The Cal State East Bay 2006 Carbon Report
FINAL

October 20, 2008

by

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and the students of the
Applied Field Studies
GEOG/ENVT 3480
Fall 2007

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1. Introduction

1.1 Purpose of Report

This report documents an analysis of Cal State East Bay's 2006 energy-related carbon dioxide emissions (CO_2) and the potential to reduce those emissions. The report addresses both direct emissions and indirect carbon emissions. Consistent with California Climate Action Registry General Reporting Protocol requirements, direct emissions include emissions from fuels purchased by the institution and indirect emissions include those from electricity and commuting.

The goal was to capture all university related emissions resulting from energy use on campus and commuting to and from campus. Ultimately, two potentially significant sources had to be left out. It was not possible, given the constraints of the study, to include emissions from energy use in the dorms (which are operated on private power contracts to which the University has no access). Nor was it possible to get information on work-related travel by faculty and staff that is not part of their regular commuting. Future studies should capture these data. These sources should be tracked in the future.

The project was conducted largely within the context on the Fall 2007 *Applied Field Studies* class, a quarter-long, cross-listed, undergraduate course in Geography and Environmental Studies *(*GEOG/ENVT 3480). The project included both educational and institution goals. Educational goals included involving undergraduates in original research, educating students about climate change and related state and institutional mandates, and training future resource managers in carbon emissions analysis and mitigation. Under the supervision of the instructor (the author) and working in groups, the students developed strategies for data collection, conducted surveys, located relevant public-domain data, and analyzed the data working together in groups. Because a primary goal was to teach students the underlying principles of carbon analysis, students carried out the carbon analyses themselves, under the guidance of the instructor, using a spreadsheet program, rather than using one of the ready-made 'calculators' available online. Two advanced students, Sally Otton (a graduate student) and Derren O'Neal (a graduating senior), took a leadership role and gave public presentations of the results, Otton at the California Association of Geographers, and O'Neal at Cal State East Bay's February 2008 Sustainability Forum. Institutional goals included establishing a benchmark for future emissions reductions and identifying key opportunities for emissions reductions.

1.2 Policy Background

It is clear that steep emissions reductions will be required of all campuses in the future. Drivers for emissions reductions include regional level, state level, CSU system-wide and East-Bay specific mandates. These are summarized below, in turn.

In 2004 the Governors of California, Oregon, and Washington acknowledged both the seriousness of the global warming problem and the benefits of addressing it head on. Summarizing the impetus for the West Coast Governor's Global Warming Initiative (WCGGWI), which laid out actions and strategies to reduce emissions, a WCGGWI staff reported that:

> *Global warming will have serious adverse consequences on the economy, health and environment of the West Coast states. These impacts will grow significantly in coming years if we do nothing to reduce greenhouse gas pollution. Fortunately, addressing global warming carries substantial economic benefits. The West Coast region is rich in renewable energy resources and advanced energy-efficient technologies. We can capitalize on these strengths and invest in the clean energy resources of our region.*[1]

The regional commitment to emissions reductions is growing, as evidenced by the expanded membership of the Western Climate Initiative, which, in 2007, superseded the West Coast Governor's Global Warming Initiative, and now includes Arizona, British Columbia, Manitoba, New Mexico, and Utah, in addition to California, Oregon, and Washington.[2] The regional goal of the Western Initiative is to reduce greenhouse gas emissions to 15% below the 2005 level by 2020.[3]

The State of California, a leader in this process, has mandated significant emissions reductions. California's Global Warming Solutions Act of 2006 (AB 32) requires the state to reduce its greenhouse gas emissions back to the 1990 level by 2020 (a 25% reduction below projected emissions based on a 'business as usual' scenario). It also mandates that emissions reductions continue by an unspecified amount thereafter. Governor Schwarzenegger's Executive Order S-3-05 is more specific with respect to future requirements, ordering that the State reduce its emissions to 80% below 1990 levels by 2050.

According to the California Energy Commission's Greenhouse Gas Emissions Inventory, fossil fuel emissions contribute 80% of the state's total warming potential of current GHG emissions.[4] Thus, considerable focus has been placed on quantifying and controlling GHG emissions from fossil fuel combustion, in particular CO_2 emissions—

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[1] Available online at http://www.climatechange.ca.gov/westcoast/index.html.

[2] Ibid and http://www.westernclimateinitiative.org/.

[3] On Sept 23, 2008, the Western Climate Initiative unveiled its draft proposal to reduce emissions. The draft plan, which will not take effect until 2012, sets a cap on greenhouse gas emissions, which would be reduced annually. It addresses a broad array of industries and sectors including transportation, housing, and utilities.
http://www.nytimes.com/2008/09/24/us/24climate.html?ref=todayspaper#

[4] Based on year 2004 data from the California Energy Commission, Energy Commission Inventory Work 1990 - 2004, Table 6. California Greenhouse Gas Emissions and Sink Summary: 1990 to 2004 (MMTCO2Eq.), available online at
http://www.climatechange.ca.gov/policies/greenhouse_gas_inventory/index.html (revised Jan 2007 and downloaded 12/28/2007).

hence the focus of this study.

These commitments are driving the adoption of increasingly stringent standards. In 2007, in its biannual *Integrated Energy Policy Report*, the California Energy Commission recommended amending California's energy efficiency standards for new buildings to require net-zero-energy residential buildings by 2020 and net-zero-energy commercial buildings by 2030.[5] While aggressive, even if this standard is adopted, because of the relatively slow turnover in the building stock, meeting increasingly ambitious emissions reductions goals will require extensive retrofitting of existing buildings, increased efficiency in electricity generation, greatly reduced reliance on fossil fuels for electricity generation, and, most important, emissions reductions in transportation, which dominates California's and, as revealed in this report, East Bay's CO_2 emissions.

In 2005, the California State University Chancellor's Office acknowledged that AB 32 would likely bind the system to significant future carbon reductions. By September 18, 2007, in a memo from Executive Vice Chancellor Richard West to the CSU Board of Trustees, the Chancellor's Office acknowledged specific obligations under AB 32 and the Governor's Order[6]:

> *[The] CSU has reduced energy use intensity from about 175,000 BTU/GSF[British thermal units per gross square foot] to 87,000 BTU/GSF. It has taken us 30 years and millions of dollars to get where we are today. AB 32 requires the CSU to further reduce our use to 41,200 BTU/GSF by 2020, and 7,000 BTU/GSF by 2050.*

Actually, an earlier deadline for energy efficiency improvements at the CSU is established by Schwarzenegger's Executive Order S-20-04, which requires energy use in state-owned buildings to be reduced by 20% by 2015 (from a 2003 baseline).

Cal State East Bay has independently committed itself to pursuing carbon neutrality. In the spring of 2007, East Bay's Academic Senate adopted a Sustainability Resolution (06-07 BEC 9)[7] specifically focused on the carbon problem. This resolution "supports actions to make climate neutrality and sustainability a part of the curriculum" and "supports the expansion of research or other efforts necessary to achieve climate neutrality and sustainability". Thus the University has recognized both its carbon reduction obligations and its responsibility to address the issues through curriculum.

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[5] See page 5 of the Executive Summary, the report is available online on the Energy Commission's website.

[6] August 22, 2005, *CSU Report on Sustainability and Energy Efficiency Goals*.

[7] Available online at http://www.csueastbay.edu/senate/excom_docs.htm.

1.3 Carbon Emission Accounting Overview

Carbon dioxide emissions from fossil fuel combustion are proportional to the amount and type of fuel consumed. As shown in Table 1.I coal is the most carbon intensive fuel per unit of heat released in combustion and natural gas is the least. The CO_2 emitted by combustion is simply the product of the amount of fuel consumed and the carbon emissions factor. The challenge, where present, is in determining the amount of fuel used. In some cases this is easy to determine, for example natural gas usage is reported in utility bills. In other cases it is non-trivial, in particular, to determine the fuel used by students, faculty, and staff in commuting, or to determine the fuel used to generate the electricity purchased from an electric service provider.

Table 1.I. Carbon emissions factors by fuel, presented (a) per unit of energy use and (b) in common units. The values in column (a) are useful to compare the carbon intensities of different fuels (the amount of carbon emitted per unit of thermal energy released by the fuel during combustion) because the values are expressed using identical energy units. The values in column (b) are provided for convenience and are used in the calculations because they are presented using units of common measure to the specific fuels considered. Source: US Environmental Protection Agency online: http://www.epa.gov/appdstar/pdf/brochure.pdf.

	Carbon Emissions Factors		
Fuel	(a) lbs-CO_2 per million Btu	(b) lbs-CO_2 per gigajoule	(c) other common units
Coal[1]	207.91	197.07	4290 lbs-CO_2 / short ton[1] 2.145 lbs-CO_2 / lb
Diesel	160.30	151.94	22.23 lbs-CO_2 / gallon
Gasoline	154.91	146.83	19.37 lbs-CO_2 / gallon
Natural Gas	116.39	110.32	11.64 lbs-CO_2 / therm

[1] For coal used by 'unspecified electric utilities'.

1.4 Report layout

This report is organized by category of emissions. Chapter 2 considers *direct emissions* from the use of natural gas and liquid fuels purchased directly by Cal State East Bay. Chapter 3 considers *indirect emissions* from purchased electricity and from commuting by students, faculty, and staff. Each of those chapters assesses both the 2006 emissions and the potential to reduce emissions. The latter considers a range of actions, some of which are under the direct control of the University and others of that are not. Chapter 4 summarizes the conclusions and makes recommendations.

2. Direct Emissions (Natural Gas and Liquid Fuels)

This chapter assesses the direct emissions from natural gas and liquid fuels (gasoline and diesel) purchased by East Bay for the two campuses (Hayward and Concord) and the potential to reduce those emissions. Natural gas is used primarily for space conditioning and the liquid fuels for fleet vehicles and equipment. Fuel usage for commuting is addressed in the next chapter, because of the very different methodology used to assess it. Because of time and resource constraints, this study omitted assessment of fuel usage for reimbursed travel. Ideally, in the future, the University would arrange travel accounting in a way that such travel information could be automatically extracted from travel claims data.

2.1 Assessment of Direct Emissions

As described in the introduction, CO_2 emissions are directly proportional to the amount of fuel consumed. Thus, for the university-purchased fuels accounted for here, that assessment is straight forward, and has very high certainty. Information on fuel consumption was obtained from Facilities management. Year 2006 utility bills from Pacific Gas and Electric Co. (PG&E) record natural gas usage. Liquid fuels are purchased by the campuses and stored on site in tanks for use by fleet vehicles and equipment. The liquid fuels data were by necessity for the year 2007, rather than 2006, the base year for the rest of the analysis, because 2007 was the first year those data were tabulated and recorded, by order of the Chancellor's Office.

Tables 2.I and 2.II document the natural gas and liquid fuels consumption, respectively, and their associated carbon emissions. CO_2 emissions from natural gas a more than a factor of 10 higher than that from liquid fuels (gasoline and diesel combined).

Table 2.I. Natural gas consumption and associated CO2 emissions in 2006 at the Hayward and Concord campuses. The data exclude natural gas consumption in the dorms, which is not purchased by East Bay.

Month	Hayward (therms)	Concord (therms)	Total (therms)	CO_2 Emissions
Jan	87,377	5,177	92,554	
Feb	45,023	5,482	50,505	
Mar	96,638	5,141	101,779	
Apr	75,406	3,428	78,834	
May	35,965	1,419	37,384	
Jun	22,473	1,007	23,480	
Jul	16,184	158	16,342	
Aug	13,828	666	14,494	
Sep	16,767	1,645	18,412	
Oct	39,786	1,980	41,766	
Nov	67,173	2,990	70,163	
Dec	81,497	3,764	85,261	
TOTAL N-gas (therms)	598,117	32,857	630,974	
TOTAL CO_2 (thousands of lbs)[1]				7,340
TOTAL CO_2 (tons)				3,670

[1] The product of total therms consumed and the carbon emissions factor (11.64 lbs-CO_2 / therm). Result rounded to three significant digits.

[2] Total CO_2 emissions in English short tons (2000 lbs/ton). Result rounded to three significant digits.

Table 2.II. Liquid fuels consumption and associated CO2 emissions in 2007 (Hayward and Concord campuses combined). Data are from fuel purchases for on site fuel tanks from which university fleet vehicles and other equipment are fueled. Note that no data were available for any offsite fueling of university-owned vehicles.

Month	Gasoline (gallons)	Diesel (gallons)	CO_2 Gasoline	CO_2 Diesel
Jan	1,134	1,562		
Feb	1,513	763		
Mar	999	825		
Apr	1,487	895		
May	1,981	1,693		
Jun	-	796		
Jul	3,002	1,309		
Sep	1,983	1,505		
Oct	1844	1539		
Nov	772	800		
Dec	1,137	805		
TOTAL Fuel Usage	15,852	12,492		
TOTAL CO_2 (thousands of lbs)[1]			307	278
TOTAL CO_2 (tons)[2]			139	154

[1] The product of total gallons consumed and the carbon emissions factor (19.37 lbs-CO_2 / gallon).

[2] Total CO_2 emissions in English short tons (2000 lbs/ton).

2.2 Potential to Reduce Direct Emissions

Although, as will be seen in Chapter 4, direct emissions from natural gas for space heating and liquid fuels purchased for fleet vehicles and equipment together account for only 10% of the total CO_2 emissions considered in this study (9% for natural as and 1% for liquid fuels), their usage is under the direct control of Cal State East Bay, unlike all other sources considered here. Therefore, the University has more leverage in controlling emissions from these sources. Clearly, between these two the more important focus would be on natural gas, because of its larger share.

The following sections focus not only on means to reduce fuel use, but also on university plans to do so, in the case of natural gas. For the reasons outlined above, the University is already actively engaged in projects to reduce natural gas usage and is planning more.

2.2.1 Reducing Natural Gas Usage for Space Heating

Decreasing carbon emissions from natural gas usage in existing buildings implies either improving the performance of heating systems and operational controls, or improving the thermal performance of the buildings, or both. While in new buildings, the greatest efficiency gains can be achieved at least cost by applying the principles of passive solar design to greatly reduce heating and cooling energy requirements in the first place. In existing buildings, improvements in heating systems and controls may be lower in cost, because retrofitting passive solar design implies changing the fundamental design of the building.[8]

Unsurprisingly, therefore, when Chevron Energy Solutions recently completed a campus energy audit for East Bay, it came to the conclusion that a heating systems upgrade (upgrading ductwork and installing a new energy management system) could save 29% of the campuses' building energy use and more than pay for itself. East Bay currently has that work scheduled. Based on interviews with President Qayoumi, who has played a very active role in improving campus energy performance, the Campus Master Plan, currently under development, will include a centralized heating system and a state-of-the-art fuel cell cogeneration system that will further improve campus heating energy efficiency in the future.

While this trajectory is clearly meritorious and deserves recognition, given the State's push for zero energy buildings, our own Sustainability Resolution, and the prodigious energy-related talents of our new President, we should also become leaders in developing

[8] Passive solar design reduces heating and cooling energy needs by appropriate location and shading of windows (that enhances the capture of solar energy in winter and rejects it in the summer), the placement of unobstructed thermal mass (e.g., concrete slab) to store thermal energy and buffer temperature swings, and good insulation in walls, floors, and ceiling to maintain indoor thermal conditions. These are all elements present in standard buildings, but it is their placement and treatment that determines their thermal value. Thus a solar building need not cost more than a standard building, but its heating and cooling energy requirements can be far lower.

zero-energy or positive-energy buildings. As suggested above, new buildings can be made far more efficient than the existing stock and at the same time net significant total cost savings over the lifetime of the building. Buildings can be made considerably more efficient at *no* additional capital cost, by just considering building orientation, specifically the placement and shading of windows to allow for winder-time solar gain, as necessary, while avoided excess heat loading. With additional investment, buildings can be made *highly* efficient or net-zero-energy.[9] Given that the cost of operating a building may be 10 times higher (or more) than the cost of building it in the first place, it is not surprising that even large investments in energy efficiency and renewable energy are justified. There is beginning to be discussion of seeking LEED certification for certain new planned buildings on campus. Given the imperatives, we hope this will develop into a more comprehensive commitment to make all new buildings zero-net-energy.

Solar water heating is also an attractive option for pool heating, costing less than the conventional natural-gas heating alternative over the lifetime of the system. While this would result in a relatively small fractional change in the University's carbon emissions, installing a solar heating system would not only save money and reduce carbon emissions, it represents a conspicuous opportunity to do so, offering educational value. Costing out a solar pool heating system and calculating its carbon benefits would make a good student project.

2.2.2 Reducing fuel usage by fleet vehicles

Obviously, the judicious selection of fleet vehicles, is the primary means to reduce their fuel use. Options are becoming more available over time, ranging from more efficient standard vehicles, to hybrid vehicles, to plug-in electric hybrids, to pure electric vehicles run on grid- or self-generated solar power. Thus improvements can range from incremental to having a zero-emission fleet. At current gasoline prices it is considerably more economical to operate a fleet of grid-fueled electric vehicles than a fleet of gasoline-powered vehicles. Even fueling with unsubsidized solar electricity is now lower in cost than gasoline. (Appendix 1 analyzes in detail the cost tradeoff in operating a gasoline powered, electric powered, and solar-powered vehicles.) Indeed, one can argue that it makes more sense to use solar electricity to charge electric vehicles that it does to supply power to buildings because solar vehicle charging costs less than the conventional alternative (gasoline) where as solar electricity for buildings typically costs more than the conventional alternative (buying that same power from the utility), particularly if that solar electricity is unsubsidized. Not only will solar vehicle charging potentially pay for itself, it can represent a conspicuous educational opportunity, with cars labeled as 'fueled by sunlight' and having arrays set up to look like charging stations that shade the fleet.[10]

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[9] In concept, zero-energy and positive-energy buildings typically do have some residual heating energy demand that cannot be provided by solar energy directly, but such buildings make up for heating energy demand by self-generating excess electricity with on-site renewable energy systems.

[10] It doesn't really matter where the PV system is installed as self generated electricity can just go into the campus grid, but setting arrays up as 'charging stations' offers both symbolic value and can provide shade to enhance thermal comfort of vehicle users and potentially reduce energy use for vehicle air conditioning.

3. Indirect Emissions (Electricity and Commuting)

This Chapter presents the results of the analysis of indirect carbon emissions from electricity (Section 3.1) and from commuting (Section 3.2). In each section, the potential to reduce emissions is also addressed. We start with electricity.

3.1 Electricity

Cal State East Bay gets its electricity from two sources. The majority is purchased from an electric service provider, which, in 2006, was APS Energy Services, an Arizona based company. A small minority is self-generated with a large, one-megawatt, solar electric system. The system consists of arrays of photovoltaic (PV) modules distributed over four buildings: Physical Education, Music and Business, Art and Education, and Meiklejohn Hall.[11] Figure 3.I shows part of the system, which was installed in March of 2004.

In 2006, the year of this study, the PV system generated 6.5% of total electricity consumed at the Hayward Campus (and 6.1% of total electricity consumed at both campuses). For the purpose of this study, PV electricity was assumed to be carbon on neutral. Therefore, the carbon emissions calculation for electricity, considered only that electricity purchased from APS.[12]

[11] Information on the system is available online at www.powerguard.eu/success/pdf/PowerLight_Case-Study_csuHayward.pdf

[12] In fact PV systems have a small energy payback period (typically less than 2 years depending on product), before the energy cost of their manufacture is offset by their energy production.

Figure 3.I Cal State East Bay's photovoltaic electricity system. The figure shows the PV panels on two of the four buildings on which the system is located, Physical Education (two rectangular systems) and Music Building (circular).

According to Facilities Management, in 2006, Cal State East Bay consumed a total of over 17 million kilowatt-hours (kWh) of electricity purchased from APS. As shown in Table 3.I the vast majority of this was consumed at the Hayward campus.

Table 3.I APS electricity consumed at the East Bay campuses in 2006.

Electricity Source	Amount purchased or generated (kWh)	Percentage of total electricity consumption
Electricity purchased from APS for the Hayward campus	16,179,793	87%
Electricity purchased from APS for the Concord campus	1,254,598	7%
Total electricity purchased from APS for both campuses	17,434,391	94%
Electricity generated by the PV system	1,151,426	6%
Total electricity consumption	18,585,817	100%

The APS power purchases were part of an enormous direct access contract, which began in April 2002 as a means to reduce and stabilize electricity costs and was renegotiated in 2005. It provided electricity for 19 of the 23 CSU campuses and 7 of the 10 University of California Campuses.[13] A new contract with a new company began in 2008.

3.1.1 Assessment of emissions from electricity consumption

It can be difficult to obtain good data to calculate carbon emissions (pounds of CO_2 per year) from electricity consumption (kilowatt-hours per year). The California Climate Action Registry (C-CAR), with whom the CSU has voluntarily registered its 2006 emissions, provides regional/power pool carbon emissions factors (pounds of CO_2 per kilowatt-hour) as the default value in its reporting tool (CARROT).[14] Unfortunately, the 'pool' is the entire State of California. As we will see, the electricity source mix for any given private contract can be very different from the average for the state. We therefore chose to use data specific to the APS contract.

Ironically, "[if] you can obtain verified emissions factors specific to the supplier of your electricity" C-CAR encourages you to do so, but the state does not require that this information be reported by electric service providers selling power into the state through direct access contracts. This is troubling, because AB 32 explicitly states that it emissions

[13] See http://www.universityofcalifornia.edu/news/article/4131.
[14] California Climate Action Registry General Reporting Protocol, Version 3.0, April 2008. Available online at the Climate Action Registry Website.

reductions mandate applies to imports of electricity as well as in-state generation and that 'leakage' is disallowed.[15]

The state does require, however, that direct access providers report to the California Energy Commission their electric source mix (the fractions of electricity coming from coal, natural gas and other sources). That information, reported in Power Content Labels (Appendix 2), can be used to estimate carbon emissions factors for electricity (CEF_{elec}) given information on the efficiency of electricity generating units and their own contributions to the mix. The procedure is documented in Appendix 3 for APS-2006 electricity under the CSU direct access contract.

Table 3.II presents the fuel mixes of electricity produced for the CSU-contract in 2006 and for two comparison cases: electricity sold by PG&E (the local utility from which Cal State East Bay would have purchased electricity had it not been part of the system-wide contract with APS) and the average electricity consumed in California. The table also presents the associated carbon emissions factors for each of these cases. As shown, the carbon emissions for the APS-CSU 2006 contract were almost twice a large per kilowatt-hour as that for electricity consumed in the PG&E service territory and about 25% higher than those for the state as a whole.

Table 3.II The top of the table indicates the fuel mix (fraction of electricity generated by different sources) for the APS-CSU contract and for electricity consumed in the PG&E service territory and in California as a whole (CA). The bottom of the table indicates the associated carbon emissions factors

FUEL MIX	APS CSU-contract[1]	PG&E[2]	CA[2]
%-coal	32.0%	3.0%	15.7%
%-gas	28.0%	42.0%	41.5%
large hydro	20.0%	19.0%	19.0%
eligible renewables	20.0%	13.0%	10.9%
nuclear	<1%	23.0%	12.9%
Total	100.0%	100.0%	100.0%
CARBON EMISSIONS FACTORS			
CEF_{elec} (lbs-CO_2 / kWh)[3]	1.03	0.51	0.80

[1] See Appendix 2.

[2] The resource mix for California's major utilities and the statewide average are available online at http://www.energyalmanac.ca.gov/electricity/electricity_resource_mix_pie_charts/index.html.

[3] Based on a detailed analysis of California Power Plants using data available from the California Energy Commission, the efficiencies for coal and natural gas plants were estimated to be the same, within estimation uncertainty for California power plants as for the APS plants. Therefore, other than the fuel mix data, the CEF_{elec} calculations for PG&E and CA-Mix are the same as for the APS CSU-contract calculation shown in Appendix 3.

[15] Leakage implies reducing in-state emissions by increasing out-of-state emissions, specifically by importing of high-carbon-electricity. The specific concern of regulators was coal-generated electricity imports from the Southwest. A concern that, as we shall see, applies specifically to contracts like the former UC/CSU contract with APS.

The product of the carbon emissions factor (CEF_{elec}, Table 3.II) and the power consumed (Table 3.I) yields the 2006 carbon emissions from electricity consumption. The results of the analysis are presented in Table 3.III, broken down by electricity source and campus, along with an estimation of emissions avoided as a result of the PV system. As shown, the Hayward campus is responsible for 93% of East Bay's CO_2 emissions. Significantly, while coal supplies only 32% of the purchased electricity, it contributes 72% of East Bay's electricity related CO_2 emissions. Finally, the PV system avoids an amount of carbon equivalent to the total emissions of the Concord campus.

Table 3.III 2006 Carbon dioxide emissions from electricity use at the Hayward and Concord campuses.

	CO2 (tons) by campus and fuel type	CO2 (tons) by fuel type	Percentage of total emissions
Hayward electricity supplied by coal	5,984		
Concord electricity supplied by coal	464		
TOTAL from coal		6,448	72%
Hayward supplied by N-gas	2,359		
Concord supplied N-gas	183		
TOTAL from N-gas		2,542	28%
TOTAL Hayward	8,343		93%
TOTAL CONCORD	647		
TOTAL CO_2 Emissions (all sources)	8,990		100%
CO_2 emissions avoided by solar electricity generation (PV)	593		7%

3.1.2 Potential to Reduce Electricity–related Emissions

Electricity-related carbon emissions can be reduced or eliminated using a variety of strategies. The analysis above immediately suggests the merit of a low-carbon electricity contract. Of key concern to reducing carbon emissions is a contract that explicitly limits the use of coal electricity or that establishes an explicit carbon standard. While the previous contract did specify a high renewable energy content (considerably higher than PG&E or the statewide average, as shown in Table 3.II) its high coal content effectively cancelled its climate protection benefits.

The APS contract ended in 2008 and a new contract was negotiated with a different company. While the author has been unable to obtain information on any source mix specifications that might have been imposed, according to conversations with CSU Chancellor's Office Facilities Management staff, carbon standards were being discussed at the time. Therefore, one can hope that the current contract is considerably better than the 2006 contract with APS. In any case, the East Bay administration should weigh in supporting a low-carbon electricity contract.

Figure 3.II emphasizes the need for a low-carbon electricity contract. It compares the actual emissions resulting from the APS-CSU 2006 contract with what emissions would have been had power been procured from the local utility (PG&E) or if they reflected the statewide average emissions per kilowatt-hour. Cleary, to be consistent with AB32, any new contract for a state institution should be well lower in emissions than the CA-Mix. In theory, it would be possible to negotiate a zero, or near-zero emissions contract.

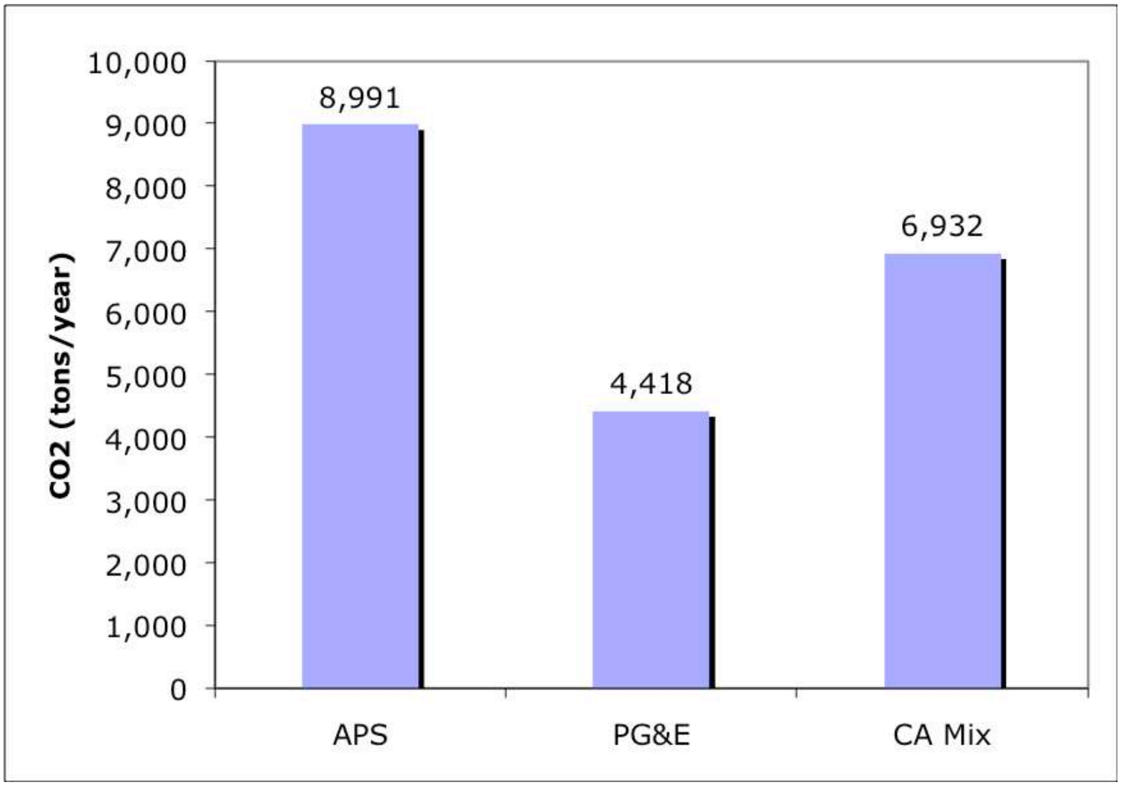

Figure 3.II Actual CO_2 emissions associated with electricity purchased from APS vs. hypothetical emissions (what they would have been if the same amount of electricity had been purchased from Pacific Gas and Electric Company (PG&E) or if emissions reflected the average source mix of power consumed in California.

Given that East Bay is bound to the system-wide electricity contract and only has modest influence over it, what are the options for further reducing electricity-related emissions? There are a number of other means that can be implemented locally. These include

- purchasing carbon offsets (renewable energy certificates),
- improving the energy efficiency, and
- installing more renewable energy capacity (solar or wind).

It would also be possible to offset some or all of the carbon emissions from purchased electricity by purchasing renewable energy certificates. Students at UC Santa Cruz voted to assess themselves a fee ($3/quarter) to do so. "Tapping the student-generated fund, the campus purchased 50 million kilowatt hours of clean energy in the form of renewable energy certificates. The purchase, on top of UC Santa Cruz's already existing electrical contract for 5 million kilowatt hours of renewable power, means the campus [electricity consumption] is now considered 100 percent green [by the EPA]—offsetting all its projected electrical consumption for fiscal 2006-07."[16]

Energy efficiency includes a broad array of options, from using solar design of buildings to reduce lighting and air-conditioning loads, and increasing the energy efficiency of electricity using devices, like lighting and computers. While solar design is highly cost effective in new buildings, only limited gains can be achieved at relatively high cost in existing buildings. On the other hand, improving the energy efficiency of electricity using devices can be highly cost effective.

Thus a dual-pronged approach makes sense.

- Commit to making all new buildings net-zero-energy or positive-energy,
- For all buildings (existing and new) pursue advanced controls technologies and high end-use efficiencies (lighting, computing, etc).

East Bay has been quite aggressive in pursuing the latter, having recently implemented both a lighting retrofit and a very successful computer server upgrade. The latter consolidated 100 servers to 3 highly efficiency VMWare servers saving 36.8kW and $49,200 per year.[17] The current energy efficiency upgrades are predicted to save the campus 22% of its current electricity use.

East Bay should continue to pursue such options, and if possible become a laboratory for the testing of advanced energy efficiency options. The California Energy Commission's Public Interest Energy Research (PIER) program field tests advanced energy efficiency technologies in institutions of higher education. Participating in such a program would keep our facilities management team appraised of state of the art technology that reduces emissions, saves money, and bring other benefits as well.

At the UC/CSU/CCC Sustainability Conference held at Cal Poly, San Luis Obispo in July and August, 2008, PIER lead tours of various systems beta tested on the Cal Poly campus. These included an outdoor walkway lighting system in which lights were outfitted with motions sensors. They not only significantly reduced electricity consumption, they improved security on the campus by alerting pedestrians to the locations and movements of others. [18] Other applications included dual-level lighting with occupancy sensors in stairwells (low level remains on always for emergency lighting, high level turns on only when in use), and advanced lighting controls in classrooms coupled with ultra-high efficiency fixtures.

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[16] UCSC Press Release available online at http://press.ucsc.edu/text.asp?pid=1043.

[17] From an *Information and Technology Services* report delivered to the Committee on Budget and Resource Allocation, December 7, 2007, by John Charles, Cal State East Bay Vice President and Chief Information Officer.

[18] Such systems were found to receive best reception when bulbs are returned to the 'off' mode via dimming rather than switching, thereby limiting the number of abrupt lighting to those that actually provide positive service.

3.2 Commuting

This chapter addresses carbon dioxide emissions from commuting to and from the university by faculty, staff, and students. The study included commuting by both non-resident students and dormers. The assessment of commute-related carbon emissions was by far the most time-intensive and difficult part of this study. As in previous chapters, the first section describes the emissions assessment and the subsequent section describes the potential to reduce emissions.

3.2.1 Assessment of CO_2 Emissions from Commuting

The emissions assessment was based on a survey of the commuting behaviors and vehicles of faculty, staff, and students on the Hayward campus, from which fuel usage could be calculated.[19] The analysis considers various subpopulations: *commuters* (considered here to be all faculty, staff, and students living off-campus regardless of how they get to campus) and *dormers* (students living on campus). In the case of dormers, their 'commute' was considered to be the extra travel incurred as a result of living at the University. This includes any international or domestic travel to get to the University and return home, and to visit family or take care of other business at home while resident. This section first describes the survey used to gather commute data, then the analysis of those data, and finally the results.

3.2.1a Commute survey

Commute emissions were assessed using a survey of faculty staff and students on the Hayward Campus. The main survey tool was a questionnaire, which was developed through an extensive in-class brain-storming session. The questionnaire was first piloted on a modest population and, based on that experience, refined, before gathering the data used in the final analysis. The final questionnaire is presented in Appendix 4.

Our goal was to accurately quantify only those emissions resulting from university-related activities, a task greatly complicated by the complex lives, especially of students, many of whom attend classes on their way to or from work. Thus, for example, if a student merely had to detour to get to campus on the way home from work, we would want to capture only the mileage associated with that detour. Additional complications arose from commuters' lack of knowledge both of relevant mileages and, for drivers of personal vehicles, of the fuel efficiency of those vehicles. Thus many alternative means were given to address these questions, as is evident in the questionnaire.

Through our experience with the pilot study, we found that the only way we could get good information was to administer the questionnaire in person, a task distributed among the student/investigators in the Applied Field Studies class, and then do considerable

[19] Note that emissions associated with the Cal State East bay shuttle are excluded from these calculations because they are accounted for under direct emissions of liquid fuels (Chapter 2).

post-interview analysis to get accurate information on mileages and vehicle fuel efficiencies. The final sample included 207 interviewees, distributed as shown in Table 3.IV among the various subpopulations.

Table 3.IV Subpopulations sampled in the travel survey.

Subpopulation	*Individuals in subpopulations*	*Traditional commuters vs. dormers samples*
COMMUTERS		161
Staff commuters	8	
Faculty commuters	9	
Student commuters	144	
DORMERS		46
Total	207	207

3.2.1b Data Analysis

The commute survey required intensive post-interview analysis and additional data collection, especially to determine reasonably accurate commute mileages and vehicle fuel efficiencies for the 207 interviewees. In practice, much of the mileage data determined from origin and destination data supplied by interviewees, which was converted to mileage estimates using Google Maps. Determining fuel efficiencies for the relevant modes of travel was even more time consuming. If personal vehicle drivers were unsure of the fuel efficiency of their vehicles, investigators asked for the model, make, and year of the vehicle and looked up the fuel efficiency of that type of vehicle reported on the US DOE / EPA fuel economy website (http://www.fueleconomy.gov/feg/findacar.htm) and take the mid-point fuel efficiency for highway and city driving and of the options for a given vehicle model and year.[20] For public transit, fuel use per passenger mile was estimated in different ways depending on the mode of travel. Appendix 5 presents the data used to calculate the fuel efficiencies of the various the various modes.

Ultimately the student investigators' data were compiled into a single dataset, that was used for the commute-based carbon analysis. Total and modal carbon emissions were calculated for each individual in the database on a per week basis. This allowed annual emissions to be calculated for the different subpopulations given their total population size and the average number of weeks per year of commuting.

Carbon emissions were calculated from weekly miles traveled and modal fuel use, as indicated in the following examples:

[20] For example, vehicle models that have options for a different numbers of cylinders can have a wide range of reported fuel efficiencies.

Private autos:

For private automobiles carbon emissions were calculated in the following manner:

$$\frac{\text{mileage}}{\text{fuel effiency}} \times \text{carbon emissions factor} = \text{carbon emissions} .$$

Which is easier to understand using a sample calculation:

$$\frac{100\ miles}{week} \times \frac{gallon}{20\ miles} \times \frac{19.64\ lb - CO_2}{gallon} = \frac{98.25\ lb - CO_2}{week}$$

Note that the second term on the left hand side of the equation is the inverse of the fuel efficiency and the third term is the carbon emissions factor for gasoline.

For BART travel:

For public transit carbon emissions are calculated from the following:

$$\text{mileage} \times \text{fuel intensity} = \text{carbon emissions}$$

Or, using a specific example analagous the previous one:

$$\frac{100\ miles}{week} \times \frac{0.11\ lb - CO_2}{person - mile} = \frac{11\ lb - CO_2}{person - week}$$

Other transit modes were calculated as for BART, using their modal carbon intensities given in Appendix A.5. Carpoolers were attributed only their share of total emissions for their trips.

3.2.1c Commute Emissions Results

Unsurprisingly, the vast majority of commuters (89%), commute in single occupancy vehicles (Figure 3.III) Also unsurprising, travel by single occupancy vehicle has the highest per person per mile emissions of any mode (Figure 3.IV). Interestingly, the per mile CO_2 emissions for AC transit buses are not all that much lower than for single occupancy vehicles because of relatively low passenger densities on regional buses.[21] This may change in the relatively near future because of the shift to high-efficiency, alternatively-fueled bus fleets and if the current trend toward increased us of public transit continues. On the other hand, vehicle fuel efficiencies will also be improving because of the new CAFE standards.

[21] This is actually true of US buses in general. One finds considerably lower fuel use per passenger mile on European buses.

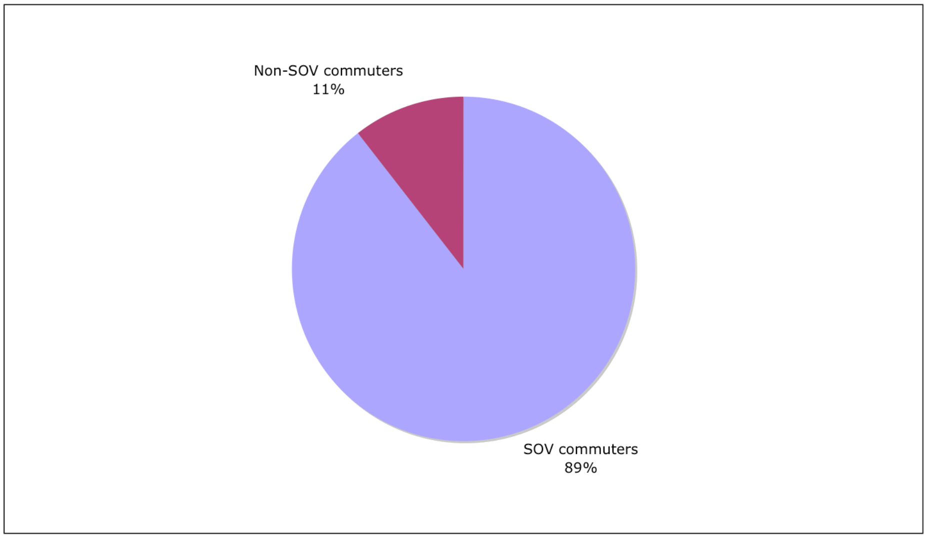

Figure 3.III Single occupancy vehicle commuters vs. non-single occupancy vehicle commuters as a fraction of the entire traditional commuting population of students, faculty, and staff (i.e., all non-dormers).

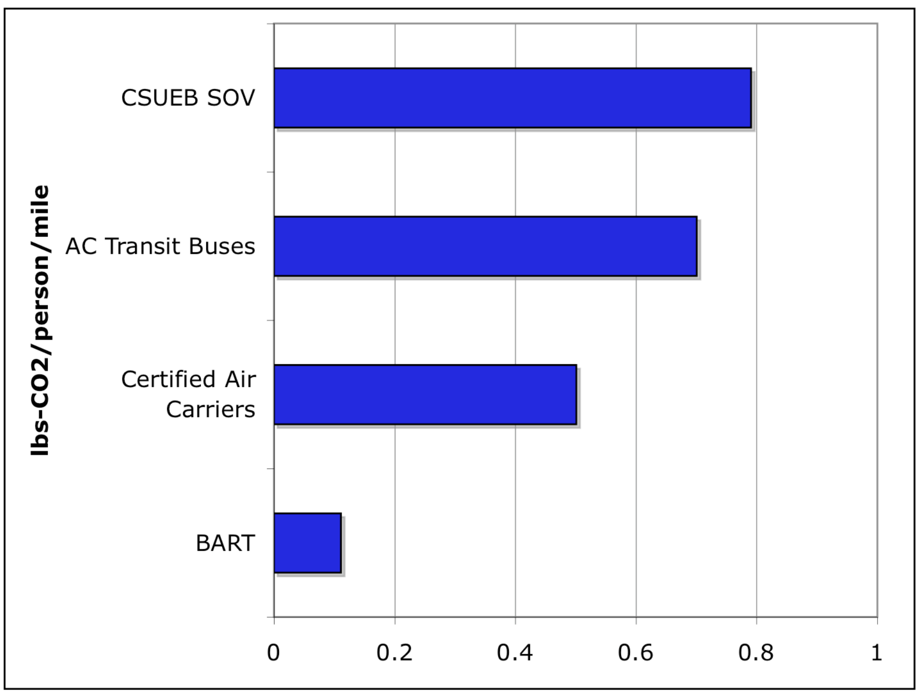

Figure 3.IV Average per person per mile emissions of different modes of travel. That of SOV's is based on the analysis of the Cal State East Bay commute survey questionnaire described in the previous section. The analysis of the other modes is as shown in Appendix 5.

Figure 3.V compares the per week per FTE carbon emissions of single-occupancy-vehicle-only (SOV-only) commuters with non-SOV commuters (all other modes). As can be clearly seen from this data, non-SOV commuters emit less than half the carbon of SOV-only commuters because of the high prevalence of BART commuters among the

non-SOV population. The mileage data (right hand cluster of bars) shows that while reduced mileage is responsible for part of the emissions reductions in the non-SOV population, it is not the dominant effect.

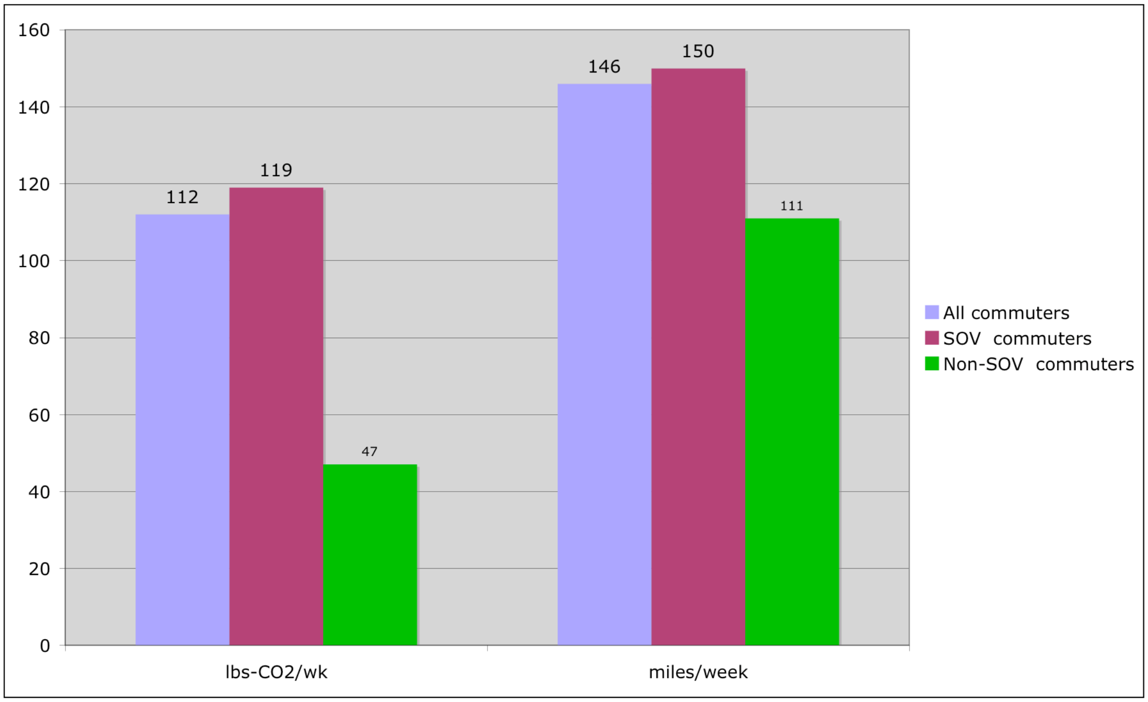

Figure 3.V Comparison of weekly carbon emissions of all commuters, SOV-only commuters and non-SOV commuters and of the average number of miles per week commuted by these populations. Both numbers are presented on a FTE basis, assuming that 15 units is full time for students. [22]

Table 3.V and Figure 3.VI compare the CO_2 emissions of the different subpopulations, with the table also indicating the input values for the calculations. Surprisingly, the annual commute emissions of international dormers per student is larger than for all other sub-populations because of the very large average distances traveled from their homelands. Of course their relatively small total numbers means that their contribution to total emissions is small relative to that of traditional commuters. But is does suggest that if increasing international student numbers is a strategy for increasing enrollments the university should consider means to offset those carbon emissions, for example using a voluntary carbon offsets program that is marketed to that population.

One should recall one important caveat here, which is that non-commute work-related travel (for example to conferences) was not included for faculty. Given the results for

[22] 15 units was the number of units used by the CSU Chancellor's Office to calculate the number of full-time equivalent students on campuses for funding purposes during 2006, the base year for this study. In Fall 2007 the funding formula changed, with graduate students being counted as full time if registered for 12 units, undergraduates still requiring 15 units. To complicate matters further, the Cal State East Bay catalog indicates that a student may be considered full time if taking 12 units!

international student travel, adding this in might significantly affect the travel estimates for faculty, though considerably less so than for a research university where international travel to conferences is more common than it is at East Bay.

Table 3.V Carbon emissions of different sub-populations of the East Bay community.

	FTES (#)	lbs-CO2 / FTES-week	weeks/yr	Tons of CO2 per year	Percent of total emissions
Intl. Dormers	150	173	37.5	486	2%
Domestic Dormers	400	58	37.5	431	2%
Faculty	516	86	42.0	931	4%
Staff	782	86	47.0	1,580	6%
Student Commuters (*)	10,792	110	37.5	22,259	87%
TOTAL	12,640			25,688	100%

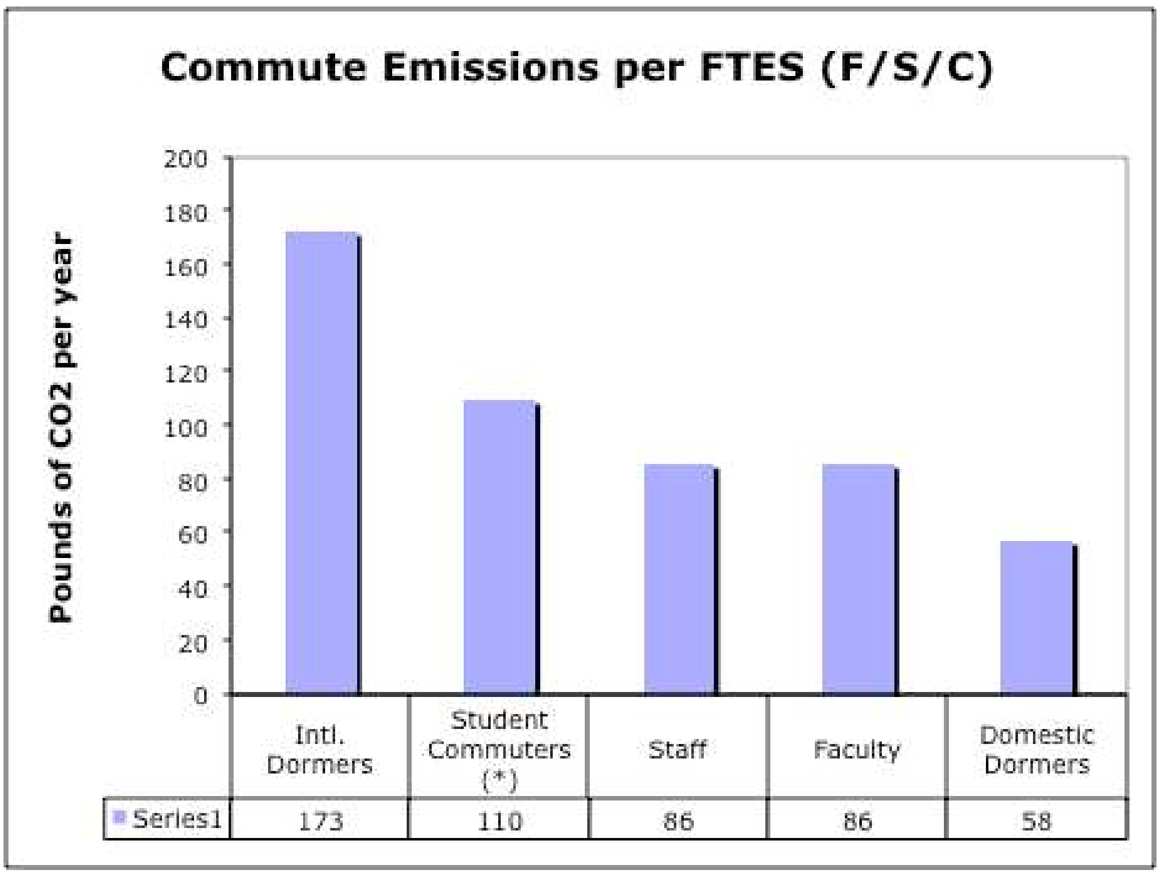

Figure 3.VI A graphical comparison of the annual carbon emission of the different East Bay subpopulations (data from the Table 3.V).

Of greater significance in Table 3.V is the large magnitude of the total carbon emissions, which, as we will see in Chapter 4, dwarfs that of all other sources.

3.2.2 Potential to Reduce Commute Emissions

This section considers the potential to reduce commute emissions that could result from changes in transit service availability, changes in the nature and scheduling of courses, changes in commute behaviors, and changes in vehicle fuel efficiency standards. Clearly these represent a range of actions, some of which the university has direct control over and some of which it has little or no influence over. The bulk of the findings are based on a survey of commuters at the Hayward campus.

3.2.2a Reduce commute survey

Students conducted a separate survey on the potential to reduce SOV commuting and related carbon emissions. The questionnaire used to administer this survey is replicated in Appendix 6. Being much easier to administer and survey than the commute assessment questionnaire, this one was administered in some cases in person, and in some cases it was distributed to entire classes to fill out on their own.

3.2.2a Survey results

The students collected responses from 165 CSU East Bay commuters. The following table summarizes the results of that survey. As shown in Table 3.VI, which summarizes the primary results of the survey, there is significant interest among students to take actions that would reduce emissions, though the motivation is almost certainly primarily the cost and inconvenience of commuting. Some measures, like the purchase of more efficient vehicles are largely beyond the scope of the University. Others potential measures are already being pursued. East Bay recently shifted more courses from three-day-per-week to two-day-per-week offerings. Unfortunately, the administration indicates that we are now at maximum for two-day-per-week classes, given the capacity of rooms. On the other hand, a major initiative now underway to increase the offering of online classes at East Bay is likely to continue into the future and lower the commute intensity of those students. Several entire majors are now offered on line, with several more likely to come online in the near future. The push in that direction will continue, both for entire majors, and for individual courses or programs that may be taught all online, or in hybrid form.

Among the surveyed options, this leaves facilitating carpooling and increasing the shuttle frequency to BART as the primary options that the University can take to reduce commute emissions. Both of these actions, according to our survey results, could result in significant reductions in SOV commuting. Given that parking demand is currently over capacity on the Hayward campus, that the university has been increasing enrollments, and that adding new parking will be costly because it will require the construction of expensive parking structures, there is a strong incentive to reduce SOV commuting, beyond environmental reasons.

Table 3.VI Results of Survey on the Potential to Reduce Commute Emissions. The survey focused on various means to reduce SOV reliance, commute frequency, and to reduce the emissions from SOVs.

Survey Question	**% Yes**	Comments
Interested in economical fuel efficient vehicle for next car?	82%	Gas prices, new CAFE standards, new CA carbon standards, and will all facilitate this
Interested in 2-day-per-week rather than 3-day-per-week classes?	76%	Two-day-per week offerings were recently increased at East Bay and according the administration are now at maximum potential
Interested in more hybrid on line classes?	66%	Major initiative underway to increase online classes at East Bay
Interest in carpooling?	61%	Could be facilitated more actively by East Bay
Would BART if BART-shuttle were more frequent?	45%	Could be facilitated more actively by East Bay

4. Conclusions and Recommendations

This section draws together the main results and recommendations from the previous analyses and draws conclusions about priorities for future carbon reductions. The total carbon emissions in 2006 from all energy-using activities at the two campuses amounts to 38.6 thousand tons. As shown in Table 4.I, if this were distributed equally among all faculty, staff, and students (full-time equivalent), it would amount to 3.1 tons of CO_2 per person per year.

Table 4.1 Total Cal State East Bay carbon emissions in 2006, numbers of students, faculty, and staff, and per capita emissions.

Total 2006 carbon emissions (tons-CO_2 / year)		38,642
FTE-students[1]	11,330	
FTE-faculty	516	
FTE-staff	782	
FTE-total		12,628
Tons-CO_2 / FTE / year		3.1

[1] In this study a student is considered full time if taking 15 quarter units per quarter.

The most important finding of this study is that commute emissions, at 25,700 tons of CO_2 per year, dominate all other sources (see Figure 4.I) Commute emissions are almost three times higher than the next largest source, electricity. Moreover, actual commute emissions are somewhat higher than those reported here, because the analysis considered only regular commuting by faculty and staff. It did not include other work-related travel, for example to conferences and workshops.

Unfortunately, commuting is the source over which the University has least control. Nonetheless, East Bay must make reducing commute emissions a high priority. Fortunately, doing so will also address the growing and increasingly costly parking problem on campus.

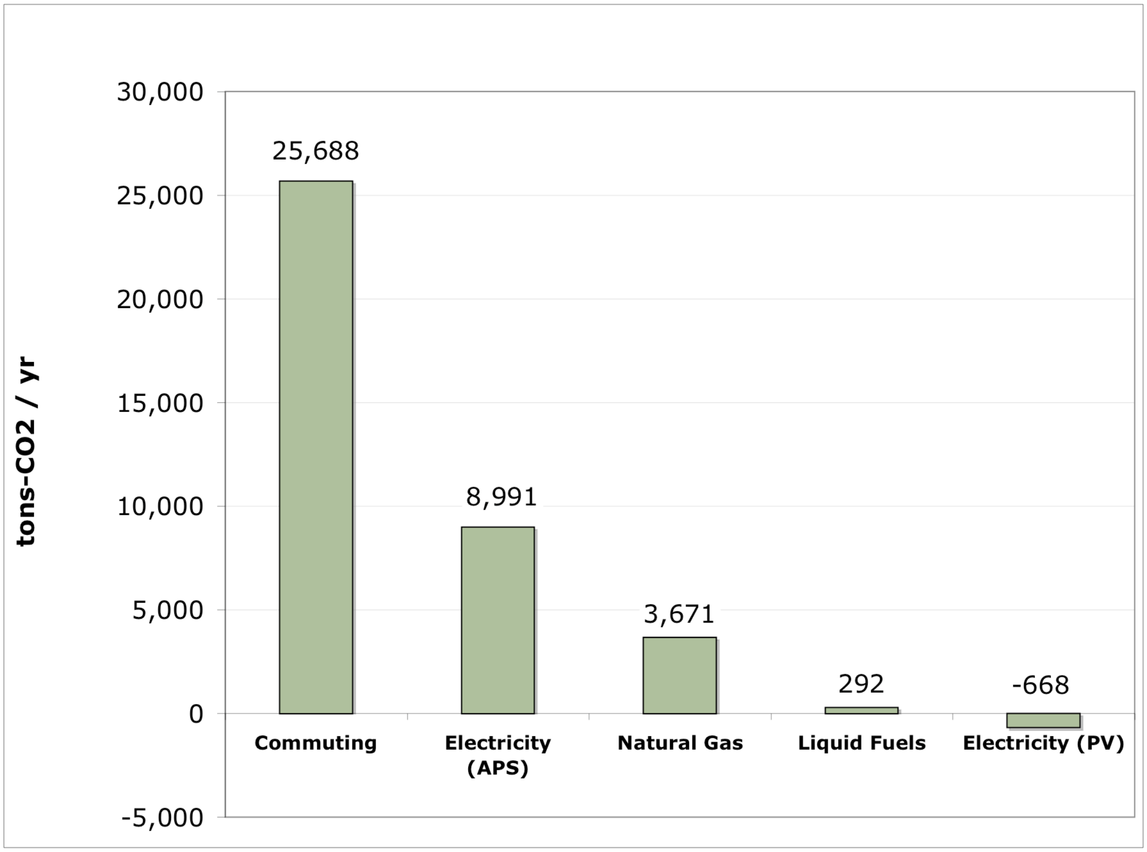

Figure 4.I Total 2006 carbon emissions (Hayward and Concord campuses) for commuting, electricity use, and natural gas and liquid fuels consumption. Also shown are emissions avoided by the PV system.

<u>Actions to reduce commute related carbon emissions should focus on increasing public transit use, but could go beyond that.</u>

- The focus needs to be on increasing the use of BART transit, because of its far lower emissions than that of other modes.
- Car-pool facilitation might also be recommended should not be pursued without some indication that it has been successful at other campuses, given the unusual complexity and variability of student's home and work schedules and very wide distribution of living locations.
- The university should investigate the possibility of using a student fee to support low-cost transit passes, again, with the emphasis on BART.
- We should also consider promoting a voluntary carbon offsets program coupled with an awareness campaign to reduce emissions. This may be the only viable approach to reduce the high per capita travel emissions of international students.

The second highest emissions source, electricity, is only partly under the control of East Bay, given the system-wide electricity contract. Fortunately in the case of electricity, East Bay has at least some voice over the nature of the contract.

Recommendations to reduce electricity-related carbon emissions include the following:

- Supporting a low carbon emissions electricity contract.
- Offsetting carbon emissions with renewable energy certificates, potentially supported through a student fee, if there is enough support for it.
- Increasing the energy efficiency of energy use (for example through increased us of advanced lighting and air cooling controls)
- Increasing the thermal performance of buildings (by committing to net-zero-energy or energy-positive new building) and by using advanced thermal controls systems in new and existing buildings.
- Installing more renewable energy capacity and advanced energy systems, such as cogenerating fuel-cell systems that generate high-efficiency heat and power simultaneously.

The next highest source of emissions, from natural gas, can also be reduced using advanced thermal controls system, by reducing duct leakage, using a centralized heating system and cogeneration, and using solar design in new buildings. The university is currently implementing a new energy managements system and duct upgrading that is expected to save 29% of campus natural gas use. According to interviews with the President, the Master Plan will include a centralized plant and cogeneration system. High efficiency green buildings are also being discussed. Thus the university is being very aggressive at reducing building heating energy. The only recommendation in this report that goes beyond what we are now doing is:

- East Bay should set a goal of having all new buildings be zero-net-energy by 2020. This is appropriately 10 years earlier that the proposed CEC statewide goal which would require all commercial buildings to be zero-net energy by 2030. The time frame is feasible and would allow the state to learn from the experience of the University.

This leaves direct use of liquid fuels, primarily by the fleet vehicles, which constitute only 3% of total emissions. While a small fraction of the total, emissions reductions here could be both highly visible and cost effective. The ultimate goal should be a zero-emission fleet of electric vehicles fun on solar or wind energy. Even using PV, the highest cost renewable energy source, it costs less to fuel a vehicle with sunlight than with gasoline at current prices. Thus our recommendation here is:

- East Bay should establish a goal of having its entire fleet vehicles be zero-emission (electric vehicles fueled by renewables) by 2018.

Final Word

This study revealed a significant flaw in the State's current carbon reporting system. The Climate Action Registry's default calculation for carbon emissions from electricity uses a state-wide average carbon emissions factor for electricity, while electricity imported from the Southwest typically has far higher carbon emissions, because of the high regional use of coal for power production. This contradicts the intent of AB 32, which calls for steep emissions reductions and explicitly applies to electricity imports as well as domestic power. The *Emission Inventory for CO_2 for 2006 for the California State University*

System used the default assumption in its analysis, thereby significantly underestimating actual electricity emissions. An artificially low baseline emissions level, means that the system will not be credited for its full future emissions reductions, including those that will presumably result from switching to a new electricity provider in 2008. It would be to the advantage of the system to correct the baseline calculation and to urge the state to collect carbon emissions data from energy service providers on direct access contracts, like it now requires them to report source mix information. The reasoning is the same, the customer needs to be able to judge the environmental impact of the product they are purchasing compared or they cannot be effective partners in improving the State's environmental future.

This report recognizes the important contributions that Cal State East Bay has already made to reducing carbon emissions. East Bay has resolved to move toward carbon neutrality and has already taken important actions leading thereto. These include its one MW photovoltaic system, its extensive energy efficiency upgrades (completed, in progress, and planned), and its planned future commitments to energy efficiency heat and power systems in the Master Plan. But there is more we can and must do to lead the State into the new green economy.

Borrowing President Qayoumi's words in his Fall 2008 Convocations speech, in addressing the sustainability problem "we must have the audacity of imagination and demonstrate the courage and firm leadership to move forward with a fierce sense of urgency". We must move yet more rapidly and begin to address the most difficult problems (most notably commuting). We must be more aggressive in our leadership, going beyond CSU system requirements and the statewide mandates. We must create the living model that the state can follow. We must create by our actions a learning lab for our students, who will be poised to become the next generations of leaders in the states emerging green economy.

APPENDIXES

APPENDIX 1 *Vehicle Fueling Costs: Gasoline vs. Grid Electricity vs. Sunlight*

Notes on solar car fueling developed for GEOG/ENVT 4320 *Energy and Society*
Revised 8/27/08
K. Garbesi

List of unit abbreviations

Btu	British thermal unit
gal	gallon
j	joule
kWh	kilowatt-hour
mi	mile

Overview
This paper compares the cost of fueling a car on gasoline with the cost of 'fueling' a car using electricity given current energy prices. We consider three separate cases for electricity: electricity purchased from a utility, electricity self-generated using unsubsidized photovoltaics (PV), and PV electricity subsidized at the current rate. The analysis is done for a residential PV system. The economics for commercial PV systems will be considerably better.

This paper first estimates the gasoline-cost-per-mile and energy-requirement-per-mile to operate a compact, efficient internal combustion engine vehicle (ICE-V). Assuming that a comparably sized electric vehicle has the same energy requirement, and knowing the price of utility electricity, the paper next calculates the cost to 'fuel' from the grid. The paper then estimates the energy costs per mile for unsubsidized and subsidized solar fueling. The last section calculates the PV array size (module area) needed to produce the electricity required to commute 10,000 miles a year on sunlight.

Calculate the cost and energy per mile to operate the gas-fueled vehicle

It is easy to calculate the cost per mile to fuel the ICE-V. Assuming gasoline costs $4/gal and the car gets a generous 35 mpg…

(1) $$\boxed{\frac{\$4}{gal} \cdot \frac{gal}{35mi} = \cdot \frac{\$0.114}{mi}}$$

Thus, it costs almost 11.4c/mile to fuel an efficient gasoline powered ICE vehicle.

Starting with how many gallons of gasoline are required per mile on average to propel the ICE-V, we can also figure out the *kinetic energy per mile* imparted to the car as follows:

(2) $$\frac{gal}{35mi} \cdot \frac{125{,}000Btu}{gal} \cdot \frac{1055\,j_{th}}{Btu} \cdot \frac{0.122\,j_k}{j_{th}} = \frac{459{,}700\,j_k}{mi}$$

We will assume that the electric vehicle receives the same kinetic energy per mile (i.e., that it is operated in the same way) and work backwards to figure its electricity requirements and thereby the cost of fueling with electricity.

Calculate the cost per mile to operate the grid-fueled electric vehicle

Assuming that the electric vehicle must have the same kinetic energy imparted to it to keep moving down the road, if we know the efficiency with which the EV converts electricity to kinetic energy, we can calculate the amount of electricity needed per mile to run the EV.

Table A.I Typical power system efficiencies for the average internal combustion engine vehicle and the average electric vehicle.

ICE-V efficiency = 12.2%	Data on page 94 of Hinrichs and Kleinbach, *Energy: Its Use and the Environment,* 4th Ed. Combined efficiency accounts for efficiency of ICE (25%), mechanical system (70%), and transmission system (70%)
EV efficiency = 64.8%	Data on page 94 of Hinrichs and Kleinbach, *Energy: Its Use and the Environment,* 4th Ed. Combined efficiency accounts for efficiency of battery (80%), engine (90%), and transmission system (90%)

The calculation starts with the kinetic energy requirement, estimates the electric energy requirement by dividing by the fuel efficiency, and then converts to the typical unit of measure for electricity (from joules to kilowatt-hours):

(3) $$\frac{459{,}700\,j_k}{mi} \cdot \frac{j_{el}}{.648\,j_k} \cdot \frac{kWh_{el}}{3.6\times10^6\,j_{el}} = \frac{0.197\,kWh_{el}}{mi}$$

Inverting this, we can express auto electric-use efficiency in a form that may feel more familiar:

The car gets $\frac{5.08mi}{kWh_{el}}$.

Admittedly, the electric vehicle might be a bit heavier due to its battery load, and so require more fuel to push. On the other hand, one can install regenerative breaking on an EV, as is used in hybrid vehicles (indeed it would be crazy not to since you already have the technology in place: a battery bank and an electric motor). This makes the car considerably more efficient. Here I assume that these two opposing factors will cancel each other out.

Using the current price of baseline electricity from the utility, we can now figure the cost per mile to 'fuel' the electric vehicle

$$(4)\quad \boxed{\frac{0.197kWh_{el}}{mi} \cdot \frac{\$0.12}{kWh_{el}} = \cdot \frac{\$0.0236}{mi}}$$

Therefore, using electricity from the grid, it costs less than 2.5c/mile to fuel the EV. Comparing Equation 4 with Equation 1, charging with electricity at the current price costs about 1/5th as much as fueling with gasoline at \$4/gal.

Calculate the cost per mile of the solar-fueled electric vehicle

So how do we compare this to the price of solar electricity?

Unsubsidized solar electricity costs about \$36c/kWh for residential systems (about 3 times the utility rate in CA today). It costs about \$20c/kWh after subsidies with the state rebate.

If it costs $\frac{\$0.0236}{mi}$ to run a car off of electricity that costs $\frac{\$0.12}{kWh_{el}}$.

It will cost three times as much, or $\frac{\$0.0709}{mi}$ to run a car off of electricity that costs $\frac{\$0.36}{kWh_{el}}$.

Comparing with Equation (1), we see this is still only 2/3 of what it costs to run a car on gasoline.

Thus, even unsubsidized residential solar electricity is no more expensive than fueling with gasoline.

Commercial solar electricity is considerably less costly than residential because of the economies of scale installation and equipment. Thus the cost tradeoff for commercial scale solar systems is even better. Moreover, both commercial and residential solar still qualify for rebates in California.

With the subsidy that CA residents receive it is considerably cheaper.

Doing the calculation with subsidized electricity costs:

it will cost $\frac{\$0.0394}{mi}$ to run a car off of electricity that costs $\frac{\$0.20}{kWh_{el}}$.

Therefore, you would be saving 7.5c/mi (11.4 – 3.9 c/mi).

So, if the car runs for 200,000 miles over its lifetime, you would save almost $15,000 on fuel over the lifetime of the vehicle (fueling with subsidized solar). Thus, even if the EV were to cost $15,000 more than the efficient ICE-V, it would still pay for itself over the lifetime of the car. And of course, as usual, we ignored all of the environmental and human rights savings (health, environmental, global warming, civil confict in Nigeria etc.).

Note that the great costs and environmental advantages of the EV come from the very high conversion efficiency of the electric motor compared to the internal combustion engine.

Calculate the PV array area needed for solar fueling a car

Use the following assumptions in the calculation:

- the car is to be driven 10,000 miles a year
- the site receives 71.7 Btu/ft^2-hr (average radiation received on a south-facing surface at a tilt equal to the latitude angle, in San Francisco, CA over the year, averaged over day and night for all seasons)
- PV cells are about 12% efficient on a module area basis

Figure out the electricity output of the cells

$$\frac{71.7 Btu_{sun}}{ft^2 - hr} \cdot \frac{0.12 Btu_{elec}}{Btu_{sun}} \cdot \frac{1055 j_{elect}}{Btu_{elec}} \cdot \frac{kWh_{elect}}{3.6 \times 10^6 j_{elect}} \cdot \frac{24 hr}{day} \cdot \frac{10.7 ft^2}{m^2} = \frac{0.651 kWh_{elec}}{m^2 - day}$$

$$\frac{10{,}000 mi}{365 day} \cdot \frac{kWh_{el}}{5.08 mi} \cdot \frac{m^2 - day}{0.651 kWh_{el}} = 8.3 m^2$$

Therefore, an panel area of approximately 2 m x 4 m will fuel an electric car to run 10,000 miles per year. Or, using typical panels of about 1m^2 each, it would take about 8 panels—a modest requirement.

Conclusions

Clearly, fueling vehicles with solar energy is a viable option with current technologies. Electric fleet vehicles are already widely available. PV installations have become routine. Fueling with sunlight is currently lower in cost than fueling with gasoline, even if the cost of the PV system is unsubsidized. The array size needed to supply the vehicle with power is reasonable using standard silicon technology.

APPENDIX 2 *Quarterly 2006 Power Content Labels from APS Energy Services*

First Quarter 2006

POWER CONTENT LABEL

ENERGY RESOURCES	UC_CSU (projected)	2005 CA POWER MIX** (for comparison)
Eligible Renewable	20%	5%
-- Biomass & waste	6%	<1%
-- Geothermal	13%	4%
-- Small hydroelectric	1%	1%
-- Solar	<1%	<1%
-- Wind	1%	<1%
Coal	32%	38%
Large Hydroelectric	20%	24%
Natural Gas	28%	33%
Nuclear	<1%	0%
Other	<1%	0%
TOTAL	100%	100%

* 16% of **UC_CSU** is specifically purchased from individual suppliers.

** Percentages are estimate annually by the California Energy Commission based on electricity sold to California consumers during the previous year.

For specific information about this electricity product, contact APS Energy Services. For general information about the Power Content Label, contact the California Energy Commission at 1-800-555-7794 or www.energy.ca.gov/consumer.

Second Quarter 2006

POWER CONTENT LABEL

ENERGY RESOURCES	PRODUCT NAME* (projected)	2005 CA POWER MIX** (for comparison)
Eligible Renewable	20%	5%
-- Biomass & waste	6%	<1%
-- Geothermal	13%	4%
-- Small hydroelectric	1%	1%
-- Solar	<1%	<1%
-- Wind	1%	<1%
Coal	32%	38%
Large Hydroelectric	20%	24%
Natural Gas	28%	33%
Nuclear	<1%	0%
Other	<1%	0%
TOTAL	100%	100%

* 16% of **UC_CSU** is specifically purchased individual suppliers.

** Percentages are estimate annually by the California Energy Commission based on electricity sold to California consumers during the previous year.

For specific information about this electricity product, contact APS Energy Services. For general information about the Power Content Label, contact the California Energy Commission at 1-800-555-7794 or www.energy.ca.gov/consumer.

Third Quarter 2006

POWER CONTENT LABEL

ENERGY RESOURCES	PRODUCT NAME* (projected)	2005 CA POWER MIX** (for comparison)
Eligible Renewable	21%	5%
-- Biomass & waste	6%	<1%
-- Geothermal	13%	4%
-- Small hydroelectric	1%	1%
-- Solar	<1%	<1%
-- Wind	1%	<1%
Coal	32%	38%
Large Hydroelectric	19%	24%
Natural Gas	28%	33%
Nuclear	<1%	0%
Other	<1%	0%
TOTAL	100%	100%

* 17% of **UC_CSU** is specifically purchased individual suppliers.

** Percentages are estimate annually by the California Energy Commission based on electricity sold to California consumers during the previous year.

For specific information about this electricity product, contact APS Energy Services. For general information about the Power Content Label, contact the California Energy Commission at 1-800-555-7794 or www.energy.ca.gov/consumer.

Fourth Quarter 2006

POWER CONTENT LABEL

ENERGY RESOURCES	PRODUCT NAME* (projected)	2005 CA POWER MIX** (for comparison)
Eligible Renewable	21%	5%
-- Biomass & waste	6%	<1%
-- Geothermal	13%	4%
-- Small hydroelectric	<1%	1%
-- Solar	<1%	<1%
-- Wind	1%	<1%
Coal	32%	38%
Large Hydroelectric	19%	24%
Natural Gas	28%	33%
Nuclear	<1%	0%
Other	<1%	0%
TOTAL	100%	100%

* 17% of **UC_CSU** is specifically purchased individual suppliers.

** Percentages are estimate annually by the California Energy Commission based on electricity sold to California consumers during the previous year.

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APPENDIX 3 *Estimating Carbon Emissions Factors from Electricity Consumption*

Carbon emissions factors for electricity consumption depend on several factors: (1) the fraction of consumed electricity that is generated by the different fossil fuels (aka the source mix), (2) the efficiency of transmission of electricity from the power plant to the point of consumption, and (3) the efficiency of the power plants used to generate the electricity (which in turn depends on the type and age of the generators). This appendix documents the procedure and data used to calculate the carbon emissions factor for electricity consumed by Cal State East Bay in 2006 under the APS direct access contract. Following the format used by the California Climate Action Registry, the carbon emissions factor for electricity is expressed in units of pounds of CO_2 per kilowatt-hour of electricity consumed (lbs-CO_2/kWh).

The relevant source mix information for the APS-CSU contract is obtained from the documents in the previous appendix. The fraction of electricity coming from coal and natural gas, are 32% and 28%, respectively. We assume here a standard reported value of 93% transmission and distribution efficiency. This leaves the problem of estimating the power plant efficiencies and then the final calculations of the carbon emissions factors, which are presented in the following two sections.

Estimation of the Average Efficiency of APS' Coal and Natural Gas Generators

The analysis accounted for both the age and type of unit at a course level. Data on efficiencies by age and type were obtained from the Internet from the sources indicated in Table A3.I. Data on the actual power plants used by APS, were obtained from several industry and APS sites:

- http://www.aps.com/general_info/AboutAPS_18.html
- http://www.powerplantjobs.com/ppj.nsf/powerplants1?openform&cat=az&Count=500
- http://www.pnm.com/systems/4c.htm.

These units were then assigned efficiencies based on their type and age using the information in Table A3.I. A weighted average efficiency was determined first for each power plant and then for all plants for each fuel type. The intermediate and final results are shown in Tables A3.II, for coal plants, and Table A3.III, for natural gas plants. The weighting factors were determined by the fractional share of capacity represented by each unit (in the power plant averages) and for each power plant (in the fuel-wide averages).

Table A3.I Generating unit efficiencies for different generator technologies.

Generator technology	assumed efficiency	Reported range of efficiencies	Data source
combustion new single (GT-new)	37%	35 – 40%	http://www.freepatentsonline.com/5819522.html
combustion old simple (GT-old)	30%	25 – 35%	http://www.cogeneration.net/Simple_Cycle_Power_Plants.htm
steam old (ST-old)	33%		standard assumption for old steam turbines
steam new (ST-new)	40%	40 – 45%	http://www.cogeneration.net/Simple_Cycle_Power_Plants.htm
combined cycle (CC)	50%	--	based on analysis of California's CC plants: input data from http://www.energy.ca.gov/database/index.html#powerplants

Table A3.II Generator efficiencies of APS coal fired power plants.

Coal Plants	Unit[1]	Type[2]	Efficiency	Age of units	Megawatts (MW)
Four Corners	ALL	ST	33%	all old	782
Cholla	ALL	ST	33%	all old	**615**
Navajo	ALL	ST	33%	all old	**2250**
OVERALL COAL			33%		

[1] Identifies generator units at power plants.
[2] Abbreviations for generator types from the previous table.

Table A3.III Generator efficiencies of natural-gas-fired power plants.

Power Plant	Unit	Type	Efficiency (e)	Year in Service	Mega-watts (MW)	Weighting Factors	Efficiency
	Unit 1	ST	33%	1960	114	34.07%	
	Unit 2	ST	33%	1960	114	34.07%	
	Unit GT1	GT	30%	1972	53	15.93%	
	Unit GT2	GT	30%	1973	53	15.93%	
Ocotillo	**Average[1]**				**333**	**100.00%**	**32%**
	Unit 1	ST	33%	1954	125	28.77%	
	Unit 2	ST	33%	1955	125	28.77%	
	Unit GE1	GT	37%	2002	78	18.02%	
	Unit GT1	GT	30%	1972	53	12.22%	
	Unit GT2	GT	30%	1973	53	12.22%	
Saguaro	**Average[1]**				**435**	**100.00%**	**33%**
	Unit GT1	GT	30%	1971	20		
	Unit GT2	GT	30%	1971	20		
	Unit GT21	GT	30%	1978	26		
	Unit GT3	GT	30%	1973	56		
Yucca	**Average[1]**				**122**		**30%**
		CC	50%		714	71.43%	
		GT	30%		286	28.57%	
West Phoenix	**Average[1]**	**CC/SC[1]**			**1000**	**100.00%**	**44%**
Redhawk	**TOTAL**	**CC**	**50%**		**1060**		**50%**
Sundance	**TOTAL**	**GT**	**30%**		**450**		**30%**
OVERALL Average NGAS							**41%**

[1] Power plant weighted average efficiency, weighted by the fractional contribution of each unit to the total power plant output.

[2] Of the total 7 units at West Phoenix, 5 are combined cycle and 2 are simple cycle. Lacking better information for this plant, the outputs of the 7 units were assumed to be the same.

Estimation of the carbon emissions factor for APS-2006 electricity

Using the results and data from the previous sections of this appendix and from Table 1.I for fuel-specific carbon emissions factors (summarized below), we estimate the carbon emissions factor for APS-2006 electricity (CEF_{elec}) consumed by Cal State East Bay.

Table A3.IV Summary of inputs for calculation of the carbon emissions factor for electricity.

Constants and Conversions	Values	Units
Efficiency of electricity transmission and distribution from the power plant	93%	
Average efficiency of APS' coal-fired power plants	33%	
Average efficiency of APS' natural-gas fired power plants	41%	
energy conversion factor	3.60E+09	joules per thousand kilowatt-hours
carbon emission factor Coal	197.07	pounds-CO2 per 10^9 joule coal
carbon emission factor N-gas	110.32	pounds-CO2 per 10^9 joule N-gas
weight conversion	2000	pounds per ton

The carbon emissions factor has contributions from both coal and natural gas. These are calculated separately below and then combined to yield the CEF_{elec}:

<u>Coal's contribution per kilowatt-hour of electricity consumed</u>:

$$\frac{0.32 kWh_{coal-elect-con}}{kWh_{elect-con}} \times \frac{kWh_{coal-elect-gen}}{0.93 kWh_{coal-elect-con}} \times \frac{1 kWh_{coal-burned}}{0.33 kWh_{coal-elect-gen}}$$

$$\times \frac{3.6 \times 10^9 \, j_{coal-burned}}{10^3 kWh_{coal-burned}} \times \frac{197.07 lb - CO_2 \text{ from coal}}{10^9 \, j_{coal-burned}} = \frac{0.74 lbs - CO_2 \text{ from coal}}{kWh_{elect-con}}$$

Notice that we must track independently electricity consumed (elec-con) vs. that generated (elec-gen) vs. the energy contained in the coal (joules of coal burned – $j_{coal\text{-}burned}$). The same procedure is followed for natural-gas-derived electricity.

<u>Natural gas's contribution per kilowatt-hour of electricity consumed</u>:

$$\frac{0.28 kWh_{Ngas-elect-con}}{kWh_{elect-con}} \times \frac{kWh_{Ngas-elect-gen}}{0.93 kWh_{Ngas-elect-con}} \times \frac{1 kWh_{Ngas-burned}}{0.41 kWh_{Ngas-elect-gen}}$$

$$\times \frac{3.6 \times 10^9 \, j_{Ngas-burned}}{10^3 kWh_{Ngas-burned}} \times \frac{110.3 lb - CO_2 \text{ from Ngas}}{10^9 \, j_{Ngas-burned}} = \frac{0.29 lbs - CO_2 \text{ from Ngas}}{kWh_{elect-con}}$$

The total CO_2 per kilowatt-hour of electricity consumed is the sum of the two previous results:

<u>Carbon emission factor for APS-2006 electricity consumed by Cal State East Bay</u>:

$$\boxed{\frac{0.74 lbs - CO_2 \text{ from coal}}{kWh_{elect-con}} + \frac{0.29 lbs - CO_2 \text{ from N - gas}}{kWh_{elect-con}} = \frac{1.03 lbs - CO_2}{kWh_{elect-con}}}$$

APPENDIX 4 *Commute Assessment Questionnaire*

Introductory Text:
To respond to the problem of climate change and state mandates to reduce carbon dioxide emissions, we are doing a campus carbon emissions assessment for our GEOG/ENVT 3480 class. In this survey we are determining how far people travel to get to campus and what modes of transportation they use. From this we will calculate the carbon emissions associated with travel.

IDENTITY

(Circle or fill in answer)

	Faculty/Staff	Student
1	Part time / full time	Units being taken: ____________
2	Live ON or OFF campus If OFF go to (I), if ON go to (II)	Live ON or OFF campus If OFF go to (I), if ON go to (II)
3	Average # of trips per week to campus __________	Average # of trips per week to campus __________

(I) LIVE OFF CAMPUS (COMMUTERS)

4. On average how far to do you have to travel to get to and from Cal State East Bay (only include additional travel if you come to school on the way home from work (or some other commitment), or if you go to work (or another commitment) on the way home from school? (Enter either mileage or indicate origin of travel on trip in and destination of travel on trip out)

Miles traveled per trip to school (include to and from): _____________________

AND

Origin coming to school _________________________
Destination leaving school _______________________

NOTE: IF coming to or from campus is a detour on the way to or from work or another commitment, indicate the detour location as the origin or destination (for example, give a Freeway Exit off of I-880 if you would be traveling up or down 880 on you way to or from campus. Create a map if necessary on the last page to help determine the commute attributable to attending East Bay.

5. What modes of transportation do you use to get to campus?

MODE (circle)	**Fraction of trips (fill in)**
Private Motor Vehicle (go to I.b)	
Carpool/Vanpool IF Carpool: Average number of people per carpool:__________________ (go to II)	
Bus	
Shuttle	
BART	
Bicycle	
Walk	
other	

(I.b) PRIVATE MOTOR VEHICLE AND CARPOOL USERS

What kind of vehicle do you usually use to get to campus?

Passenger vehicle   Van   SUV   Truck   Motorcycle   Motor Scooter

What is the fuel efficiency of the vehicle? ________________________________

OR   What is the make, model, and year of the vehicle

(II) LIVE ON CAMPUS (DORMER)

As a result of being a student living on campus, do you travel long distances to visit family and friends or must you engage in other long distance travel that would not be necessary had you not moved to campus?

If so: Where do you travel?
About how often each year?
By what mode?

COMMUTE MAP

Surveyer: Use this section to draw a commute map, if necessary to determine what part of the interviewees commute trip is to bring them to campus as opposed to servicing other activities (e.g. getting to and from work).

APPENDIX 5 *Carbon Intensities of Public Transit and Single Occupancy Vehicles*

Carbon dioxide emissions for Bay Area bus travel (AC Transit), Bay Area commuter rail travel (BART), and Air Carriers (average) estimated from year-2005 mileage and fuels data, the most recent data, compiled by the Federal Transit Administration in its online National Transit Database (see indicated websites). Calculated values assumed the following carbon emissions factors: 22.23 lbs-CO_2/gallon for diesel and 19.64 lbs-CO_2/gallon for gasoline and 0.5505 lbs-CO_2 per kilowatt-hour for the electricity used to run BART. The was was calculated, as shown in the Electricity section of this report, assuming the electricity source mix of the local utility (PG&E) used in this report. For comparison the average per mile emissions of Cal State East Bay single occupancy vehicles is also shown.

Table 5.I Calculation of carbon emissions per passenger mile by mode based on annual fuel consumption and total passenger miles reported by the agencies.

Mode / Amount	Units	Data Source
AC Transit		
6,218,300	Gallons of Diesel Consumed 2005	http://www.ntdprogram.gov/ntdprogram/pubs/dt/2005/PDF/2005_Table_17.pdf
138,600	Gallons of Gasoline Consumed 2005	http://www.ntdprogram.gov/ntdprogram/pubs/dt/2005/PDF/2005_Table_17.pdf
200,106,310	Passenger Miles 2005	http://www.ntdprogram.gov/ntdprogram/pubs/profiles/2005/agency_profiles/9014.pdf
140,917,491	Total Carbon Emissions	Calculated
0.70	Carbon Emissions lbs-CO2/passenger-mile	Calculated
BART		
281,027	kWh Consumed 2005	http://www.ntdprogram.gov/ntdprogram/pubs/dt/2005/PDF/2005_Table_17.pdf
1,255,541	Passenger Miles 2005	http://www.ntdprogram.gov/ntdprogram/pubs/profiles/2005/agency_profiles/9003.pdf
0.22	kWh Consumed/Passenger Mile 2005	Calculated
0.11	Carbon Emissions lbs-CO2/passenger-mile	
Certified Air Carriers		
3,264	BTU per passenger mile	US DOE Transportation Energy Data Book. http://cta.ornl.gov/data/chapter2.shtml, Table 2.14. Energy Intensities of non-highway
0.50	Carbon Emissions lbs-CO2/passenger-mile	Calculated
Cal State East Bay Average Private Vehicle		
25	Fuel efficiency: Miles per gallon	Calculated from Commute Survey data
0.79	Carbon Emissions lbs-CO2/mile	Calculated

APPENDIX 6 *Survey on Potential to Reduce Commute Related Emissions*

Potential to Reduce Private Vehicle Commuting and Carbon Emissions

1. Do you commute in a private vehicle to get to and/or from school? ◯ Yes ◯ No
   (If no, please discontinue survey)

2. Why don't you use public transportation to get to campus (at all or more often)? *(Check all that apply)*
   ◯ it takes too much time ◯ it costs too much ◯ it doesn't feel safe
   ◯ too many connections to get here *(car, BART, shuttle, etc.)* ◯ I need to do other errands on the way in / out
   ◯ other:

3. Do you know how to get to campus on public transportation from your home/work? ◯ Yes ◯ No

4a. Have you ever taken public transportation to get to campus? ◯ Yes ◯ No

4b. If so, please rank your experience ◯ 5 ◯ 4 ◯ 3 ◯ 2 ◯ 1
(Excellent) ◄ *(Neutral)* ► *(Terrible)*

4c. Please explain why you ranked your experience this way:

5. Would you take public transit more often if the shuttle/bus service to BART were increased in frequency and/or duration? ◯ Yes ◯ No

6. Would you consider car-pooling if a service were available to help you find fellow travellers at convenient time? ◯ Yes ◯ No

7. Would you purchase a small fuel-efficient car as your next vehicle if its price were comparable to that of other small economy cars? ◯ Yes ◯ No

8. If three-day-a-week classes (MWF) were offered twice-a-week (MW) instead, would reduce the frequency that you would have to commute to campus? ◯ Yes ◯ No

9. If more hybrid/on-line courses were offered, would you opt to take them to reduce the need to commute to campus? ◯ Yes ◯ No

10. If more courses were offered on the Concord campus, would this reduce your commuting energy needs? ◯ Yes ◯ No

11. If more services were offered on campus *(**Beer,** for instance!)*, would this reduce the number of trips you take too and from campus? ◯ Yes ◯ No

Thank you for your participation