fuel were oxidized. The Carbon Emission Coefficients (see following page for specific values) are fuel-specific carbon content values based on research by the Department of Energy (USDOE 1998).

Step #4

Total Carbon Oxidized (Carbon Oxidation Correction)

In reality, not all the fuel is completely oxidized and the tonnage figures reached in step two above need to be reduced. In this methodology, a 1% reduction is used for fossil fuels.

II. Disaggregation

Since the different sources of Rice University's energy have varied carbon coefficients and overall efficiencies, we identified these sources and calculated the individual carbon contribution of each source. A total was then found by summing these individual carbon contributions.

The Reliant Energy total was divided into the major combustion fuels used in Reliant Energy's electricity production. According to Reliant Energy's website. Rice University's electricity purchased from the grid has the following makeup (Energy sources are price-dependent, so the mix of power supplies can fluctuate dramatically.):

Natural Gas: 32-39%
Coal and lignite: 40-47%
Nuclear: 9-14%
Large hydro: 1%
Renewable sources (solar, wind, small-scale hydro): negligible

The Cogeneration Energy total was divided into Turbines and Duct Burners. Since Duct Burners produce heat from the direct combustion of natural gas, Duct Burners have a higher overall efficiency (which we assumed to be ~100%) than Turbines (assumed to be 30%).

B. Methodology Used to Determine Carbon Emissions from Energy Consumption (cont.'d).

		Step #1	Step #2	Step #3		Step #4
	Energy Consumed[1] (kWH/yr)	Energy Consumed (million BTU/yr)	Energy Produced (million BTU/yr)	Carbon Coefficient (lbs C/ million BTU)	Total Carbon (tons/yr)	Total Carbon Oxidized (tons/yr)
Overall Input						
Reliant Energy						
Natural Gas (39%)	15,802,800.00	53,919.15	179,730.51	31.90	2,866.70	2,838.03
Coal (47%)	19,044,400.00	64,979.49	216,598.31	56.60	6,129.73	6,068.43
Nuclear (13%)	5,267,600.00	17,973.05	59,910.17	0.00	0.00	0.00
Hydroelectric (1%)	405,200.00	1,382.54	4,608.47	0.00	0.00	0.00
Total	40,520,000.00	138,254.24	460,847.47	39.04	8,996.43	8,906.47
Cogeneration Energy						
Turbines	34,880,000.00	119,010.56	396,701.87	31.90	6,327.39	6,264.12
Duct Burners	9,021,100.00	30,779.99	30,779.99	31.90	490.94	486.03
Total	43,901,100.00	149,790.55	427,481.86	31.90	6,818.34	6,750.15
Campus Total	**84,421,100.00**	**288,044.79**	**888,329.33**	**35.61**	**15,814.77**	**15,656.62**

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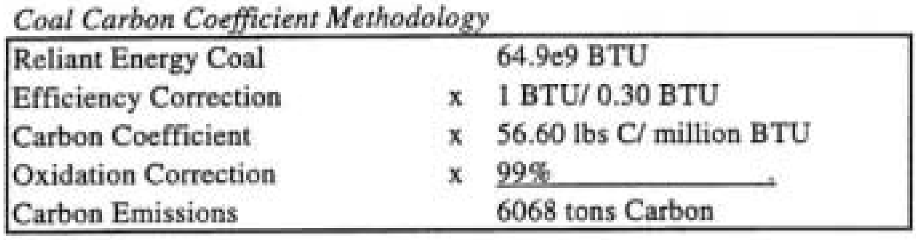
1 Data from Rice University, Facilities and Engineering Department, Eric Valentine, Energy Coordinator, 12 February 1999.

C. Carbon Coefficient Methodology Reality Check.

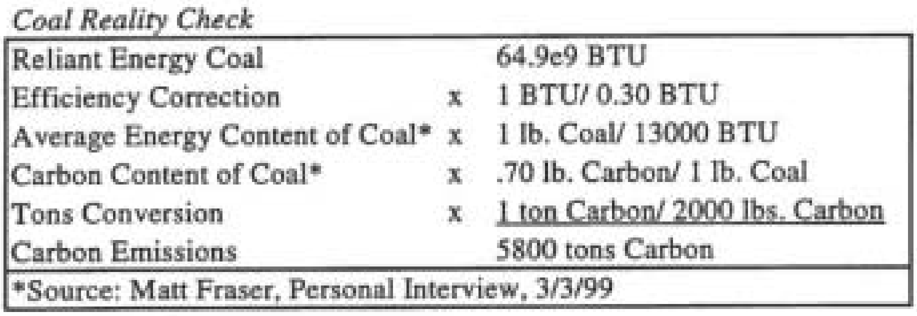
Using the following rough calculations, we can verify the Carbon Coefficient Methodology described in Section B.

Reliant Energy Coal Emissions



Coal Carbon Coefficient Methodology

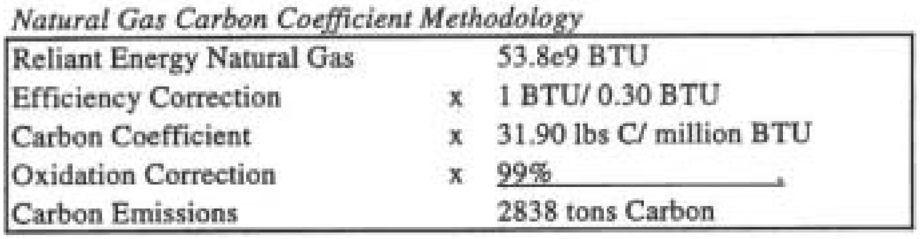
Reliant Energy Coal		64.9e9 BTU
Efficiency Correction	x	1 BTU/ 0.30 BTU
Carbon Coefficient	x	56.60 lbs C/ million BTU
Oxidation Correction	x	99% .
Carbon Emissions		6068 tons Carbon



Coal Reality Check

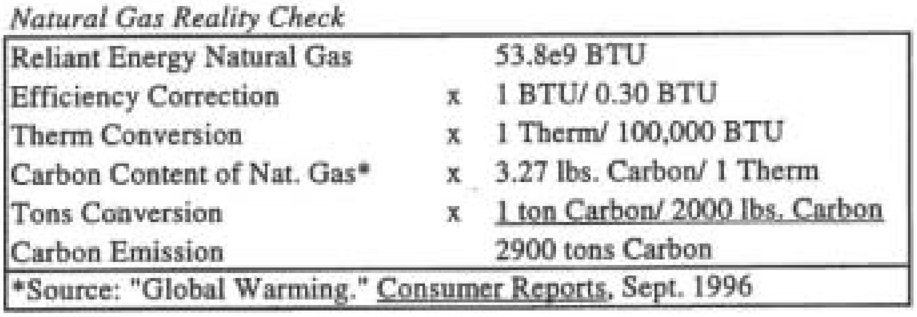
Reliant Energy Coal		64.9e9 BTU
Efficiency Correction	x	1 BTU/ 0.30 BTU
Average Energy Content of Coal*	x	1 lb. Coal/ 13000 BTU
Carbon Content of Coal*	x	.70 lb. Carbon/ 1 lb. Coal
Tons Conversion	x	1 ton Carbon/ 2000 lbs. Carbon
Carbon Emissions		5800 tons Carbon
*Source: Matt Fraser, Personal Interview, 3/3/99		

Reliant Energy Natural Gas Emissions



Natural Gas Carbon Coefficient Methodology

Reliant Energy Natural Gas		53.8e9 BTU
Efficiency Correction	x	1 BTU/ 0.30 BTU
Carbon Coefficient	x	31.90 lbs C/ million BTU
Oxidation Correction	x	99% .
Carbon Emissions		2838 tons Carbon



Natural Gas Reality Check

Reliant Energy Natural Gas		53.8e9 BTU
Efficiency Correction	x	1 BTU/ 0.30 BTU
Therm Conversion	x	1 Therm/ 100,000 BTU
Carbon Content of Nat. Gas*	x	3.27 lbs. Carbon/ 1 Therm
Tons Conversion	x	1 ton Carbon/ 2000 lbs. Carbon
Carbon Emission		2900 tons Carbon
*Source: "Global Warming," Consumer Reports, Sept. 1996		

D. Building Groups by Use.

Following is the list showing buildings assigned to each use category.

Science and Research:
Abercrombie, Anderson Biological Laboratories, Dell Butcher Hall, Old Chemistry, George R. Brown Hall, Keith-Wiess Geology, Mechanical Engineering, Mechanical Engineering Laboratories, Physics Laboratories, Ryon Engineering Laboratories, Space Science

Academic:
Alice Pratt Brown Hall, Anderson Hall, Baker Hall, Duncan Hall, Fondren Library, Herman Brown Hall, Herring Hall, Rayzor Hall, Sewell Hall

Colleges:
North - Jones and Brown
South - Baker, Hanszen, Lovett, Sid Richardson, Wiess, Will Rice

Administration:
Allen Center, Facilities and Engineering, Lovett Hall, RMC

Miscellaneous:
Annex Building, Central Kitchen, Cohen House, Continuing Studies, Copy Club, Gymnasium & Autry Court, Hamman Hall, Mudd Building, O'Connor House, Rice Media Center, Rice Stadium

E. Rice University Carbon Emissions by Building from Energy Consumption in 1998.

	Energy Consumed[1] (kWH/yr)	Energy Consumed[2] (million BTU/yr)	Energy Produced[2] (million BTU/yr)	Carbon Coefficient[2] lbs C/ million BTU	Total Carbon[2] (tons/yr)	Total Carbon Oxidized[2] (tons/yr)
Residential Colleges (8)						
Colleges North (2)	2,021,604.00	6,897.71	22,992.38	35.80	411.56	407.45
Colleges South (6)	5,528,079.00	18,861.81	62,872.69	35.80	1,125.42	1,114.17
Sub-Total Colleges	**7,549,683.00**	**25,759.52**	**85,865.06**	**35.80**	**1,536.98**	**1,521.61**
Average College North	1,010,802.00	3,448.86	11,496.19	35.80	205.78	203.72
Average College South	921,346.50	3,143.63	10,478.78	35.80	187.57	185.69

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[1] Data from Rice University, Facilities and Engineering Department, Eric Valentine, Energy Coordinator, 12 February 1999.

[2] Further calculations derived using methodology in Section B.

E. Rice University Carbon Emissions by Building from Energy Consumption in 1998 cont'd.

	Energy Consumed[1] (kWH/yr)	Energy Consumed[2] (million BTU/yr)	Energy Produced[2] (million BTU/yr)	Carbon Coefficient[2] (lbs C/ million BTU)	Total Carbon[2] (tons/yr)	Total Carbon Oxidized[2] (tons/yr)
Nonresidential Buildings						
Abercrombie	1,786,354.00	6,095.04	20,316.80	35.80	363.67	360.03
Alice Pratt Brown	1,909,738.63	6,516.03	21,720.09	35.80	388.79	384.90
Allen Center	1,224,141.20	4,176.77	13,922.57	35.80	249.21	246.72
Anderson Biological Laboratory	3,446,674.00	11,760.05	39,200.17	35.80	701.68	694.67
Anderson Hall	524,427.00	1,789.34	5,964.48	35.80	106.76	105.70
Annex Building	380,515.50	1,298.32	4,327.73	35.80	77.47	76.69
Baker Hall	444,794.01	1,517.64	5,058.79	35.80	90.55	89.65
Central Kitchen	507,352.88	1,731.09	5,770.29	35.80	103.29	102.26
Dell Butcher Hall	1,277,172.81	4,357.71	14,525.71	35.80	260.01	257.41
Cohen House	308,059.00	1,051.10	3,503.66	35.80	62.72	62.09
Continuing Studies	292,103.20	996.66	3,322.19	35.80	59.47	58.87
Copy Club	55,982.60	191.01	636.71	35.80	11.40	11.28
Old Chemistry	747,385.00	2,550.08	8,500.26	35.80	152.15	150.63
Duncan Hall	1,896,150.00	6,469.66	21,565.55	35.80	386.02	382.16
Facilities & Engineering	910,868.42	3,107.88	10,359.61	35.80	185.44	183.58
Fondren Library	2,934,176.40	10,011.41	33,371.37	35.80	597.35	591.37
George R. Brown Hall	5,277,552.80	18,007.01	60,023.37	35.80	1,074.42	1,063.67
Gymnasium & Autry Court	2,797,429.00	9,544.83	31,816.09	35.80	569.51	563.81
Hamman Hall	240,381.20	820.18	2,733.94	35.80	48.94	48.45
Herman Brown Hall	827,821.20	2,824.53	9,415.09	35.80	168.53	166.84
Herring Hall	542,272.80	1,850.23	6,167.45	35.80	110.40	109.29
Keith - Wiess Geology	1,527,652.51	5,212.35	17,374.50	35.80	311.00	307.89
Lovett Hall	617,359.20	2,106.43	7,021.43	35.80	125.68	124.43
Mechanical Engineering	804,636.29	2,745.42	9,151.40	35.80	163.81	162.17
Mechanical Laboratory	357,823.00	1,220.89	4,069.64	35.80	72.85	72.12
Mudd Building	525,557.57	1,793.20	5,977.34	35.80	106.99	105.92
O'Connor House	96,311.50	328.61	1,095.38	35.80	19.61	19.41
Physics Laboratories	494,754.00	1,688.10	5,627.00	35.80	100.72	99.72
Rayzor Hall	379,480.00	1,294.79	4,315.95	35.80	77.26	76.48
Rice Media Center	384,582.02	1,312.19	4,373.98	35.80	78.29	77.51
Rice Stadium	1,597,594.80	5,450.99	18,169.98	35.80	325.24	321.99
RMC/Ley Student Center	1,113,914.55	3,800.68	12,668.92	35.80	226.77	224.51
Ryon Engineering Laboratory	956,365.00	3,263.12	10,877.06	35.80	194.70	192.75
Sewall Hall	1,318,027.13	4,497.11	14,990.36	35.80	268.33	265.64
Space Science	2,457,422.00	8,384.72	27,949.08	35.80	500.29	495.29
Sub-Total Nonresidential	**40,962,831.19**	**139,765.18**	**465,883.93**	**35.80**	**8,339.32**	**8,255.93**
Total Metered at Buildings	**48,512,514.19**	**165,524.78**	**551,748.99**	**35.80**	**9,876.31**	**9,777.54**

1 Data from Rice University, Facilities and Engineering Department, Eric Valentine, Energy Coordinator, 12 February 1999.
2 Further calculations derived using methodology in Section B.

F. Rice University Carbon Emissions per Square Foot by Building from Energy Consumption in 1998.

	Energy Consumed[1] (kWH/yr)	Energy Consumed[2] (million BTU/yr)	Energy Produced[2] (million BTU/yr)	Carbon Coefficient[2] (lbs C/ million BTU)	Total Carbon[2] (tons/yr)	Total Carbon Oxidized[2] (tons/yr)
Nonresidential Buildings						
Abercrombie	25.01	0.085	0.284	35.8	10.18	10.08
Alice Pratt Brown	16.68	0.057	0.190	35.8	6.79	6.73
Allen Center	21.83	0.074	0.248	35.8	8.89	8.80
Anderson Biological Laboratory	37.60	0.128	0.428	35.8	15.31	15.15
Anderson Hall	12.23	0.042	0.139	35.8	4.98	4.93
Annex Building	21.16	0.072	0.241	35.8	8.62	8.53
Baker Hall	8.15	0.028	0.093	35.8	3.32	3.28
Central Kitchen	22.66	0.077	0.258	35.8	9.23	9.14
Dell Butcher Hall	16.37	0.056	0.186	35.8	6.66	6.60
Cohen House	16.69	0.057	0.190	35.8	6.79	6.73
Continuing Studies	26.09	0.089	0.297	35.8	10.62	10.52
Copy Club	38.34	0.131	0.436	35.8	15.61	15.46
Old Chemistry	10.47	0.036	0.119	35.8	4.26	4.22
Duncan Hall	17.93	0.061	0.204	35.8	7.30	7.23
Facilities & Engineering	42.85	0.146	0.487	35.8	17.45	17.27
Fondren Library	13.71	0.047	0.156	35.8	5.58	5.53
George R. Brown Hall	43.99	0.150	0.500	35.8	17.91	17.73
Gymnasium & Autry Court	23.22	0.079	0.264	35.8	9.45	9.36
Hamman Hall	12.37	0.042	0.141	35.8	5.04	4.99
Herman Brown Hall	14.80	0.050	0.168	35.8	6.02	5.96
Herring Hall	12.09	0.041	0.138	35.8	4.92	4.87
Keith - Wiess Geology	32.74	0.112	0.372	35.8	13.33	13.20
Lovett Hall	15.64	0.053	0.178	35.8	6.37	6.30
Mechanical Engineering	29.11	0.099	0.331	35.8	11.85	11.73
Mechanical Laboratory	18.51	0.063	0.211	35.8	7.54	7.46
Mudd Building	21.36	0.073	0.243	35.8	8.70	8.61
O'Connor House	14.03	0.048	0.160	35.8	5.71	5.65
Physics Laboratories	11.65	0.040	0.132	35.8	4.74	4.70
Rayzor Hall	13.33	0.045	0.152	35.8	5.43	5.37
Rice Media Center	24.89	0.085	0.283	35.8	10.14	10.03
Rice Stadium	22.13	0.076	0.252	35.8	9.01	8.92
RMC/Ley Student Center	15.94	0.054	0.181	35.8	6.49	6.43
Ryon Engineering Laboratory	20.49	0.070	0.233	35.8	8.34	8.26
Sewall Hall	14.79	0.050	0.168	35.8	6.02	5.96
Space Science	30.76	0.105	0.350	35.8	12.52	12.40
Residential Colleges (8)	13.19	0.045	0.150	35.8	5.37	5.32
Campus Average	**24.02**	**0.082**	**0.273**	**35.8**	**9.78**	**9.68**

[1] Data from Rice University, Facilities and Engineering Department, Eric Valentine, Energy Coordinator, 12 February 1999.

[2] Further calculations derived using methodology described in Section II.

G. Rice University Carbon Emissions by Building Group from Energy Consumption in 1998. Data from Sections E and F.

	Total Carbon Oxidized[1]	
	(tons/yr)	(Lbs/sf)
Science and Research		
Abercrombie	360.03	10.08
Anderson Biological Laborato	694.67	15.15
Dell Butcher Hall	257.41	6.60
Old Chemistry	150.63	4.22
George R. Brown Hall	1063.67	17.73
Keith - Wiess Geology	307.89	13.20
Mechanical Engineering	162.17	11.73
Mechanical Laboratory	72.12	7.46
Physics Laboratories	99.72	4.70
Ryon Engineering Laboratory	192.75	8.26
Space Science	495.29	12.40
Science Total	**3856.36**	**111.53**
Science Average	**642.73**	**11.19**
Academic		
Alice Pratt Brown	384.90	6.73
Anderson Hall	105.70	4.93
Baker Hall	89.65	3.28
Duncan Hall	382.16	7.23
Fondren Library	591.37	5.53
Herman Brown Hall	166.84	5.96
Herring Hall	109.29	4.87
Rayzor Hall	76.48	5.37
Sewall Hall	265.64	5.96
Academic Total	**2172.05**	**49.86**
Academic Average	**434.41**	**5.54**
Residential Colleges (8)		
Colleges North	407.45	
Colleges South	1114.17	
Residential Total	1521.61	5.32
Total/8 colleges	**190.20**	
Residential Average	760.81	5.32
Average/8 colleges	**95.10**	
Administrative		
Allen Center	246.72	8.80
Facilities & Engineering	183.58	17.27
Lovett Hall	124.43	6.30
RMC/Ley Student Center	224.51	6.43
Administrative Total	**779.24**	**38.80**
Administrative Average	**311.69**	**9.70**

G. Rice University Carbon Emissions by Building Group from Energy Consumption in 1998. Data from Sections E and F.

	Total Carbon Oxidized[1]	
	(tons/yr)	(Lbs/sf)
Miscellaneous		
Annex Building	76.69	8.53
Central Kitchen	102.26	9.14
Cohen House	62.09	6.73
Continuing Studies	58.87	10.52
Copy Club	11.28	15.46
Gymnasium & Autry Court	563.81	9.36
Hamman Hall	48.45	4.99
Mudd Building	105.92	8.61
O'Connor House	19.41	5.65
Rice Media Center	77.51	10.03
Rice Stadium	321.99	8.92
Miscellaneous Total	**1448.29**	**97.93**
Miscellaneous Average	**241.38**	**8.90**
Overall Totals		
Science	3856.36	111.53
Academic	2172.05	49.86
Residential	190.20	5.32
Administrative	779.24	38.80
Miscellaneous	1448.29	97.93
Campus Total	**8446.14**	**303.45**
Overall Averages		
Science	642.73	11.19
Academic	434.41	5.54
Residential	95.10	5.32
Administrative	311.69	9.70
Miscellaneous	241.38	8.90
Campus Average	**345.06**	**8.13**

[1] Further calculations derived using methodology described in Section B.

H. Projected Rice University Carbon Emissions due to Increased Energy Consumption from Future Construction 1999-2004.

Year	Construction Project	Square Footage[1] (ft^2)	Building-Specific Average Carbon Emissions[4] (lbs/ft^2)	Projected Carbon Emissions[6] (tons C)
1999	Graduate House	42000	5.32	111.72
	Old Chemisty	71165[2]	11.19	398.17
2000	Humanities	48000	5.54	132.96
	Baseball Stadium	3427[3]	9.2[5]	15.76
2001	South College	178000	5.32	473.48
2002	Jones School	157000	5.54	434.89
2003	Martel College	178000	5.32	473.48
	Wiess College	113000	5.32	300.58
2004	Library Extension	40000	5.53	110.60

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[1] Mack, W.G. Vice President of Facilities and Engineering. Rice University. Telephone call and electronic mail (25 February 1999).

[2] Old Chemistry is currently being renovated and will be back in service in 1999. The square footage of Old Chemistry was determined by taking the energy consumption data provided by Facilities and Engineering and dividing it by the energy consumption per square foot.

[3] The Baseball Stadium's carbon emissions were determined by seating capacity and not by square footage. The stadium is an outside facility, and square footage does not reflect energy use accurately. Seating capacity was found at <http://www.riceowls.com>.

[4] Data from Appendix, Section D.

[5] Units are pounds carbon per seat.

[6] Projected Carbon Emissions were calculated by multiplying Square Footage by the Building-Specific Average Carbon Emissions. This number was then scaled from pounds to tons.

I. Projected Rice University Carbon Emissions due to Increased Energy Consumption 1990-2010.

	Year	Energy Consumed[1] (kWH/yr)	Energy Consumed[2] (million BTU/yr)	Energy Produced[2] (million BTU/yr)	Carbon Coefficient[2] (lbs C/ million BTU)	Total Carbon[2] (tons/yr)	Total Carbon Oxidized[2] (tons/yr)
i	1990	92,925,498.24	317,061.80	1,056,872.67	35.53	18,776.06	18,588.30
	1991	89,088,733.88	303,970.76	1,013,235.87	35.21	17,835.89	17,657.53
ii	1992	85,251,969.52	290,879.72	906,370.40	34.88	15,807.22	15,649.15
	1993	81,415,205.16	277,788.68	842,167.60	34.55	14,550.43	14,404.93
	1994	88,417,573.27	301,680.76	840,901.87	34.84	14,646.42	14,499.95
	1995	90,490,794.26	308,754.59	854,026.31	35.04	14,964.61	14,814.97
	1996	92,868,158.22	316,866.16	871,550.72	35.50	15,469.13	15,314.44
	1997	82,651,352.38	282,006.41	865,159.76	35.59	15,394.73	15,240.79
	1998	**84,421,100.00**	**288,044.79**	**888,329.33**	**35.61**	**15,816.70**	**15,658.54**
iii	1999	86,663,613.98	295,696.25	916,694.37	35.63	16,331.74	16,168.42
	2000	86,954,970.99	296,690.36	924,560.22	35.65	16,481.96	16,317.14
	2001	88,963,130.53	303,542.20	950,806.72	35.68	16,960.23	16,790.62
	2002	90,744,441.83	309,620.04	974,837.23	35.70	17,399.51	17,225.51
	2003	94,281,448.54	321,688.30	1,018,021.19	35.72	18,181.39	17,999.57
	2004	94,322,272.70	321,827.59	1,023,651.31	35.74	18,293.11	18,110.17
iv	2005	96,406,478.58	328,938.90	1,051,574.56	35.76	18,803.58	18,615.54
	2006	98,135,631.30	334,838.77	1,075,834.79	35.78	19,249.12	19,056.63
	2007	99,864,784.01	340,738.64	1,100,285.28	35.81	19,698.59	19,501.61
	2008	101,593,936.72	346,638.51	1,124,926.04	35.83	20,152.01	19,950.49
	2009	103,323,089.44	352,538.38	1,149,757.06	35.85	20,609.38	20,403.28
	2010	105,052,242.15	358,438.25	1,174,778.35	35.87	21,070.70	20,859.99

[1] See following page for data source of boxes i-iv.

[2] Further calculations derived using methodology described in Section B.

I. Projected Rice University Carbon Emissions due to Increased Energy Consumption 1990-2010 (cont.'d).

i) These values (1990-1991) were calculated by forecasting back from 1992-1993 values using the Microsoft Excel forecast function.

FORECAST (x, known y's, known x's)

x is the data point for which you want to predict a value.
Known y's is the dependent array or range of data.
Known x's is the independent array or range of data.

The equation for FORECAST is a + bx, where:

a=Y-bX

And:

$$b = \frac{n\sum xy - (\sum x)(\sum y)}{n\sum x^2 - (\sum x)^2}$$

ii) These values (1992-1998) were obtained from Rice University, Facilities and Engineering Department, Eric Valentine, Energy Coordinator, 12 February 1999.

iii) These values (1999-2004) were calculated by forecasting forward from 1997-1998 values using the forecast function described above. The forecast values were then added with the new construction values determined in Section H.

iv) These values (2005-2010) were calculated by forecasting forward from 1997-2004 values using the forecast function described above.

J. Rice University Cogeneration Upgrade Projection 2000-2010.[1]

Energy Cost

Year	Current Cost	100% Cogeneration	Savings
2000	$3,535,204	$3,212,182	$323,022
2001	$3,616,926	$3,286,437	$330,489
2002	$3,689,297	$3,352,195	$337,102
2003	$3,833,226	$3,482,973	$350,253
2004	$3,834,852	$3,484,451	$350,402
2005	$3,919,421	$3,561,292	$358,129
2006	$3,989,759	$3,625,203	$364,556
2007	$4,060,097	$3,689,114	$370,983
2008	$4,130,842	$3,753,395	$377,447
2009	$4,199,960	$3,816,197	$383,763
2010	$4,269,078	$3,879,000	$390,078

Total Savings = $3,936,223

Carbon Emissions (tons C emitted)

Year	Current	100% Cogeneration	Savings
2000	16,317	14,599	1,718
2001	16,791	15,014	1,777
2002	17,226	15,393	1,832
2003	18,000	16,075	1,925
2004	18,110	16,164	1,946
2005	18,616	16,605	2,011
2006	19,057	16,988	2,069
2007	19,502	17,374	2,128
2008	19,950	17,763	2,187
2009	20,403	18,155	2,248
2010	20,860	18,550	2,310

Total Carbon Reduction = 22,150

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[1] Data from Rice University Facilities and Engineering, Projections from Appendix I, Section I.

Appendix II

Calculation of Air Travel by Rice Athletes

Sport	Out-of-State Events	Players on Roster	Team Trips
Baseball	7	33	231
Men's Basketball	9	14	126
Women's Basketball	10	14	140
Men's Cross-Country	1	16	16
Women's Cross Country	2	14	28
Football	4	98	392
Golf	5	11	55
Men's Swimming	4	11	44
Women's Swimming	4	15	60
		Total Number of Trips	**1,092**

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