Greenhouse Gas Emissions Inventory

&

2050 Projections

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ABSTRACT

This report contains projections of UC Berkeley greenhouse gas emissions out to 2050. Business-as-usual and best-case scenarios are included. Emissions reductions for the best-case scenario were calculated for vehicle transportation, business air travel, water use, electricity use, and electricity supply. Vehicle transportation emissions were estimated to drop below the business-as-usual by 30% due to industry changes and by 17% due to mitigation projects for a total 38% reduction by 2050. Combining realistic technological changes across the industry and mitigation strategies such as videoconferencing, the University could reduce its air travel emissions by 18% below current levels. By implementing several water conservation measures, campus could avoid an anticipated 20% emissions increase by 2050 and instead maintain water demand and emissions at a constant level. Performing ventilation upgrades, lighting improvements, and similar mitigation projects could halve 2050 electricity consumption to 1990 levels. Decarbonization of the electricity supply will further reduce electricity emissions below 1990 levels. Combing reductions from each of these areas would allow UC Berkeley to cut greenhouse gas emissions 30% below 1990 levels by 2035, representing a potential future goal for campus.

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EXECUTIVE SUMMARY

This project sought to project UC Berkeley greenhouse gas emissions to 2050. Potential emissions reductions were calculated for five different areas: vehicle transportation, business air travel, water use, electricity use, and electricity supply. Reductions from each of the five categories were combined to provide comprehensive emissions reductions projections to 2050.

Vehicle transportation emissions reductions resulted from both expected industry changes and specific mitigation projects. The reductions from industry changes were based on several different metrics, incorporating legislation and public policy, technological improvements, long-term fuel efficiency trends, and vehicle turnover rates. Vehicle emissions were estimated to drop by approximately 30% by 2050 due to industry changes. Specific mitigation projects were also identified to further reduce vehicle transportation emissions. The projects include bicycle and pedestrian programs, enhanced car share, daily use parking fees, increased parking permit prices, and expanded transit programs. These projects align with recommendations from the UC Berkeley Parking and Transportation Demand Management Master Plan. Due to these projects, vehicle emissions were estimated to drop by 17% by 2050. Combining both industry changes and mitigation projects results in a 22% drop in emissions by 2020, and a 38% drop by 2050.

The business air travel mitigation measures rely on future industry changes delivered by the CONSAVE committee and on videoconferencing equipment and incentives on campus. The business-as-usual scenario based on population growth trends in California projects an 18% increase in CO_2 emissions. In the best-case scenario, relying on realistic projections for aircraft technologies and videoconferencing incentives on campus, CO_2 emissions could be reduced by 23% relative to 2011 levels. The University could set a goal to reduce trips taken by 20% in favor of videoconferencing in 2020, followed by another 20% reduction by 2050. An intermediate goal would be to target a 35% decrease in average trips taken by 2035.

Emissions cuts associated with water use were evaluated by assessing the future carbon profile of campus water supply with respect to EBMUD's reservoirs growth and desalination projects. A series of mature water conservation systems were studied for possible implementation on campus and corresponding water savings were calculated. The conservation systems include low flow showerheads, water-efficient toilets, rainwater harvest in three laboratory buildings, greywater reuse systems from showers to toilets in three residential halls, heat exchanger replacement, drip irrigation, and irrigation metering. In the best-case scenario, the emissions associated with water would mostly remain constant to 2050 rather than increasing by 20%. All the assessed mitigation strategies discussed for water are mature and readily implementable to achieve water use stabilization as campus population grows.

Improved models of current and future electricity use on campus were required to evaluate mitigation projects and identify opportunities for emissions reductions. Projections of campus electricity use were improved by increasing the detail of existing energy use data. Electricity consumption by end use was estimated by determining the energy intensities of major end use categories including lighting, ventilation, cooling, process and other, for five different types of facilities including classrooms, residences and laboratories. Existing electricity mitigation strategies were evaluated based on the space type and end use impacted, and energy savings as predicted by the campus Strategic Energy Plan were used to model electricity consumption to the Plan's completion in 2020.

Predictions of trends in technology efficiency for each end use under two projection scenarios were used to project trends in electricity on campus out to 2050. Under the business-as-usual scenario, the largest single consumer of electricity is projected to be laboratory ventilation at a predicted 27% of total electricity use, while the same end use comprised only 6% of total electricity under the best-case scenario projection. This comparison identifies laboratory ventilation as the single mitigation project which will result in greatest electricity savings. Total electricity consumption in 2050 is projected to reach as low as 1990 levels under the best-case scenario projection or as high as twice that under the business-as-usual scenario. Projected electricity savings associated with following the best -case scenario are over 2 billion kWh between 2020 and 2050 relative to the business-as-usual scenario. Mitigation measures to reach the best-case scenario trajectory include ventilation upgrades and lighting improvements. Despite mitigation projects, electricity production is expected to remain high, and will constitute a greater fraction of total emissions if steam is eliminated in favor of lower carbon heating technologies.

Long-term industry trends in the emissions associated with purchased electricity were investigated. Several scenarios were considered, including a business-as-usual scenario, which assumes that the emissions associated with electricity remain at 2011 levels indefinitely. A second scenario assumes that electricity is decarbonized to the extent that California is able to achieve its goal of 80% below 1990 levels by 2050. A third scenario represents a middle-of-the-road approach, where electricity is partially decarbonized, but not to the extent that the 80% below 1990 target is achieved. An improved business-as-usual scenario to 2050 is calculated based on predicted growth of 18 to 24-year-olds in California. The results of the investigation show that changes in industry will greatly reduce the quantity of greenhouse gasses due to electricity, but are not a silver bullet for achieving neutrality goals. By 2050, electricity will no longer be a principal contributor to the overall emissions portfolio, shifting the bulk of emissions to other sources such as heating due to steam, and raising the possibility of electrification.
A final 2050 projection was calculated, including all the best-case scenarios for the five different sectors considered in this report. Ultimately, it was concluded that the University

can reduce their annual emissions to 110,000 metric tons of CO_2e by 2035. This represents a 30% cut below 1990 levels and a strong potential milestone for the future.

I. INTRODUCTION

This report was completed in conjunction with the UC Berkeley Office of Sustainability and the Cal Climate Action Partnership (CalCAP) to improve existing projection models of greenhouse gas emissions on the UC Berkeley campus. The models will aid in the campus intention to set the next emissions reduction target by the end of the 2013 academic year, and inform a future campus climate neutrality goal. The report makes use of existing emissions projections, including a basic greenhouse gas emissions projection through 2020 and a "business-as-usual" projection through 2050. The work here improves these estimates and proposes additional emissions reduction strategies designed to aid in meeting campus goals. The report combines the additional energy conservation recommendations and incorporates long-term changes in energy sources, demand and efficiency to provide a comprehensive 2050 projection for campus emissions. Two other student groups focused specifically on steam generation and renewable energy on campus, so this report will consider remaining mitigation options.

This report details five different opportunities for reducing greenhouse gas emissions: student and faculty commute (11% of 2011 emissions), business air travel (11%), water use (1%), electricity use (24%), and electricity supply. The vehicle transportation study examines the impact of transit industry changes on future commute emissions, and proposes specific mitigation projects to further reduce emissions. Business air travel projections predict trends in air transportation emissions, promote reduction schemes such as direct flights, and encourage alternatives such as videoconferencing. Water conservation efforts include projections and conservation measures such as behavior change programs, rain harvesting, and water recycling. Energy efficiency measures to reduce electricity use focus on HVAC systems and improvements in temperature control methods, as well as lighting systems to maximize efficiency and user comfort. The future of electricity production in California is also examined to estimate emissions reductions provided by changes in the energy supply. The emissions reduction calculations for each of these five sectors are discussed separately within the report

All proposed mitigation strategies are assessed by their ability to meet campus goals and their feasibility. The reductions associated with the mitigation strategies from each of the five areas are combined into a comprehensive greenhouse gas emissions projection scenario to 2050.

II. VEHICLE TRANSPORTATION

Background

Data Sources

Vehicle transportation accounted for around 11% of campus emissions in 2011. This breaks down to approximately 9% of emissions from faculty and staff commutes, 1.5% from student commutes, and 0.5% from the campus fleet.[1]

Commute emissions data come from campus-wide surveys that must be conducted at least every three years as mandated by the LRDP Environmental Impact Report.[2] Faculty and staff are surveyed separately from students, and the most recent survey was completed in 2011. The surveys are typically completed by a quarter to a third of campus, and the responses are treated as representative of the entire campus population.[3] Commute emissions are considered part of scope 3, but show the most potential for reduction within the vehicle transportation sector.

Fleet emissions are calculated directly from fuel purchases, meaning the available data are accurate and reliable. Gasoline, diesel, ethanol, and biodiesel are all currently used in different vehicles, allowing for the possibility of changing the distribution among these sources.[1] Despite the fact that fleet emissions contribute a small amount to the overall total, they are one of the few direct, scope 1 emission groups.

Current Mitigation Efforts

A large majority of students already walk or bike to campus. This is due to long-term efforts by the University to reduce transportation emissions through strategic location of campus housing. As outlined in the LRDP, all housing investments should be within walking distance of a 20-minute public transit ride to campus.[4] A greater percentage of faculty and staff members drive-alone to campus, primarily due to the increased travel distances. Many of these drivers list the ease and flexibility of a car for lunchtime errands and activities as the main advantage of driving over public transportation.

Identified commute mitigation projects include promoting bicycling and public transportation, as well as generic reductions in student and faculty drive-alone rates. Survey results indicate that commute emissions decreased by 2,000 metric tons of CO_2e from 2006 to 2009, proving that these programs have been beneficial in the short term.[5] However, the logic behind the future emission reductions ascribed to these commute mitigation projects is unclear, and will be refined.

The UC Berkeley Parking and Transportation Demand Management Master Plan has identified several measures primarily intended to reduce parking demand on campus.[6]

Several of these projects will provide emissions reductions corresponding to the decrease in parking demand. These reductions will be quantified in order to unify the parking plan with the emissions projections.

Fleet emissions mitigation is covered solely by the continuation of the University's existing green vehicle replacement program.[5] Although individual departments fund vehicle purchases across campus, the University already has policies in place dictating the fuel efficiency requirements for any new vehicle. The percentage contribution of fleet emissions will begin to grow as other areas are reduced, and campus fleet vehicles are more publically visible than other sources like purchased steam and natural gas. Making efforts to reduce emissions in the most visible sectors like this may help raise community awareness.

Methodology

Industry

In order to project future campus emissions, both industry changes and mitigation projects were considered. The emissions reductions calculated for each of these two categories were then applied to the BAU projections as part of the reduced emissions projection scenario.

The industry changes category of reductions attempts to capture the technological improvements, long-term efficiency and behavior trends, and legislation and public policy initiatives affecting vehicle transportation. Even if UC Berkeley had no specific plan to reduce transportation emissions by 2050, the emissions total would still drop due to changing vehicles, increased awareness, and other similar factors.

This effect is difficult to precisely predict because there are so many variables involved, and because of the large timescale being examined. Instead of using a single metric or study to estimate industry changes, multiple sources were examined and a curve was created to fit the criteria of each source.

Executive Order S-3-05, signed in 2005, commits the state of California to reducing greenhouse gas emissions to 2000 levels by 2010, 1990 levels by 2020, and 80% below 1990 levels by 2050.[7] Similarly, the Global Warming Solutions Act of 2006 aims to reduce vehicle greenhouse gas emissions by 30% before 2016, followed by further reductions after 2017.[3] Finally, California State Assembly Bill 375, passed in 2007, promotes intelligent land use and transportation by compelling a reduction in vehicle miles traveled and outlining laws to reduce emissions by curbing urban sprawl.

Clearly, there is political commitment within the state of California to minimize the environmental impact of transportation. Regulations like this are not incorporated into the existing projections, with implicit assumption being that the transportation industry will remain stable across the projected period. Given the increasing awareness and action regarding climate change, as well as the visible increase in laws governing greenhouse gas emission at both the state and federal level, this is an unrealistic assumption. However, this legislation is not a guarantee that the stated goals will be achieved. In order to estimate a more attainable industry change in emissions, historical fuel economy data was examined.

As shown in Figure 1, the fuel economy of US light-duty vehicles, used by commuters and the campus fleet, has almost doubled since 1975, rising from just over 13 mpg to 26 mpg. Fuel economy plateaued in the 1990's, but began increasing again in the latter half of the last decade.[8]

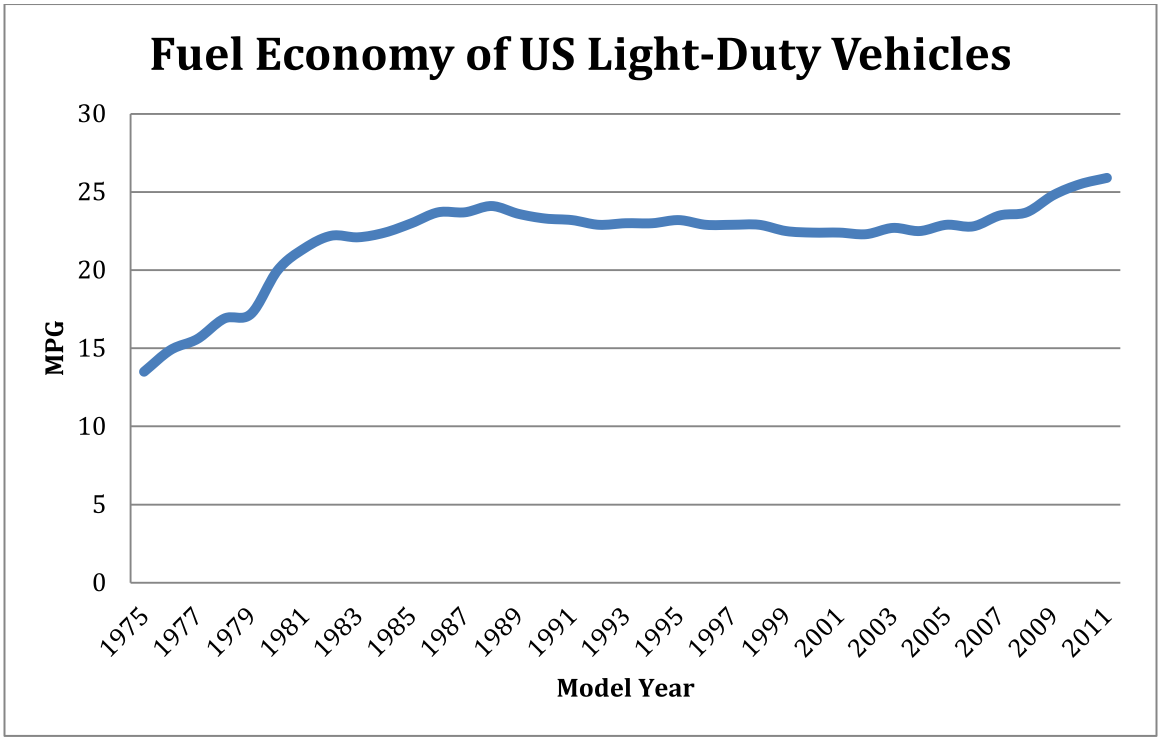

Figure 1. Long Term Fuel-Economy Trends

("Light-Duty Automotive Technology, Carbon Dioxide Emissions, and Fuel Economy Trends: 1975 Through 2011" Transportation and Climate Division. US Environmental Protection Agency.)

The historical trend was extrapolated to give a conservative idea of vehicle fuel efficiency in 2050. This increased efficiency corresponds to a reduction in emissions, as less fuel is required to complete identical trips. The emissions reductions were then adjusted to account for vehicle turnover rates.[9] The average campus fleet or commuting vehicle is not the latest and most efficient model, so the efficiency and emissions numbers were pushed back to reflect the average age of vehicles in the fleet. The emissions reductions estimated by projecting fuel efficiency were then compared against legislative goals and manufacturer statements to ensure their viability.

Mitigation Projects

In contrast to industry changes that require no direct action by the university, there are a number of specific mitigation projects that the campus can focus on to reduce vehicle transportation emissions. These projects were originally proposed in the UC Berkeley Parking and Transportation Demand Management Master Plan, and intended to meet the future parking demand on campus. Calculating the emissions reductions associated with these projects may provide further incentive to complete the tasks.

The first step the University could take to reduce vehicle emissions is the further improvement of bicycle and pedestrian infrastructure to encourage these modes of transportation. With comfortable bike lanes and safe storage, survey respondents indicated they would be more likely to move towards biking as their primary mode of transportation. The parking plan recommends building 75 secure bike parking spaces at a cost of $61,500.[6] Based on the midpoint value from national transportation research literature on parking demand elasticity, the corresponding reduction in drivers was calculated.[10] Using the peak number of campus drivers, the percentage reduction in commute emissions was found.[6]

The campus could also look at enhanced car share programs to reduce vehicle emissions. Since survey respondents indicated that having a car for mid-day trips is a significant reason they drive to work, the availability of car share vehicles for this purpose would increase the use of public transportation and carpooling for the primary journey to campus. Two car share companies, Zipcar and City Carshare, currently have locations nearby campus, and offer minor discounts to UC Berkeley students, faculty, and staff. However, both companies still require membership fees to join initially, and neither has a hub on the main campus itself. UC Riverside negotiated with Zipcar, allowing car share vehicles to be parked on campus in exchange for waiving membership fees for campus affiliates.[11] Implementing a similar program would increase the visibility and convenience of the program by adding locations on campus, while simultaneously removing the main barrier to entry. People would be able to try the program without as upfront cost to decide if it is feasible for them, ultimately leading to a reduction in drive alone rates and therefore vehicle emissions.

Increasing the cost of parking permits would also reduce emissions. As the price of driving to campus increases more people will reconsider their mode choice, especially with simultaneous projects increasing the viability of the alternatives. The parking plan recommends the price increases shown below in Table 1.

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Price Increase	0%	6%	6%	6%	6%	6%	6%	6%	6%	5%	0%
Commuter Students	$82	$87	$92	$97	$102	$108	$114	$121	$128	$134	$134
Resident Students	$98	$104	$109	$116	$122	$129	$137	$144	$153	$160	$160
Faculty/Staff "C Permit"	$124	$131	$139	$146	$155	$164	$173	$183	$193	$203	$203
Faculty/Staff "F Permit"	$90	$95	$101	$106	$112	$119	$126	$133	$140	$147	$147

Table 1. Recommend Parking Permit Increases to 2020

("Parking and Transportation Demand Management Master Plan." University of California, Berkeley. February 2011.)

Again using the national midpoint value for elasticity of parking demand, the reduction in driving rates based on these price increases can be calculated, as well as the associated emissions reductions.

Parking permits could also be used to reduce emissions by establishing a daily use fee. Instead of charging a monthly or annual rate for a parking pass, the University could charge a daily fee. A commuter would be given a smart card to swipe whenever they drove to campus and parked. If they drove every day, the price would be the same as that of a monthly pass. However, they would not be charged to park on days they did not drive. This would allow commuters to evaluate their mode choices on a daily basis, removing the sunk cost of a long-term pass. People could choose to bike or ride the bus to campus whenever possible, with the option of driving still available when needed. The University of Milwaukee recently implemented a similar program beginning as an opt-in pilot program that was later expanded campus-wide.[12] Emissions reductions corresponding to a daily use fee were based on the estimated number of parking spaces saved within the parking plan, as well as the peak use of parking spaces on campus.[5]

Perhaps the most effective way to reduce vehicle emissions would be to expand transit programs. The Class Pass program was first implemented in 1998, and helped almost double student use of public transit from 14% in 1997 to 27% in 2008.[3] Students pay a mandatory fee towards this program, but it is generally considered to be free. Faculty and staff currently have the Bear Pass program, which is subsidized but not free. Enrollment in the program was high when it was widely publicized upon launch, but has fallen off in subsequent years without continued marketing. Fully subsidizing the Bear Pass program to make it free, and expanding both Class Pass and Bear Pass to include BART in addition to AC Transit, would result in a significant increase in public transportation use.

Universal transit programs have been widely shown to reduce driving rates. Table 2 below shows the success of such programs at other universities.

	Drive			Public Transit		
School	Before	After	Change	Before	After	Change
UCLA (Faculty/Staff)	46%	42%	-4%	8%	13%	5%
Univ. of Washington, Seattle	33%	24%	-9%	21%	36%	15%
Univ. of British Columbia	68%	57%	-11%	26%	38%	12%
Univ. of Wisconsin, Milwaukee	54%	41%	-13%	12%	26%	14%
Univ. Colorado, Boulder	43%	33%	-10%	4%	7%	3%

Table 2. Effects of Universal Transit Pass Introduction at Universities

("Parking and Transportation Demand Management Master Plan." University of California, Berkeley. February 2011.)

The program implemented at UCLA most closely mirrors the potential changes to be made at Berkeley. The UCLA program was solely for faculty and staff, and UCLA is similar to Berkeley in both size and geographical location. Assuming a universal transit program at Berkeley would have effects similar to the UCLA program, and assuming that the new public transit riders would be split evenly among the Berkeley population rather than focused specifically on one mode such as walkers or drivers, the emissions savings from a universal transit program can be calculated.

Results and Discussion

Industry

After incorporating legislation and public policy, technological improvements, long-term efficiency trends, and turnover rates, the estimated future emissions reductions due to changes in the vehicle transportation industry are shown below in Figure 2.

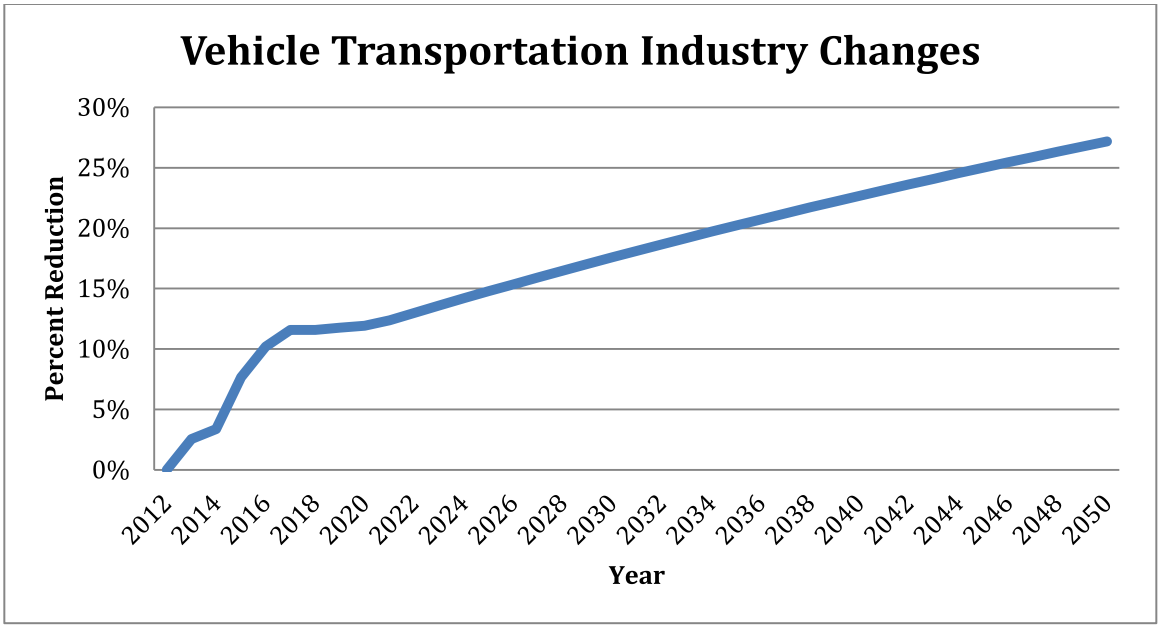

Figure 2. Vehicle Transportation Emissions Reductions Due to Industry Changes

The industry emissions reductions are estimated to be 12% below 2012 levels by 2020, and almost 30% by 2050. These numbers were calculated to be conservative. They are below the California goal of reaching a 30% reduction in 2000 emissions by 2016, and also below the national fuel efficiency goal of reaching 54.5 mpg by 2025.[13] They are also below the stated expectations of various automobile manufacturers. A conservative estimate in industry reductions allows the university's emissions plan to remain independent of the need to fully meet ambitious goals set in a political environment. If the industry falls short of the desired standards, emissions should still meet these estimations and allow the campus reduction plan to remain on track.

Mitigation Projects

The emissions reductions associated with each of the mitigation projects described above are shown below in Table 3. The cost associated with each of these projects comes from Parking and Transportation Demand Management Master Plan.[5]

Item	Cost	2020 Reduction	2050 Reduction
Bicycle and Pedestrian Programs	$61,500	0.5%	0.7%
Enhance Car Share	$50,000	0.5%	0.7%
Establish Daily Use Fee	-	1.8%	2.7%
Differential Pricing	$122,000	3.6%	5.4%
Expand Transit Programs	$527,000	4.7%	7.1%
Total	$760,500	11.0%	16.5%

Table 3. Vehicle Transportation Emissions Reductions Due to Mitigation Projects

The universal transit programs and changes in permit pricing have the greatest effect on emissions, with the bicycle, pedestrian, and car share programs contributing a smaller amount. As with the industry reductions, these numbers are relatively conservative to ensure that they will be realized if the projects are undertaken. For example, in order to match the parking plan project, the bicycle and pedestrian programs line item is based on adding only 75 new parking spaces. An increase in the number of spaces added would result in an increase in reductions, although diminishing returns would make the relationship logarithmic. The transit programs item is also conservative, as it is based on the results of a similar program at UCLA. Although the UCLA program was the best match for Berkeley in terms of size, location, and transit program, the public transportation system in Los Angeles is generally viewed to be worse than the Bay Area system. Since other schools saw up to three times more migration to public transportation than UCLA, there is a chance that a universal transit program at Berkeley would more successful than at UCLA. Once again, the assumptions used were conservative to ensure the realization of the emissions reductions.

Combining the reductions from the industry changes with those from the mitigation projects gives total reductions shown in Figure 3.

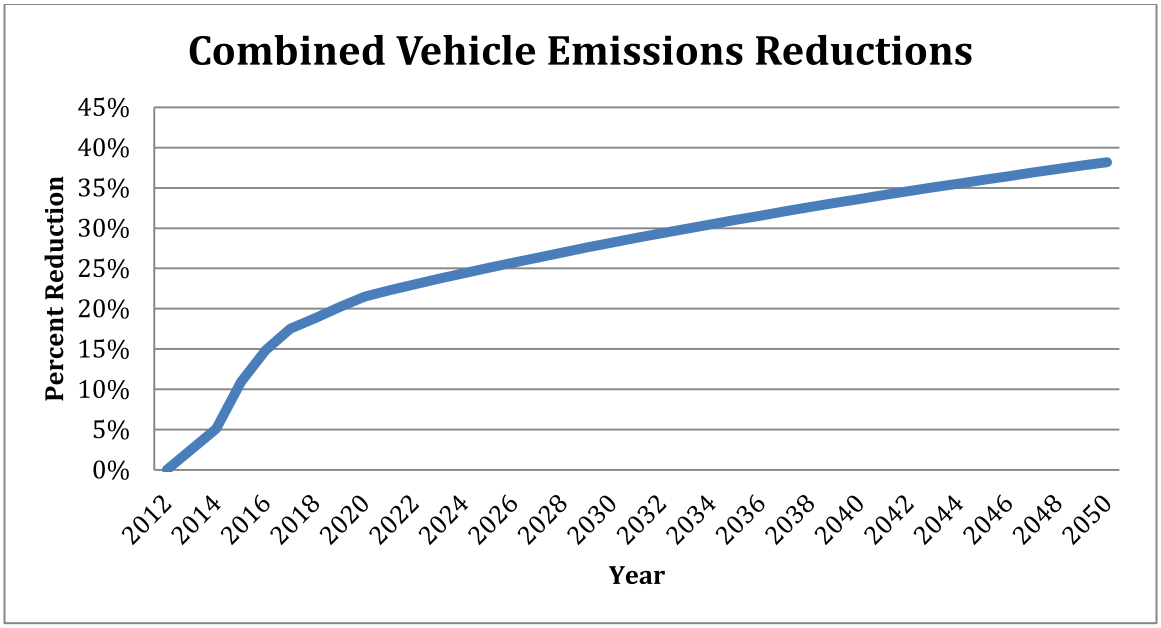

Figure 3. Combined Vehicle Transportation Emissions Reductions

The combined reductions amount to a 22% decrease in emissions by 2020 and a 38% decrease by 2050. Note that this does not match a simple summation of the industry changes and mitigation projects, but rather a combined percentage reduction.

Uncertainty Assessment

The main pieces of data used to quantify vehicle transportation emissions and reductions were reliable, with the main uncertainty coming in the industry reductions. The fleet emissions data is highly accurate and reliable as it comes directly from fuel purchase data for each vehicle. The commute data is slightly less ideal, as it comes from a representative survey sample. The sample size is large enough to accurately represent the population by statistical metrics, but assumptions about trip length and fuel efficiency become involved since emissions cannot be calculated directly from fuel purchase data. The parking demand data used in the mitigation project calculations is also good quality. The campus demand numbers came from a consulting study within the parking plan, and were confirmed against survey results provided by the City of Berkeley Transportation Division.

The main uncertainty in the calculations comes with the industry changes. The fuel efficiency trend data is reliable, as it is historically recorded by the EPA. However, the variation in numbers from source to source introduces error. To solve this issue, multiple sources were combined to make the projection instead of using a single source. The projections were also made from a conservative point of view. While this means the numbers may not fully capture the potential for industry emissions reductions, they will not overstate any efficiency or technological gains. Therefore, the numbers can be better relied upon for planning purposes, despite the uncertainty inherent in calculations with such long time scales.

Recommendations

UC Berkeley has made good progress to date in reducing vehicle transportation emissions. Driving rates are down and public transportation rates are up among students, faculty, and staff. The campus should plan to see these reductions continue as the transportation industry develops over time. Technology and efficiency improvements spurred by legislation and public demand will help reduce the environmental impact of travel, including greenhouse gas emissions.

In order to supplement the downward trend in emissions from industry changes, UC Berkeley should begin implementing the specific mitigation projects listed both in this report and in the Parking and Transportation Demand Management Master Plan. These projects will serve a dual purpose of meeting campus parking demand and reducing vehicle transportation emissions. The projects to implement a universal public transit system and revise parking permit pricing should be prioritized, as they provide the greatest reduction emissions.

III. BUSINESS AIR TRAVEL

Business air travel is currently responsible for 10% of the total greenhouse gas emissions of the campus; it is the 7th most global warming intensive activity of the campus community. It is a scope 3 activity but it is expected to become a larger part of the GHG emissions pie chart in the next decades, as buildings become more efficient and energy generation also reduces its carbon footprint. Current strategies aimed at mitigating the global warming impact of business air travel are behavioral incentives promoting direct flights over cheaper flights and videoconferencing.

Methodology

The approach to assess the GHG emissions of campus air travel to 2050 consists of relying on the 2050 predictions in the aviation industry made by the CONSAVE committee in 2005, calculating the predicted campus air travel demand and combining both to retrieve the predicted carbon footprint from campus business air travel.[14]

CONSAVE 2050 Predictions

The predictions delivered by the CONSAVE committee are consistent with the 1999 IPCC predictions for aviation as well as with a 2009 study from the Dalton Research Institute, Manchester Metropolitan industry.[15,16] The air travel industry is currently responsible for 3 to 5% of all anthropogenic greenhouse gas emissions. GHG emitted from airplanes are mainly CO_2 and H_2O and are emitted at high altitudes. Minor emissions include NOx, CO, soot, and unburned hydrocarbons.

Demand will likely increase through rising wealth in the developing world, whereas North America and Europe will show comparatively slow growth. Most predictions envision a 4 to 5% annual growth globally and anticipate that current air travel demand would more than quadruple by 2050. In comparison, UC Berkeley's current trend in business air travel calculated from 2005 to 2011 is 0.4% annually (in terms of average-length trips taken) extrapolated from population growth on campus.

The CONSAVE committee identified the main drivers for air travel demand as economy (GDP), population growth, technology, social trends, resources and energy patterns. The four scenarios envisioned are derived from the predictions made by the International Panel on Climate Change (IPCC) (four realistic scenarios, A1, A2, B1, B2, to assess future climate change) by translating their major assumptions into consequences on air travel. Unlimited skies (USK) is a high market-driven growth scenario, Regulatory push and pull (RPP) is a regulation-ruled high growth scenario, fractured world (FW) is a moderate and highly regional demand scenario due to international politics stress and Down to Earth (DtE) is a low demand, environmental consciousness driven scenario. The characteristics of those four scenarios are given in Table 4.

Scenario	Unlimited Skies	Regulatory Push & Pull	Fractured world	Down to Earth
Economy	High growth	High growth	Fragmented market	Low demand
Social trend	High mobility	High mobility	Regional mobility	Low mobility
Technology Turnover	Vigorous innovation	Radical shift	Slow development	Material efficiency
Technologies	Liquid hydrogen Supersonic travel Fuel efficiency	Liquid hydrogen Supersonic travel Fuel efficiency	Heterogeneous Cryoplane in Eurasia Resource constraints	Liquid hydrogen NOx reductions

Table 4. Characteristics of the CONSAVE four future industry-wide aviation scenarios

(Schmitt, R. B. (2005). CONSAVE 2050 Constrained scenarios on aviation and emissions.)

Technologies under development include increasing the engine pressure to insure complete combustion, designing lower cruise-altitude airplanes to operate outside of the tropopause or changing the fuel to liquid hydrogen, electricity, or biofuels.[17] However, technology transition will be slow because of the high lifetime of aircrafts, heavy infrastructure development around airports, and high-safety certification constraints associated with them. Aircrafts are also assumed to grow larger over time. Typically, a design and certification phase lasts 10 years and airplanes have 30 year service lives, making a full implementation possible within a 40 year minimum.[18] Therefore, the technologies envisioned by the CONSAVE Committee as implementable by 2050 are liquid hydrogen, fuel efficiency, and NOx emissions reductions. The four scenarios implement those technologies, at different rates and scales. In the Fractured world scenario, for instance, technological development would be very uneven and the Middle East will rely heavily on kerosene.

Using the AERO model, the total annual demand was calculated per passenger kilometer and the associated CO_2 and NOx emissions as well, with respect to new technologies.[14]

	Air travel (Billlion pax-km) **2020**	**Air travel** (Billion pax-km) **2050**	**CO_2 emissions** (Billion kg) **2020**	**CO_2 emissions** (Billion kg) **2050**
ULS	6505	21185	907	2442
RPP	5284	14636	749	1654
FW	4157	6990	623	955
DtE	3920	4164	625	719

Table 5. Worldwide Air Travel Distance and CO_2 Emissions Predicted by AERO Model

(Schmitt, R. B. (2005). CONSAVE 2050 Constrained scenarios on aviation and emissions.)

UC Berkeley Air Travel Demand Growth

The University currently records all business air trips which were reimbursed. A study on this data was able to separate business trips from athletic travel.[19] The Sustainability office also assumed that 10% of campus business air trips did not ask for reimbursement so they corrected the campus air travel inventory by this amount. Based on California population growth trends, air travel demand on campus should rise by 0.4% annually in terms of average-length trips taken.

To determine the business-as-usual demand in business air travel from the University, the annual increase was calculated in terms of kilometers travelled. Even though a unit metric for air travel is a trip, the annual trips taken have variable lengths. The Office of Sustainability was able to divide them into three categories (short, medium, and long haul) but a km basis is more precise to quantify an annual growth of the order of less than a percent. The underlying assumption for this calculation is that the distribution of trips lengths (fractions of short flights, medium flights and long flights) will remain the same over time.

Videoconferencing

A high-quality, reliable videoconferencing service is financed by the University and consists of three videoconferencing rooms in Dwinelle Hall. A technician performs a test prior to each meeting to make sure the service is operational. This service is offered for the whole UC Berkeley community and is becoming popular for a variety of applications including guest lectures, job interviews, distance learning, and distant collaboration.

Assuming that 60% of all business trips are indispensable and need to be taken in order to meet in person, the strongest mitigation strategy the campus is likely to implement is to encourage faculty and staff to replace as much as 40% of average business trips by videoconferencing by 2050. Obviously, athletics air travel cannot be replaced by videoconferencing but they account for only 10% of the campus's trips taken in 2008. Moreover, faculty air travel is generally longer-distance whereas athletic air travels were mostly domestic with an average travel length of roughly 1400 miles.[19] Thus, the fraction of air travel due to athletics is even shorter in terms of km travelled, approximately 3%. So, if videoconferencing were to take up to 40% of campus air travel in terms of km travelled, a mitigation strategy targeting mainly faculty and staff travel, it would correspond to drastically eliminating unnecessarily long trips, such as guest lectures and seminars, and replacing them by videoconferencing. This assumption would mean that 40% of business air travel is superfluous, which is quite an aggressive emissions reduction measure. The implementation of an enlarged videoconferencing service along with behavioral switch to videoconferencing over in-person meeting is assumed to be linear to 2020 to reach a 20% reduction in average-length trips taken as a first-step and then to be linear to 2050 to reach an overall 40% reduction to 2050 as compared to 2011 air travel demand levels. The first portion of reduction is assumed to go faster than the second one because a fraction of superfluous trips is easy to identify and replace at first but larger reductions are more difficult to achieve.

Even though growth in demand for videoconferencing would require substantial additional installation of computers, screens and other appliances as well as more rooms attributed to that purpose, it was assumed that making a life-cycle impact assessment of the videoconferencing service is not necessary since the global warming potential of implementing operating, maintaining or retrofitting this service is negligible as compared to air travel GHG emissions savings.

Results

The demand growth for air travel from the campus population in km would remain constant to 2020 and increase by 18% to 2050 in the business-as-usual scenario, based on extrapolation of projections in population growth in California to air travel demand in the next forty years.

The worldwide predictions computed by CONSAVE 2050 anticipate 5 trillion passenger-km travel worldwide in 2020 and 12 trillion km in 2050, associated with total emissions of 730 million metric tons CO_2 in 2020 and 1440 million metric tons in 2050. The carbon footprint of air travel globally would decrease by 18% between 2020 and 2050 due to technological turnover.

The global warming potential associated with campus air travel would rise by remain constant to 2020 and increase by 18% in 2050 above 2011 air travel emissions in the business as usual scenario. 29,158 trips were taken in 2011 and air-travel related emissions were 20,000 metric tons CO_2 in 2011. In the best-case scenario, assuming substantial behavioral change towards videoconferencing use will already be under way by 2020 and that videoconferencing equipment can keep up with demand, industry changes and videoconferencing would make CO_2 emissions decrease by 23% in 2050 as compared to 2011 levels.

	# of trips 2020	**# of trips 2050**	**CO_2 emissions 2020**	**CO_2 emissions 2050**	**GWP increase 2020**	**GWP increase 2050**
BAU	28,900/yr	34,300 /yr	20,000 tons	16,000 tons	0%	18%
BCS	23,100 /yr	20,500 /yr	20,000 tons	24,000 tons	0%	-23%

Table 6. Campus Air Travel Demand and CO_2 Emissions Projections 2020, 2050

NOx emissions from air travel are also contributing to climate change and are referenced in the environmental literature as indirectly global warming potent. NOx are suspected to be a precursor to greenhouse gases, but the atmospheric chemistry of in-flight NOx emissions in the upper troposphere is not well understood. Several studies were conducted to show this indirect effect but they introduced very different radiative forcing coefficients to quantify it. Direct NOx emissions associated with UC Berkeley's air travel, in the upper troposphere, lower stratosphere could represent 46 metric tons in 2050 in the best-case scenario and 76 metric tons in the business as usual scenario. Since there was no consensus on the radiative forcing figures, NOx emissions were not included in terms of global warming potential, that is, in CO_2e.

Campus data for air travel demand and videoconferencing equipment are accurate and precise. The major source of uncertainty in the data collected is the choice of the most probable future path the aviation industry will follow and the indirect effect of NOx emissions from aircrafts, on global warming.

Recommendations

An interesting recommendation would be to set a 20% reduction in trips taken for replacement by videoconferencing to 2020 followed by another 20% reduction to 2050. An intermediate goal would be to target a 35% decrease in average trips taken to 2035. To encourage such behavioral change, the campus should communicate more broadly on the availability and quality of its videoconferencing service in particularly for each plane ticket reimbursement request. If this strategy proves to be efficient, the campus will need to enlarge its videoconferencing capacity. The campus should continue to calculate its air travel emissions on an annual basis. The campus could also check regularly if emissions associated with air travel follow one of the four scenarios forecast by the CONSAVE model to validate the accuracy of these data. It is also important to highlight that NOx emissions from air travel have not been assessed so far in terms of global warming potential but it should be reported in the campus emissions as an air pollutant.

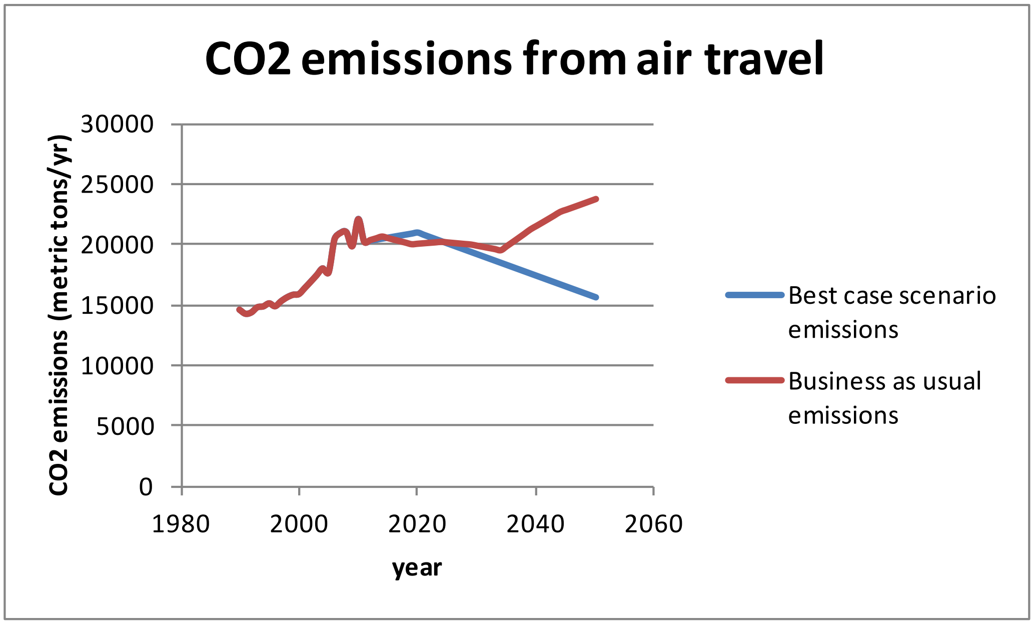

Figure 4. CO_2 Emissions Projections Associated with UC Berkeley Business Air Travel

IV. WATER USE

UC Berkeley's water distribution comes from the Mokelumne River through 90 miles of aqueducts and pipes owned by the East Bay Municipal Utility District.[20] Water use represents 1% of campus GHG emissions; it is a scope 3 contributor like transportation, air travel and waste. It has the same carbon footprint as waste on campus but water savings are crucial because of the constrained water supply in California. In 2011, the main campus used 600 million gallons of water, associated with a GWP of 769 metric tons of CO_2 equivalents. The distribution of water use on campus is shown below:

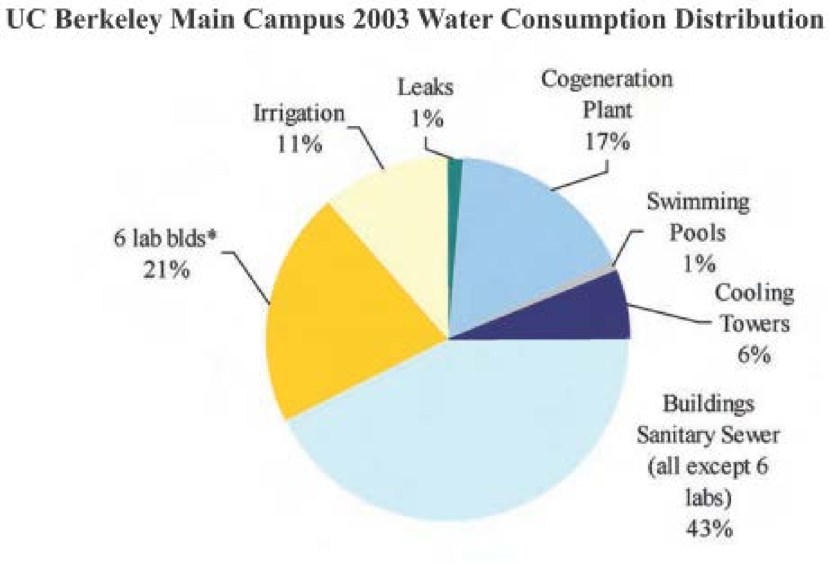

Figure 5. 2003 Campus Water Consumption Distribution

(Berkeley, U. "A sustainable water plan for UCB, UC Berkeley water usage and conservation study report.")

Several studies have been conducted to report water consumption and assess the water conservation potential on campus.[22,23,24] These studies mainly focus on short term predictions using mature technologies or simple retrofits with short payback periods. Such retrofits include low-flow toilets, waterless urinals, low-flow faucets on campus buildings and residence halls. Water-efficient irrigation devices as well as behavioral incentives promoting shorter showers and voluntary leak detection and report are also considered.

In order to forecast water use in the long haul, for a forty year time span, an efficient strategy consists in systematically applying those simple retrofits (converting every toilet on campus to 1.6 gallon per flush and waterless urinals for instance) but also adding a rainwater harvest and water recycling component to relieve a portion of flushing water consumption.

Methodology

The approach used to estimate future water supply related emissions to 2050, consists of determining EBMUD's carbon footprint per gallon of water supplied using a LCA approach and the annual water savings of a selection of mitigation strategies. Carbon embodied in construction and maintenance is negligible except for rainwater and greywater systems because of the pumping and disinfection energy consumption.

EBMUD 2040 Predictions

EBMUD disclosed a Water Supply Management Plan to 2040 to present its future demand projections as well as means to reach them.[25] Increasing water demand is expected to result from land use and population growth mainly but also, to a lesser extent to climate changes such as temperature rise (more air conditioning use) and hydrology patterns (evaporation, early snowmelt). However, EBMUD also plans to rely on aggressive recycled water and conservation programs associated with 10% rationing in draught years. The water supply needed will be met through a mix of enlarged reservoirs, groundwater basins and desalination. Five portfolios are envisioned to help attain the 2040 goal; the average projected total water supply district-wide would be 260 million gallons per day as compared to 214 million gallons per day in 2005.

The operation of the district-wide water supply would then consume 136 GWh of electricity annually. The life-cycle carbon footprint generated by the additional water infrastructure and the total water supply operations in the district would be dominated by indirect emissions through energy consumption. Indeed the environmental report associated with this long-term plan concluded that the carbon footprint of the construction phase would be negligible on an annual basis because of the long life-time of the infrastructure built and because new regulations developed under the mandate of AB 32 will increase GHG efficiency of construction activity.[20] Worker trips for maintenance are also negligible compared to emissions associated with daily energy-intensive activities such as water conveyance, pre-treatment, extraction wells and desalination plants. The environmental impact of conservation measures was not included in this analysis. Thus electricity use accounts for 77% of the global warming potential of EBMUD, the rest is due to transportation and natural gas powered equipment. The global warming potential related to electricity is not the same as PG&E because EBMUD benefits from electricity supply on its own. The Pardee and Camanche dams generate 180 GWh/year and the Pardee reservoir is expected to generate 19 GWh/yr more by 2040. Wastewater sludge is also used to produce methane for combustion through waste-to-energy processes.[26] This converted to an average 136,000 metric tons of CO_2e annually. It was assumed that water supply in 2050 will have a similar GWP profile as 2040.

Results

UC Berkeley Water Demand

Relying on historical water use and campus population growth, the business as usual scenario is predicted to raise water use by approximately 0.8% annually, on a volume basis. To reduce its water use, the campus intends to achieve savings through drastic water conservation strategies using a series of best available technologies.[24] Technologies included are toilets retrofitting, leak management, rainwater harvest, low-flow showerheads, rainwater reuse, heat exchangers and irrigation retrofitting. Because those technologies are readily available and economically attractive, a linear implementation over time was considered. The baseline year used for water use is 2005 because two important reports with substantial water use data on campus were issued in 2005.[4,24]

Toilet Retrofitting

All new toilets manufactured after 1994 are required by the EPA to be water efficient (1.6 gallons per flush or 2.5 gallons per minute). It was assumed that all existing toilets on campus will be retrofitted by 2050 with 1.6 gallons per flush toilets. These toilets are also proven to leak less frequently than regular toilets and to require less maintenance. With regular leak checking, a large quantity of toilet water would be saved. There are presently approximately 1400 toilets on campus (male and female) and 630 urinals (33% of male restrooms and 45% of female restrooms on campus were audited). Assuming a similar growth in toilet water as in total water use (44% increase as compared to 2005), and assuming that the fraction of water used for flushing will remain the same, toilet flushing water will represent 22% of total main campus water use in 2050. This is 50% of all "building sanitary sewer" needs which encompasses all the restrooms, water fountains, cooking water and cleaning water in campus restaurants, reverse osmosis, and process and equipment cooling water that is not hooked up to the cooling towers. This also means that the profile of water-consuming activities will have little changes to 2050 and will grow proportionally. With respect to population growth, use of campus restrooms per day per person is: 3 toilets use for female students and 1 toilet use plus 2 urinals use for male students. All urinals would all be retrofitted to waterless urinals. Toilets retrofitting will represent 90 million gallons of water savings in 2050. To assess the carbon footprint of toilets retrofitting, construction and maintenance activities were considered to be dominated, on an annual basis, by the emissions associated with purifying and conveying the volume of water.

Rainwater Harvest

Berkeley has a Mediterranean climate with a typical precipitation average of 650mm/year. Campus halls are several-stories compact buildings so it is considered a compact urban environment. Based on capacity, the choice of references was based on volume of rainwater collected annually (size of the tank) and precipitation profile. The laboratory buildings on campus are particularly water-intensive because of their cooling systems, water processes and laboratory supplies sterilization. The six lab buildings on campus (Koshland, Cory, Life Science Annex, Latimer, Valley Life Science, McCone) account for 21% of campus total water use. Adding rainwater harvest on the rooftops of three of these lab buildings is evaluated in the following table (Cory, Valley Life Science and Life Science Annex) to relieve their water needs.

Building	**GSF**	**Roof area** (m^2)	**Annual rainwater** (m^3)	**# toilets**	**Fraction of total flushing water use**	**Annual flushing water need** (m^3)
Cory	206,054	3,800	2,500	29	2.2%	3,700
VLSB	418,707	7,600	4,900	43	3%	5,100
LSA	201,824	3,750	2,400	28	2.2%	3,700

Table 7. Annual Rainwater and Flushing Water Demand in Lab Buildings on Campus

The total rainwater harvest capacity for these three buildings would be 9,800m^3 or 2.6 million gallons, annually. In comparison, the annual flushing water need is 12,500m^3. Rainwater harvest could then take up 78% of flushing water needs and save 2.6 million gallons annually. A life-cycle standpoint requires an assessment of the GWP of such an installation. The best-fitted study in terms of precipitation profile and size is the Environment Agency's report.[27] The report considered rainwater harvest systems for a 60-year lifetime. The carbon footprint of the systems consists of embodied carbon (cradle-to-grave assessment and component replacement) and operational carbon (pumping, treatment, and control energy). This is compared to mains offset and foul water reduction (water supply and treatment savings, reduced foul water pumping). The result of this study quantifies the carbon footprint as 1kg CO_2e/m^3 harvested. So, 10 metric tons CO_2e annually must be added to the GWP of water use on campus due to this installation.

Residence Halls

The campus owns five units of residence halls around the campus. Assuming Units 1 to 3 would retrofit their toilets to 1.6 gallons per flush and their showers with low flow shower-heads (1.5 gallons per minute), probable water savings from these residence halls were quantified. These strategies were assumed to be accompanied by positive behavioral changes towards water conservation through reduced shower-time (8 minutes/student/day) and leak-reporting, leading to quicker repairs. Possibilities for greywater systems were considered: shower water reuse for flushing purposes, for these three units.

	# students	**Daily flushing water use** (gallons)	**Annual flushing water use** (Mg)	**Daily shower water use** (gallons)	**Annual flushing water use** (Mg)
Unit 1	946	7,700	2.3	11,300	3.4
Unit 2	969	7,900	2.4	11,600	3.5
Unit 3	920	7,500	2.3	11,000	3.3
Total	2,835	23,100	7	34,000	10

Table 8. Annual Shower Water Use and Flushing Water Demand in Residential Halls

The shower water quantities exceed flushing water needs so 100% of toilet water could be taken up by shower water reuse, resulting in 7 million gallons saved annually through the greywater system. Moreover, behavioral change, low-flow shower-heads and water-efficient toilets would save an additional 30 million gallons in 2050. The life-cycle analysis carried out by the Environment Agency assessed a comparable system in similar conditions using the same methodology as described for rainwater harvest systems: the carbon footprint associated is 1 kg CO_2e/m^3 reused and includes chemical and biological disinfection and processes.[27]

Heat Exchangers and Irrigation

A previous study made for the campus showed that replacing 10 leaking heat exchangers on campus would generate 10 million gallons of water savings annually.[23] The same study identified potential areas of improvement in irrigation equipment. Using more water-efficient sprinklers (rotary sprinklers, drip and micro irrigation) as well as better leak detection (through metering and frequent checks) could reduce the irrigation share of water use on campus. A 10% reduction in irrigation water would correspond to 8 million gallons saved annually.

Further possibilities not assessed in this report include greywater reuse for irrigation, converting irrigated lawns to dry meadows, investing in more efficient lab equipment, consolidating the cooling towers.

Campus data for water use, restroom equipment, heat exchangers and rooftop areas are 100% accurate. EBMUD's water management plan and environmental reports are detailed and quantitative, and geographically representative. The major source of uncertainty in the data collected is the life-cycle emissions ratio of rainwater and greywater systems because the study was not completely geographically similar to California.

Recommendations

The business-as-usual scenario anticipates a 20% rise between 2002 and 2020 which is in accordance with the projections of the Long Range Development Plan 2020 and a total increase of 44% between 2002 and 2050.[4] The 2050 business as usual water demand would then be 710 million gallons annually on the main campus and 280 million gallons annually for the residential halls. Combining the water savings of all the mitigation strategies previously quantified, water demand in the best-case scenario was calculated. On main campus, toilets retrofitting, rainwater harvest, heat exchangers and irrigation improvements reduce the projected water demand to 600 million gallons in 2050, 15% less than the business-as-usual scenario, in terms of volume of water supply. In the residential halls, toilet retrofitting, low flow showerheads, greywater systems and behavioral change in 3 units account for 35 million gallons of water savings, reducing the water demand to 245 million gallons in 2050, 13% less than the business as usual scenario.

Mitigation strategy	**Annual water savings** (Mg)
On main campus	
Toilets retrofits	90
Rainwater harvest	3
Heat exchangers replacement	10
Irrigation	8
On residential halls only	
Greywater reuse, bathrooms retrofits	35

Table 9. Mitigation Strategies and Associated Annual Water Savings

	Water demand 2020	Water demand 2050	GHG emissions 2020	GHG emissions 2050	GWP increase 2020	GWP increase 2050
BAU	570 MG	710 MG	800 tons CO_2 e	920 tons CO_2 e	5%	20%
BCS	530 MG	600 MG	770 tons CO_2 e	780 tons CO_2 e	0.3%	1%

Table 10. Campus Water Demand and GHG Emissions Projections 2020, 2050

Main campus water related GHG emissions were 769 metric tons $C0_2$e in 2011. In the Best-Case-Scenario, the emissions associated with water would mostly remain constant to 2050 instead of increasing by 20%. The projected total population on campus, including students, faculty and staff, is expected to be around 57,800 people. The campus water consumption per person would then be 28 gallons per day in the best case scenario: this number shows a possible stabilization of water use per person because historically, water demand increased from 26 to 29 gallons per person per day between 1999 and 2003. All the previously assessed mitigation strategies are mature and readily implementable and useful to achieve water use stabilization as campus population grows. These technologies are also expected to be more common and affordable in the near future so a consistent recommendation would be to start implementing them steadily and have more than half of them done by 2035. Toilets' retrofitting seems to be the more pressing issue due to substantial leak losses in the present situation and because of the large water savings potential. Considering greywater reuse for irrigation purposes is also a measure that has the potential to considerably reduce water demand on campus.

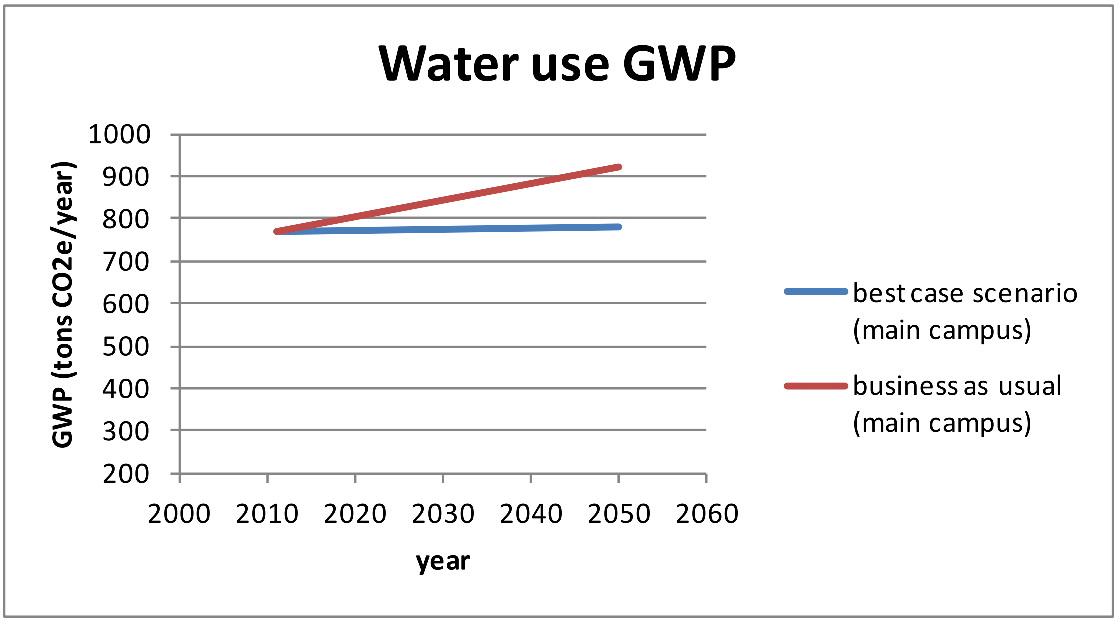

Figure 6. CO_2 Emissions Projections Associated with UC Berkeley Water Use

V. ENERGY EFFICIENCY

In 2011, purchased electricity accounted for 24% of the University's greenhouse gas emissions, making it the second largest source after purchased steam. In order to make targeted emissions reductions plans, the University must first develop a more in depth understanding of how and where electricity is used on campus. Such information may be used to identify high consumers, and evaluate reduction measures targeted at areas that will yield the greatest results. Once energy intensive technologies have been identified, projected changes in the efficiencies of those technologies may be incorporated into existing projections of campus growth to create a better understanding of how electricity will be used in the future, and how those changes can be changed through targeted energy efficiency programs.

Estimating Electricity Use by Space Type and End Use

Campus spaces are used for a wide variety of different purposes, ranging from study to research and athletics. Energy consumption and electricity end uses are different in every type of space, but may be extremely useful in identifying major consumers on campus and opportunities to improve energy efficiency in areas which will yield the greatest results. Table 11 shows the division of campus square footage into six different use categories both in terms of absolute square footage and as a fraction of total square footage.[28] The space categories examined in this study include classroom, laboratory, office, residential, unassigned and other. Residential spaces include all dormitories and other on and off site student and faculty housing facilities. Offices include personal and shared workspaces for faculty, staff, and graduate students, but are considered separate from laboratory support spaces which may be used in a similar manner by faculty and students. Laboratory spaces include research facilities, laboratory support spaces, and teaching laboratories. Unassigned space includes spaces that cannot be used for other purposes, such as hallways, stairwells, and thoroughfares. The energy needs of each space categories must be evaluated individually in order to gather an accurate estimate of the relative contributions of different end uses to total electricity consumption.

Space Type	Square Footage (million ft^2)	Percent of Total Square Footage (2012)	Percent of Total Square Footage (2050)
Laboratory	2.15	13%	25%
Office	2.35	14%	15%
Classroom	1.26	8%	8%
Residential	1.91	12%	13%
Unassigned	4.53	28%	31%
Other	4.04	25%	9%

Table 11. Current and Projected Distributions of Campus Area by Space Type

There is no campus specific data concerning electricity use in each different space type, with the exception of residential spaces. Most buildings are shared between multiple space uses, meaning no building consists of 100% classrooms, but rather divides space between classrooms, offices, laboratories, and unassigned space. For this reason, metered electricity use could not be used to evaluate the energy intensity of each different space type, for this reason national average consumption data drawn from the EIA's Buildings Energy Data Book were used to approximate energy consumption and the relative contribution of different electricity end uses in each type of space.[29]

Energy consumption per square foot is given in the Data Book for residential buildings as well as several types of commercial buildings including educational facilities and offices. The educational facilities described are for K-12, which are assumed to consist mainly of classrooms. Thus this figure was used to evaluate classroom energy use. Energy intensities for each building type are further subdivided into percent expenditure on lighting, cooling, ventilation and plug load among other minor contributors which have been classified for the purposes of this study as "other" end uses. In the case of residential facilities, total energy intensity was determined using existing campus data facilitated by the presence of nearly 100% residential buildings which are not shared among other space types.[30] Unassigned spaces are assumed to have similar lighting, cooling and ventilation requirements as classrooms, but with negligible demand on plug load.

Energy use in labs was calculated using the Department of Energy's Labs 21 Benchmarking Tool which enables laboratory facilities to create a record of their energy consumption and how it changes as greater attention is paid to energy efficiency.[31] Facilities with submetering abilities include additional data for lighting, ventilation, cooling and plug load consumption, although the number of fully metered buildings in the database is limited. Both total and end use specific electricity consumption varies considerably from one facility to the next depending primarily on the type of being research conducted. The Labs 21 tool divides lab facilities into categories including biological, chemical, physical, manufacturing, teaching, and combination/other to address these differences between the various types of facilities.

Laboratory buildings have been benchmarking their electricity use in the Labs21 Benchmarking tool since the year 2000. While the website records the time at which each facility was entered into the database, it does not include information about the age of the facility. The temporal relevance of the database to the question at hand may be assessed by considering the energy requirements of the facilities based on the year in which they were entered into the database. There are both high and low performers entered every year, and while some of the highest performing facilities have been entered in recent years, many low performing facilities have also been entered recently. It may therefore be concluded that both outdated and newly retrofitted buildings are continuing to be entered into the database. Because Berkeley has laboratory facilities of all ages and conducts research of all types, it is assumed that the average energy use in labs on campus corresponds to the average energy use of all buildings entered into the database for the warm-marine climate type corresponding to the Bay Area. Further study in this area might involve improved estimates of electricity use specific to Berkeley's lab facilities. Such a study could be conducted using submetering, or by analyzing energy use in specific buildings and comparing the percentage of square footage in that building which is designated lab space.

Electricity unaccounted for by the energy intensities of the five space types described above is allocated to the "other" space use category. Such electricity needs include network servers, computer labs, campus owned medical facilities, storage facilities, and other relatively minor space uses which may or may not have high energy use needs. This remainder accounts for about 23% of purchased electricity prior to implementation of the strategic energy plan.

The amount of energy used by each type of space compiled from each of the sources discussed above is summarized in Figure 7. The figure reveals substantial differences in the relative energy intensities of each space type. Laboratories, it may be observed, consume roughly six times more electricity per square foot than do residential facilities. The differences in energy intensity may be useful both in determining the campus average energy intensities of each use of electricity, in evaluating opportunities for reductions in electricity use, and for targeting reduction measures so as to maximize reductions in purchased electricity.

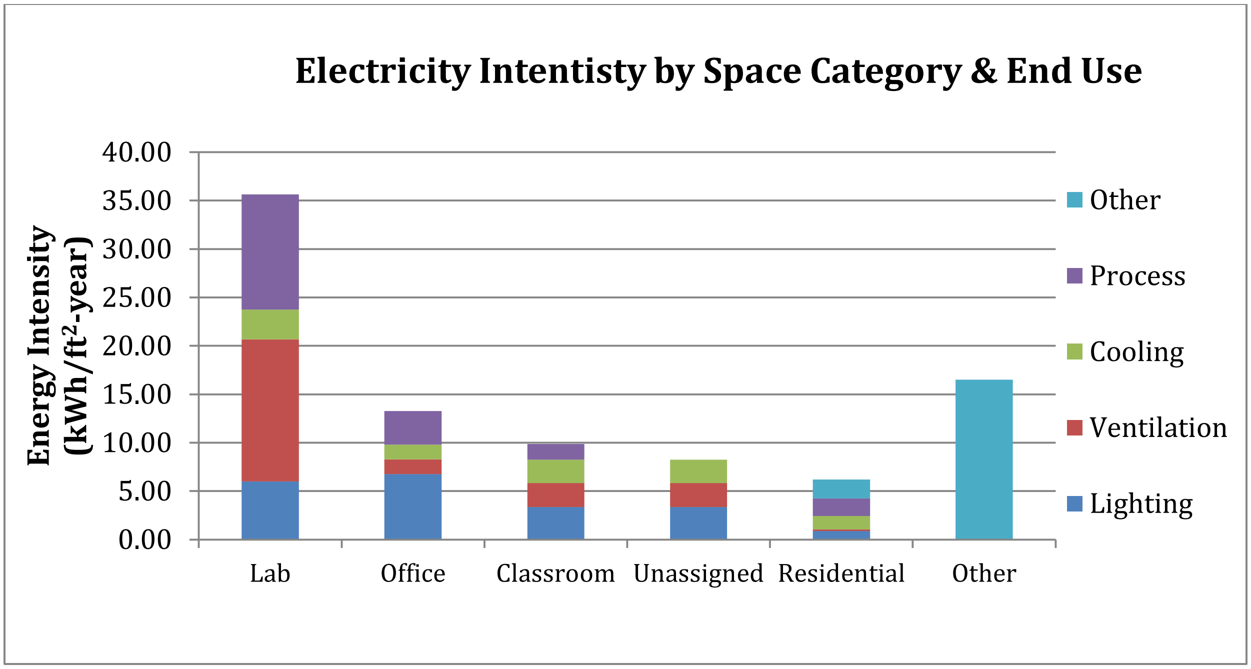

Figure 7. Electricity Intensity of Space Categories and Contributions by End Use

Results: Current Electricity Consumption by Space Type and End Use

The energy intensity and space use data discussed above may be analyzed to estimate current electricity use by multiplying electricity intensity per square foot, as given in Figure 7, by the square footage of the corresponding space type, as listed in Table 11. The resulting data may be presented either in terms of electricity consumption by space use, or in term of electricity consumption by end use. Both methods of presentation may be useful in identifying future mitigation projects.

The fraction of total purchased electricity consumed by each space type is summarized in Figure 8. Laboratories are by far the highest consumers, using an estimated 34% of total electricity, even though they make up only about 13% of total square footage. Unassigned spaces, on the other hand, make up nearly 30% of square footage but consume only 18% of total electricity. This discrepancy is due to the differences in the demand for each type of space. Laboratories require very high ventilation rates to maintain healthy indoor environment, while unassigned spaces have no such requirements. Similarly, laboratory equipment tends to have very high energy demand which may be required to operate around the clock, while unassigned spaces have negligible process load demand.

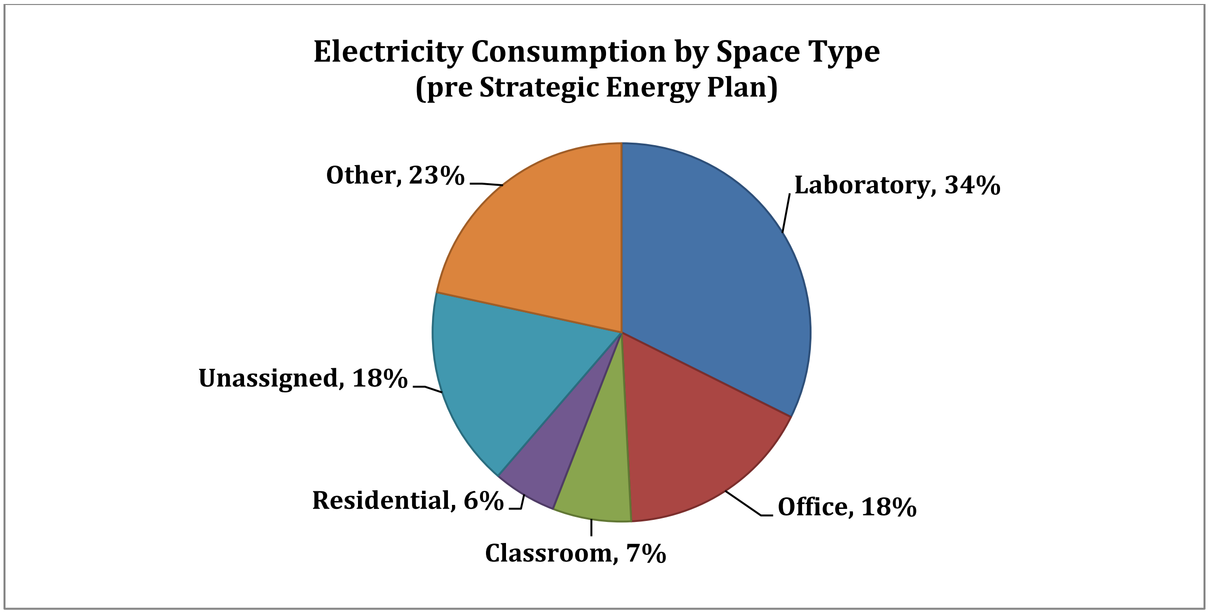

Figure 8. Estimated Percent of Total Electricity by Space Category Prior to Strategic Energy Plan

Figure 9 describes the fraction of total purchased electricity consumed by each end use. It is important to return here to the scope of the “other” end use category, which includes all electricity used in the “other” space category. Such spaces are certain to have lighting, cooling and ventilation requirements as with any other type of space, but no assumptions were made about the percent contribution of each end use because of the variety of space uses which fall into this category.

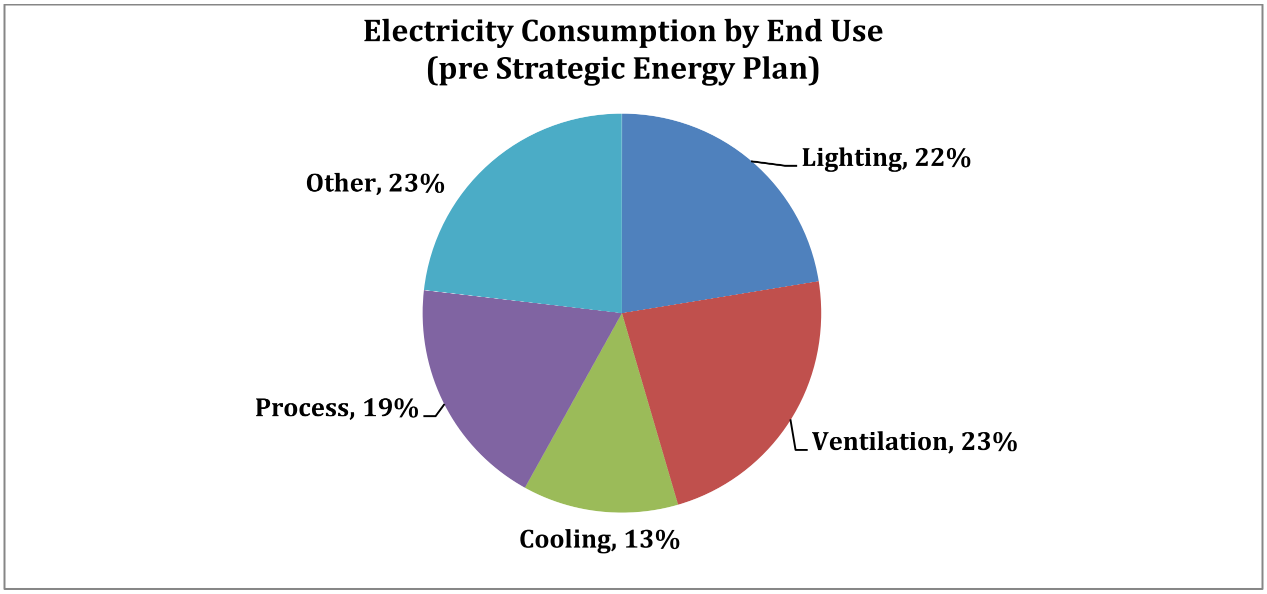

Figure 9. Estimated Distribution of Total Purchased Electricity by End Use

Projecting Growth by Space Type Category

In order to incorporate the energy use due to each space type into forecasts of future energy use, one must first evaluate the growth in square footage of each of the space categories being considered. Several assumptions may be made which correlate each space type to related variables for which historical and projected data are readily available. For example, the amount of classroom space may be assumed proportional to the number of students in enrollment. A correlation between the two allows projected enrollment estimates, as described in later in this report, to be used to project the growth of that space type relative to growth in total square footage. As with the present day estimate, any square footage predicted in the existing model but unaccounted for by growth in the five specific space categories is delegated to "other" uses. Assumptions made about growth in each space use category are described in detail below.

Laboratory square footage is taken to be proportional to the amount of available research funding. It is presumed that the cost requirements to maintain laboratory space are constant, evaluated at about $330 per square foot, and that any increase in available funding results in an increase in laboratory square footage. Historical trends show an overall increase in research funding from 1994 to 2013 over which period such data is available, as shown in figure 10.[32] It may be observed that growth is not uniform, but does show a relatively steady increase with time. Thus research funding is assumed to be linear with respect to time. This assumption was used to predict available funding out to 2050, and projects nearly $1.6 Billion in funding for that year. While this may be a generous growth model when evaluated in terms of economic growth, it is not unreasonable to assume that Berkeley will maintain its position as an outstanding research institution. Assuming no change in the cost per square foot of laboratory space, dedicated this space category is predicted to reach 25% of total campus square footage in 2050.

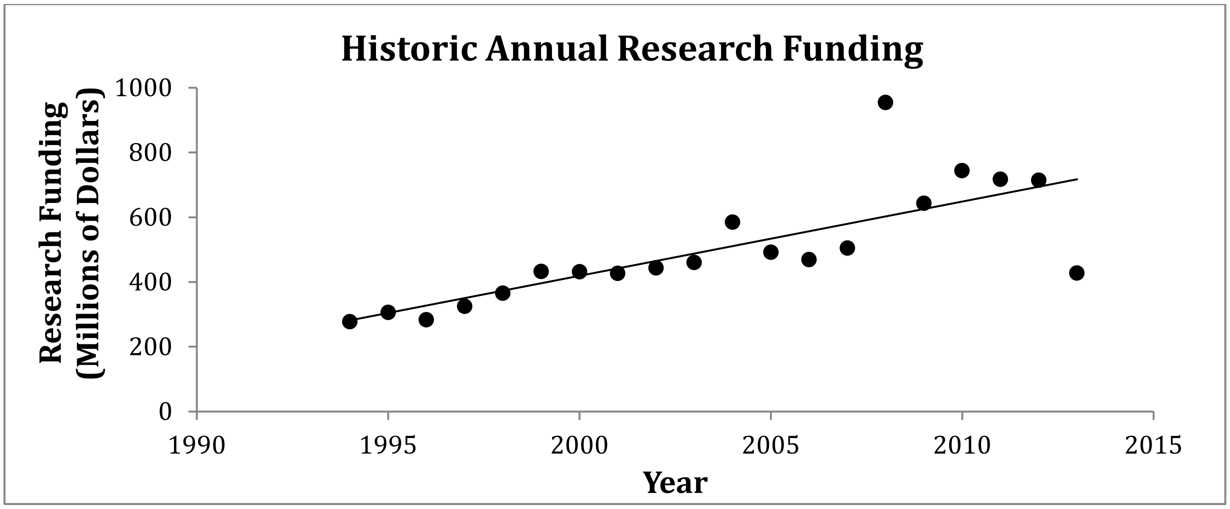

Figure 10. Historic Annual Research Funding with Projection Trendline

All remaining space types in this model are correlated to campus population. Residential and classroom spaces are taken to be proportional to enrollment, while office space is assumed proportional to the faculty and staff population. Unassigned space is assumed proportional to total square footage, which is in turn predicted from enrollment figures. Total area of “other” spaces is taken as the difference between the total projected area and the sum of the five space categories discussed above.

The projected distribution of space types in 2050 is summarized in the final column of Table 11. The changes in distribution of space between the six categories are negligible except in the cases of laboratory and other spaces. This discrepancy may be explained by the assumption that total square footage will increase at a rate proportional to enrollment which is embedded into the existing growth projections. Because laboratory space is the only variable not calculated using population data, this is the only space use category which sees a significant change in percent contribution to campus square footage. This increase is compensated for entirely by a large decrease in other square footage. It is likely, however, that the space uses which fall into the other category will grow as well, and that laboratory growth will increase the total square footage rather than drawing area away from other space uses. Historically, total space has grown more quickly than enrollment suggesting that other factors, such as research funding, may also play a role in campus growth.

One notable variable which is left out of the above model but is likely to play a role in energy efficiency is how the campus expands in area to accommodate increasing enrollment. Historic trends show that square footage has increased with campus population, indicating that the campus has accommodated growth through acquisition and construction of new buildings. One strategy currently under consideration for reducing electricity consumption includes more efficient use of existing square footage. Such a strategy might include using unassigned spaces for study purposes, or increasing the density of residential facilities. These are both trends which are emerging in new building construction, but which have had little momentum in reorganization of old buildings. Ultimately consideration of measures by which to improve the efficiency with which space is used will slow the increase in square footage relative to population growth, but in the absence of data, these factors cannot be incorporated into the projection model.

Projecting Energy Efficiency of End Use Technologies

In order to project electricity use as far into the future as 2050, improvements in energy efficiency of end use technologies must be factored into the model. Maintaining updated technologies poses a particular challenge to older universities like Berkeley, where most buildings were constructed before energy efficiency was a deciding factor in building design. In order to accurately predict electricity consumption, replacement of existing outdated technologies with new energy efficient equipment must be considered both as a factor in routine building maintenance, and as an opportunity for reducing electricity consumption. This section will first introduce existing plans to reduce energy consumption and how these are projected in impact electricity consumption, and then discuss models used to incorporate predicted improvements in equipment efficiency into projections beyond the scope of existing projects. Two scenarios will be considered, the first is an improved business as usual scenario, and the second includes an aggressive plan to reduce consumption through investment in energy efficient technologies.

The Strategic Energy Plan[30]

Berkeley is already in the process of implementing a plan to improve energy efficiency on campus. The Strategic Energy Plan (SEP) is designed to reduce electricity use through extensive projects involving deferred building maintenance, monitoring based commissioning and replacement of outdated equipment. This plan is part of a strategy for meeting 2014 emissions goals, and is expected to be fully implemented by 2020. A comprehensive report detailing the specifics of the SEP and the projected savings associated with each project to be implemented was released in 2008 by a third party consultant. Although the report is somewhat outdated and does not include any observed savings from projects already implemented, it is the most comprehensive analysis of the SEP and has therefore been used to project savings in each of the space use and electricity end use categories discussed above. The projections assume electricity savings relative to 2005 consumption, prior to which energy efficiency projects were not being implemented on a large scale.

The majority of SEP projects deal with general building maintenance, monitoring and renovation. Other projects include campus-wide installment of compact fluorescent light bulbs among other lighting projects, installation of high efficiency ventilation equipment both building-wide and in laboratories, high efficiency chillers, as well as Energy Star rated computer monitors in offices and refrigerators in laboratories. While some projects impact all of campus, others will result in reductions specific to a particular space type. Over two hundred projects are being implemented, resulting in a projected 5% reduction in electricity consumption after completion despite growth in square footage.

In order to evaluate electricity savings by both end use and space type, each of the SEP projects were categorized based on the scope of their impact. Lighting, ventilation and cooling projects were assumed to impact all space types equally, with the exception of laboratory specific fume hoods which improved efficiency of lab ventilation without affecting other space types. Monitoring based commissioning, deferred maintenance and renovation project savings were likewise distributed equally among all space types. Replacement of laboratory refrigerators were allocated specifically as savings in the laboratory process load category, and energy efficient computer monitors for faculty and staff were allocated to office process load savings. In this manner, all SEP projects were classified and incorporated to project electricity savings in each different category. The resulting reductions in energy intensity of each end use are shown on a per square foot basis in figure 11, while the impact on total campus electricity use is demonstrated in figure 12.

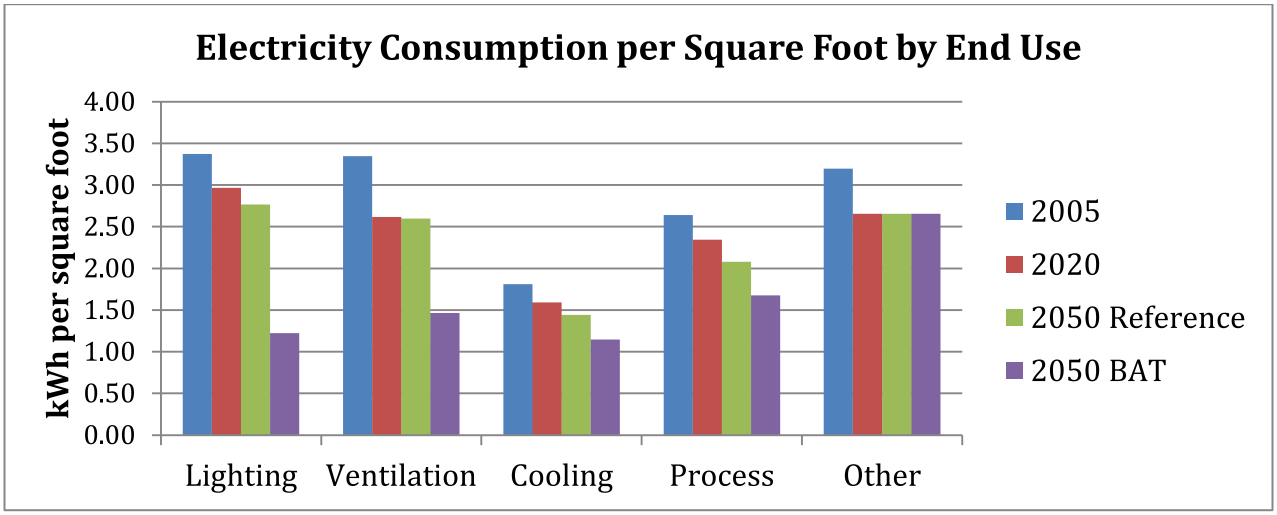

Figure 11. Historic and Projected Energy Intensities by End Use

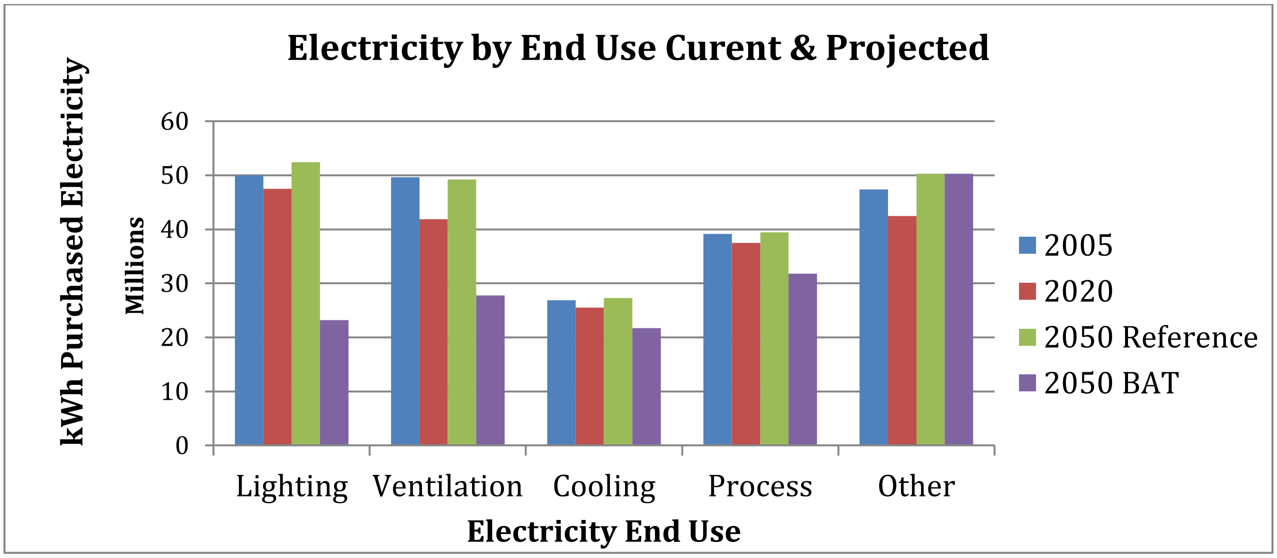

Figure 12. Historic and Projected Total Campus Electricity Consumption by End Use

The Strategic Energy Plan is not the only existing program to reduce energy use on campus.[33] Other initiatives include the campus Green Buildings Projects and a statewide Energy Efficiency Partnership both of which aim towards reducing electricity use. Both student and department led initiatives to reduce consumption through behavior change, as well as a Green Computing initiative are also being implemented. These projects should be incorporated to provide a more complete picture of energy savings on campus, but due to the lack of a comprehensive document detailing the projected energy savings associated with each of those projects, the projections compiled in this report focus exclusively on the SEP, as detailed in the 2008 report forecasting savings associated with those projects.

Projection Scenarios: 2020 and Beyond

While the SEP provides a window into the near future, and demonstrates the impact of replacing outdated equipment with contemporary technology, it does not give any insight into how the efficiency of those technologies will continue to change. In its Annual Energy Outlook, the EIA examines trends in energy and technology to project energy efficiency of high consumption end uses.[34] The 2012 report makes projections out to 2035, but for the sake of extending projections out to 2050, it is assumed that these technologies will see comparable improvements in efficiency on the same scale between 2035 and 2050.

The Annual Energy Outlook uses 40 different scenarios to predict national energy consumption which incorporate existing and future regulatory policies, energy prices, and consumer choices. Two scenarios were evaluated to project campus electricity use, the first is arguably a business as usual scenario which the EIA calls its "reference case", and the second involves an aggressive attempt to reduce consumption, which is described by the EIA as the "best available demand technology" scenario. The assumptions and efficiency projections associated with each scenario are described in detail below.

- *Business as Usual*

The business as usual projection scheme for electricity consumption is derived from the EIA's reference case, as described in depth in the Annual Energy Outlook 2012. This scenario assumes no changes in policy regarding energy use and supply, and no significant innovation in terms of end use or power generation technologies. This may be a conservative estimate due to California's role in pioneering new standards for energy efficiency. The model assumes slight decrease in electricity costs associated with increased production of domestic natural gas, which may contribute in some part to the stagnation of innovation in energy efficient technology.

The scenario assumes a 0.5% decrease in per capita electricity consumption between 2012 and 2035, as consistent with existing trends and projected electricity costs. Improvements in efficiency of some end use technologies are projected to result in fuel switching from petroleum to electricity as such a change becomes economically advantageous. Federal regulations of certain equipment, including freezers and refrigerators, are projected to decrease the energy intensity of process load in residential facilities and laboratories.

The reference case is a more accurate prediction of electricity use in the absence of mitigation projects than is the existing business as usual scenario. It assumes no consumption reduction strategies, but follows market trends which favor cost effective technologies. This projection scenario is an improvement to the existing business as usual projection because it incorporates inevitable improvements in industry technologies which will occur independent of additional University projects. If the University were to cease all electricity reduction measures after the SEP, it would likely follow an increase in energy consumption consistent with this projection scenario. The projected energy efficiencies of the reference case for different commercial end use technologies are listed in table 12. It may be observed that all technologies have some associated improvement in efficiency.

End Use Technology	Best Available Demand Technology	Reference
Lighting	157	17
Ventilation	112	2
Electric space heating	65	16
Refrigeration	60	38
Electric space cooling	52	21
Natural gas space heating	19	8
Natural gas water heating	10	4

Table 12. Projected Energy Efficiency of Commercial Technologies in 2035 Under Two Projection Scenarios.

Estimates given in units of percent change in efficiency relative to 2010 installed stock.

(Source EIA Annual Energy Outlook, 2012)

A separate set of assumptions were made to predict improvements in efficiency of technologies not discussed in the Annual Energy Outlook. Improvements in laboratory process load efficiency were assumed to follow a set of recommendations made by PG&E designed to reduce energy waste in labs.[36] Such measures were predicted to result in as much as a 44% reduction in the process load, but full implementation of these measures would be quite aggressive. The business as usual trajectory was therefore assumed to incorporate half of the suggested measures resulting in a 22% reduction in laboratory process load.

Due to uncertainty in how electricity is used in the “other” end use category, no assumptions are made about energy efficiency improvements in that area. The energy intensity is projected to remain constant from 2020 to 2050, which contributes significantly to projected growth in total electricity consumption. It is important to note that the University is likely to see efficiency improvements in this field as well; they have been excluded simply because they cannot easily be quantified without more information about the technologies involved.

All efficiency improvements were evaluated relative to energy use after completion of the SEP in 2020. In order to evaluate trends in energy use with, the transition to higher energy efficiency between 2020 and 2035 was assumed to follow a linear trend. It is also assumed that the energy demand per square foot remains constant. This means that any improvements in energy efficiency result in reductions of energy use per square foot. This assumption is consistent with the projection that growth in square footage is proportional to increases in enrollment, but does not incorporate the possibility of increasing population density through more efficient use of space. If the University were to follow such a growth pattern, the energy demand per square foot would likely increase.

In order to extend projections beyond 2035, an increase in energy efficiency was assumed to occur by 2050 which was equivalent to that seen in 2035 relative to 2020. The projected energy intensity of each end use is shown in figure 11 alongside the energy intensities for pre SEP, post SEP, and best available demand technology scenarios. The business as usual scenario shows a modest reduction in energy intensity, but when multiplied by the projected square footage in 2050 reveals a major increase in total electricity consumed for all end uses. This trend demonstrates that the modest reductions which result from this predicted market trends are insufficient to reduce electricity use, and that a mitigation plan following the SEP must be implemented if serious emissions cuts are to be made.

- *Best Case Scenario*

The best case consumption scenario, also drawn from the Annual Energy Outlook, is taken to be the EIA’s “Best Available Demand Technology” scenario, or the BAT projection scheme. This scenario is more specific to forecasting energy efficiency of equipment, and less targeted towards predicting national energy use trends and fuel consumption. The scenario assumes that maximum efficiency technologies are purchased regardless of cost. However, this assumption applies only to new equipment purchases and does not factor in premature upgrades or retrofitting. The projected energy efficiencies for some end use technologies are shown alongside the business as usual projections in table 2. In this scenario, a more aggressive strategy was adopted to address electricity use in labs, adopting in full PG&E’s laboratory process load waste reduction program resulting in 44% savings for that end use.[36]

The projected energy intensities associated with each space type for this projection scenario are shown in Figure 11 along with the other energy intensities discussed. This scenario has by far the lowest consumption per square foot. When scaled up to include the projected growth in total square footage, the best available technology scenario results in a net decrease in total electricity consumption relative to current consumption, as demonstrated by the consumption by end use projections detailed in figure 12.

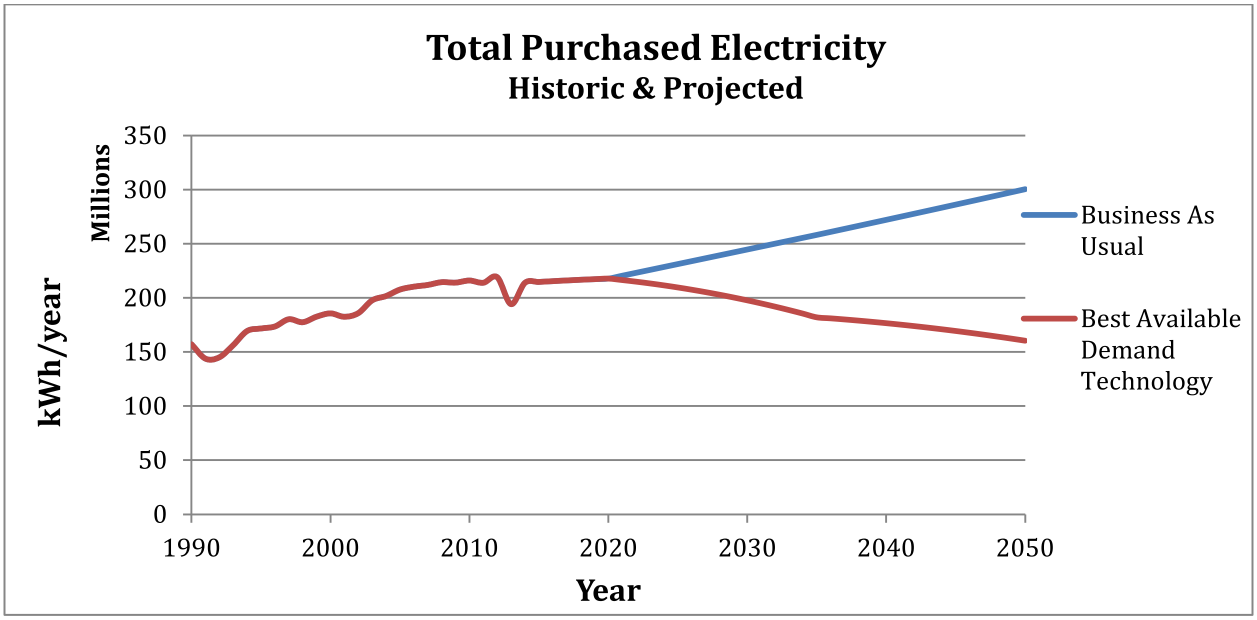

Figure 13: Projected Trends in Electricity Consumption Evaluated to 2050 Based on Two Technology Efficiency Scenarios

Figure 13 shows historic and projected total campus electricity consumption trends for both scenarios. From 2005 to 2020 the 5% reduction associated with the strategic energy plan can clearly be seen, followed by a split where mitigation projects cease in the business as usual scenario and escalate in the best available demand technology scenario. The second shows a constant decrease in consumption despite campus growth, resulting in 2050 electricity consumption figures comparable with 1990 consumption despite significant growth. The first scenario shows a steady increase in consumption despite moderate improvements in equipment efficiency, resulting in a doubling of electricity use relative to 1990 levels. The difference between the two paths represents a total of over 2 billion kWh saved between 2020 and 2050, corresponding to 455 $GtCO_2$ calculated using business as usual forecasted emissions factors for electricity, or $200 Million calculated using existing electricity cost estimates[3].

Recommendations

While the University has already begun to improve energy efficiency, the small reductions in total consumption achieved through the strategic energy plan are not sufficient to set the campus on an aggressive emissions reductions track. It is important to note that although investment in energy efficiency will reduce consumption, electricity needs of the University will remain high. The projected 1990 level electricity use in 2050 will represent a reduction in greenhouse gas emissions because PG&E's emissions factor is projected to decrease as more renewables enter the grid. If PG&E is able to reach its aggressive emissions target, electricity will be significantly less carbon intensive than it is today. However, historic trends suggest the PG&E will not meet its emissions goals, and that the University will need to play a role in decarbonizing its own electricity through generation and renewable credits. There are ample opportunities for investment in solar photovoltaics and solar thermal heating alternatives for new buildings, and investment in offsite big wind facilities may prove less expensive than purchasing electricity PG&E as a long term alternative.[36]

The potential for decarbonization also makes electricity an attractive alternative for fuel switching. Existing fuels used for heating on campus, namely steam and natural gas, have extremely high emissions with little promise for future reductions. Table 12 shows substantial improvements in commercial electric heating equipment in 2035, while natural gas heating shows only a moderate increase in efficiency. Unless the cogeneration plant undergoes substantial renovation, heating buildings with steam will continue to have high embedded emissions which may even increase as power plant maintenance projects continue to be deferred. Although ceasing to purchase steam will not actually reduce emissions, it will mean that the University does not need to count those emissions as part of the inventory. This switch will need to be considered if the University is going to strive towards achieving climate neutrality. Electricity should be considered as an alternative for heating buildings. One opportunity for further analysis would be to compare emissions associated with steam to the emissions embedded in the electricity, and calculate the difference in emissions required to heat buildings using electric heaters. The projected efficiency improvements of those technologies may also be used to inform a decision about when such a switch might become economically feasible.

Figure 12 may be used to identify opportunities for maximum electricity savings. The end uses which show the greatest difference between the two projected consumption values are lighting and ventilation. This means that these technologies provide the greatest opportunities for reductions in electricity use through installation of more efficient technologies that will emerge between now and 2035. While many ventilation projects have already been conducted under the SEP, only a small number of laboratory ventilation systems have been upgraded.[30] Ventilation of labs currently accounts for an estimated 13% of total purchased electricity, and is projected to account for as much as 10% after implementation of the SEP. In the BAU scenario, this figure is estimated to increase to account for as much as 25% of the total, while with mitigation strategies following the best available technology scenario it could be as low as 6%. This case study in laboratory ventilation provides a prime opportunity to address electricity consumption trends by improving efficiency of a single technology.

Other major opportunities lie in lighting technologies. Eventually the University will need to consider upgrading to LED bulbs because their consumption is so much lower. Lighting also provides an opportunity to extend mitigation projects even below the projected best available technology scenario. The projections assume that lighting requirements do not change, but there are several technology options that would decrease demand for artificial lighting. One such example is daylighting, the process of increasing the amount of natural light available indoors. Daylighting retrofits are already a part of the SEP, but still hold substantial potential for expansion. Daylight harvesting is another option which would integrate light sensors into existing fixtures, activating artificial lights only in the absence of natural lighting. Other technologies to consider include occupancy sensors to eliminate lighting of empty spaces including offices, hallways and classrooms, and task lighting which would eliminate the need for high intensity overhead lighting, thereby reducing waste. All of these lighting technologies are currently being installed on campus with huge success. Moffitt, for example, was submonitored as part of a research study of a mesh grid lighting technology which found a 65% reduction in the electricity intensity associated with lighting for the building after installation of the new lighting system.[37]

Energy Efficiency Conclusions

A comprehensive strategy to reduce electricity consumption on campus will heed to include a portfolio of solutions. Reductions in electricity use will occur naturally as outdated inefficient devices are replaced with newer more energy efficient technologies, but a do-nothing approach will not suffice in reducing electricity use in spite of campus growth. In order to make a meaningful reduction in emissions and set an ambitious new emissions goal, the University will need to take measures which combine energy efficiency projects in all areas and decarbonization of electricity sources. Major cuts in electricity consumption may be achieved by installing energy saving technologies on a campus-wide scale. The SEP provided a good starting place and a precedent for such large scale reduction measures, but such measures will need to be scaled up substantially in order to yield the types of reductions that will enable Berkeley to set a precedent for leadership in energy efficiency within higher education.

VI. ELECTRICITY SUPPLY TO 2050

Another factor with the potential to significantly impact the University's greenhouse gas emissions is the carbon intensity of purchased electricity. As the University approaches its 2014 goal, it becomes increasingly important to focus attention on future goals and projections. Since the carbon intensity of electricity is likely to undergo great changes over the coming decades, it is useful to investigate some of the expected trends as well as the impact of those trends on the University's emissions profile. Furthermore, the ability to generate long-term emissions projections will help to inform the next mitigation goal.

Background

Emissions scenarios out to 2020 have been well modeled by previous work, but there is much to be done beyond 2020.[1,38] Figure 14 below depicts four scenarios predicting the release of greenhouse gasses between 2011 and 2020 under business-as-usual conditions.

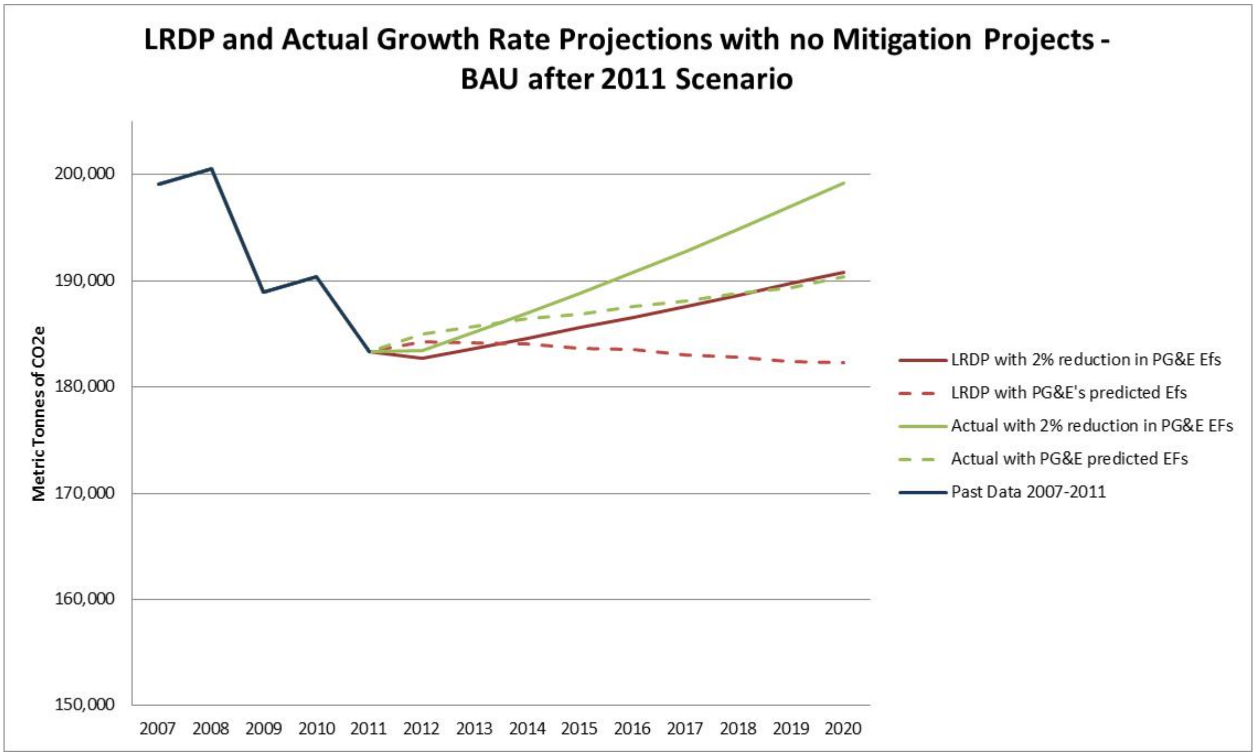

Figure 14. BAU Emissions Projections Based on Long Range Development Plan and Actual Growth Rate

(UC Berkeley Climate Action Partnership. "CalCAP Sub-Group Meeting #1." PowerPoint. 1 October 2012)

The above projections are based off of two basic models. The "LRDP" projections reflect University growth rates based off of the UC Berkeley 2020 Long Range Development Plan.

The LRDP reports expected growth factors in student population, faculty and staff population, and growth in square footage.[4] From the expected growth in population, predictions are made regarding campus emissions due to travel, water, and wastewater. Similarly, trends in building space are used to predict electricity and steam usage. In addition to the "LRDP" model, there is an "Actual Growth Rate" model. This projection was created by extrapolating known emissions data from past years. Both models have merits and shortcomings. One of the reasons why this additional model was considered is inconsistencies between the LRDP estimates, and current data. For example, the LRDP anticipated a student population of 33,450 in 2020. The 2011 student population of 35,450 already exceeds this value, suggesting that campus is growing faster than anticipated by the LRDP.

While the purpose of the AGR model is to account for some of the inconsistencies of the LRDP projection, it may have some shortcomings as well. The growth factors that were calculated for use in the AGR projection may be misrepresentative. For example, the growth factor for student population was calculated from the change in campus population from 1995 to 2011.[1] Only those two data points were used, as opposed to obtaining a least squares fit over all the data between those years. It is unclear why 1995 is chosen as the cutoff point when data exists as far back as 1990. A similar method is used to obtain other growth factors. Furthermore, the growth rates that are characteristic of the last decade are unlikely to remain into the future. Berkeley's 2020 Long Range Development Plan reports an uncharacteristically high population growth between the years of 1998 and 2010 in response to the California Master Plan for Higher Education. During those years, UC Berkeley underwent an expansion of 4,000 full time students, or a 13% increase relative to 1998. This represents "a significant increase for any campus."[4] Prior to this increase, populations were relatively stable and are expected to stabilize in the future. The growth factor used by the AGR projection, therefore likely represents a significantly higher growth rate than is probable in the future. Furthermore, the use of the phrase "actual growth rate" suggests a disproportionate level of certainty in the data. One of the necessary tasks in predicting emissions out to 2050 is to create a more realistic business-as-usual scenario. This is particularly challenging as the University has not yet released a development plan beyond 2020.

The other two trajectories on the graph are due to the carbon intensity of electricity provided by Pacific Gas and Electric. One pair of scenarios represents an emission factor reduction of 2% per year by PG&E. However, PG&E has estimated a more ambitious target of ~5% reduction in future emissions.[40] This corresponds to the other pair of scenarios. The extension of these industry trends out to 2050 will be discussed it detail later in the report.

Methodology

Improvements to BAU Scenario

As previously mentioned, one of the primary challenges in projecting emissions is the creation of a representative business-as-usual scenario. Much like the previous work, two business-as-usual scenarios were considered. Ultimately, one of them was selected for use in projecting emissions out to 2050. The first BAU scenario is very similar to the AGR model that was previously used. One exception is that the new scenario employs a least squares exponential fit of all known data, whereas the AGR uses a linear fit between just two data points, as pointed out in the preceding paragraphs. This exponential fit is then used to calculate an annual growth factor. Rather than calling this model "Actual Growth," it will be referred to as "Extrapolated." Ultimately, incorporating more data by using a least squares method had very little impact on the outcome. Both the AGR method and the Extrapolated method yielded similar results, with Extrapolated showing slightly higher emissions in 2050 than AGR.

The second BAU scenario that was considered is similar to the LRDP scenario. Although no development plan currently exists for the University beyond 2020, the University's development plans are based off of predicted growth in California's college-aged population. The period of aggressive campus growth from 1998 to 2010 coincided with a growth in the number of college-aged Californians. This growth is expected to stabilize, eventually beginning to decrease around 2014.[41] The table below reports California's college-aged population as predicted by the Demographic Research Unit of the California Department of Finance.

2015	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
4,041,234	3,915,953	3,953,465	3,909,640	3,817,688	4,144,113	4,418,381	4,587,395

Table 13. California's Predicted College-Aged Population (18-24yrs)

(Schwarm, Walter. "Interim Projections of Population for California: State and Counties." Demographic Research Unit. California Department of Finance. May 7, 2012. Downloaded from http://www.dof.ca.gov/research/demographic/reports/projections/interim/view.php)

Details regarding how these predictions are formed can be found at the above URL. College-aged population is assumed to be 18 to 24 years of age. The Demographic Research Unit reports data in 5-year increments. Linear interpolation is used to predict population in between these increments.

Figure 15 below depicts the predicted campus population based off of two different models.

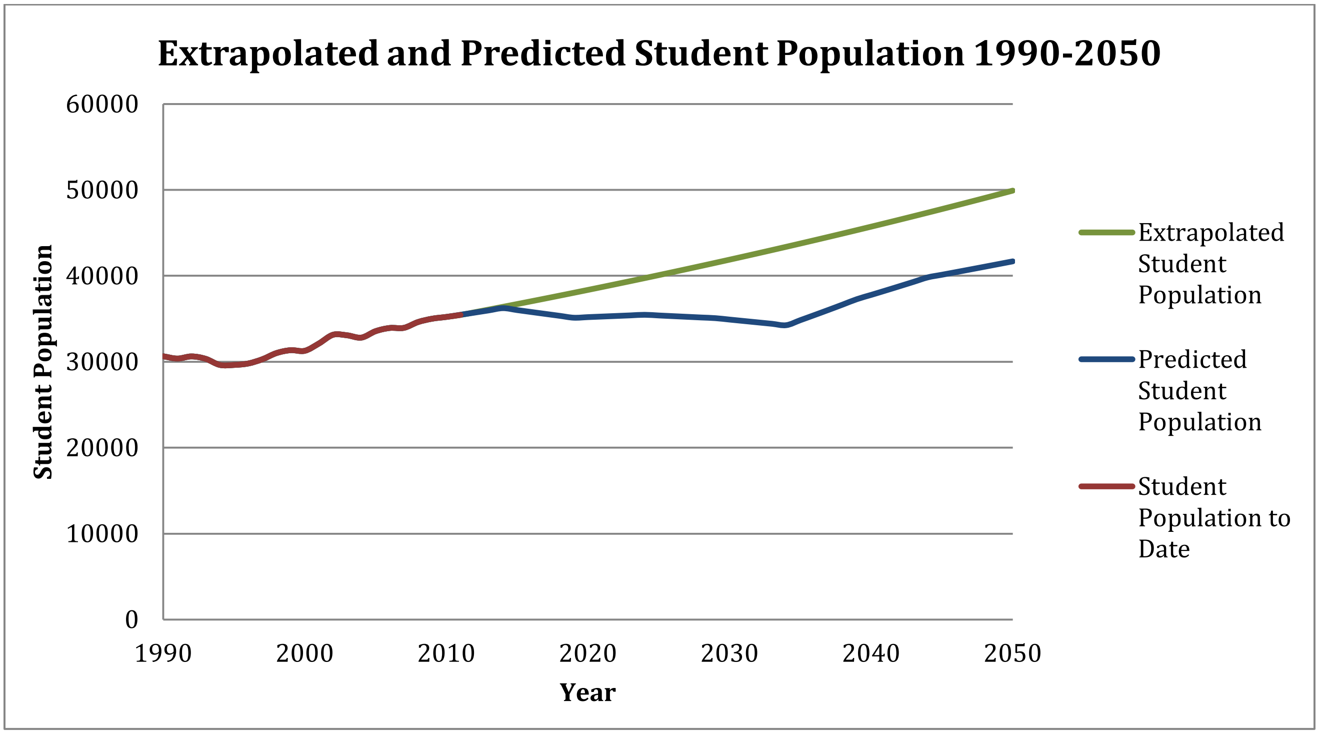

Figure 15. Student Population Models to 2050

As shown above, the model based off of the growth in college-aged population demonstrates a less aggressive rate of campus growth than the extrapolated model. This is due to two factors. First of all, the University recently went through an uncharacteristically rapid period of growth in response to a boom in California's college-aged population, skewing the extrapolated model. If the extrapolated model is to be believed, then the 2050 campus population would reach 50,000 students, roughly a 40% increase over today's population. This scenario is highly unlikely given the University's size constraints. Secondly, college-aged population is expected to stabilize in the coming decades, before returning to another period of strong growth around 2035.

Figure 16 below depicts the differences in BAU emissions between the extrapolated and the predicted models.

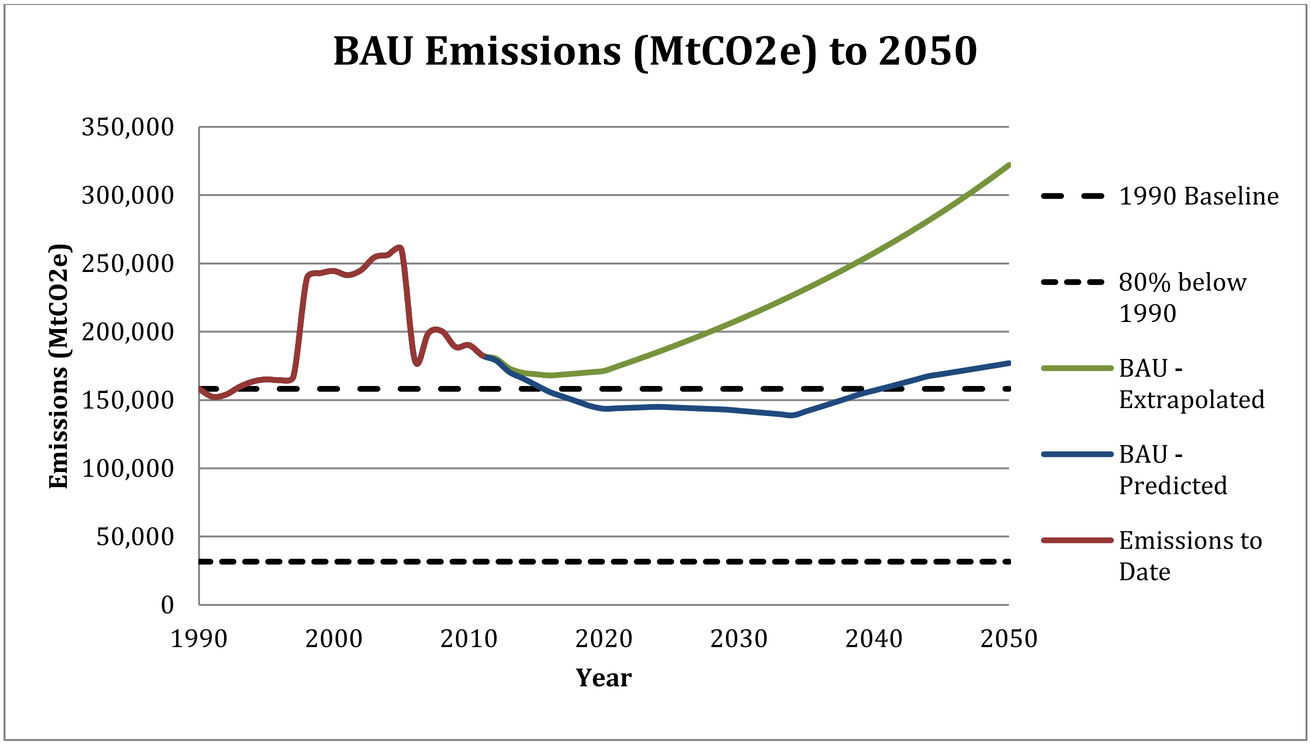

Figure 16. Business-As-Usual Projections Based on Extrapolated and Predicted Models

Both of these models include current mitigation projects that are either planned or in action. The mitigation projects are assumed to extend to 2020. Beyond this point, savings are conserved, but not expanded upon. Similar to the LRDP model discussed earlier, the Predicted model assumes that campus emissions are proportional to campus population.

Ultimately, it was concluded that the predicted BAU model is a more representative scenario than that of unconstrained exponential campus growth. This model is used as a baseline in future mitigation calculations. A discussion of the uncertainties of this model will be included later in the report.

Electricity Trends

In order to assess the likely changes in the electricity sector, California's long-term energy goals were considered. In 2005, Governor Schwarzenegger set a goal for the state of California to reduce greenhouse gas emissions to 80% below 1990 levels by 2050.[43] A 2009 report by Energy and Environmental Economics, Inc. investigated what would be necessary in order to achieve this goal. One of their conclusions was that the carbon intensity of California's electricity supply must be reduced to 0.02 $MtCO_2/MWh$ by 2050. Given that PG&E's 2011 emission factor for electricity was 0.207 $MtCO_2/MWh$, this would require a factor of 10 reduction. Two scenarios were considered: one that looks at campus emissions assuming that PG&E achieves the decarbonization goal set by E3, and a second one that assumes PG&E is only able to achieve half of the annual decarbonization required to reach the goal. The scenarios assume that PG&E reduces their emissions factor by a constant rate each year from now until 2050.

Results and Discussion

The results of the investigation are shown below in Figure 17.

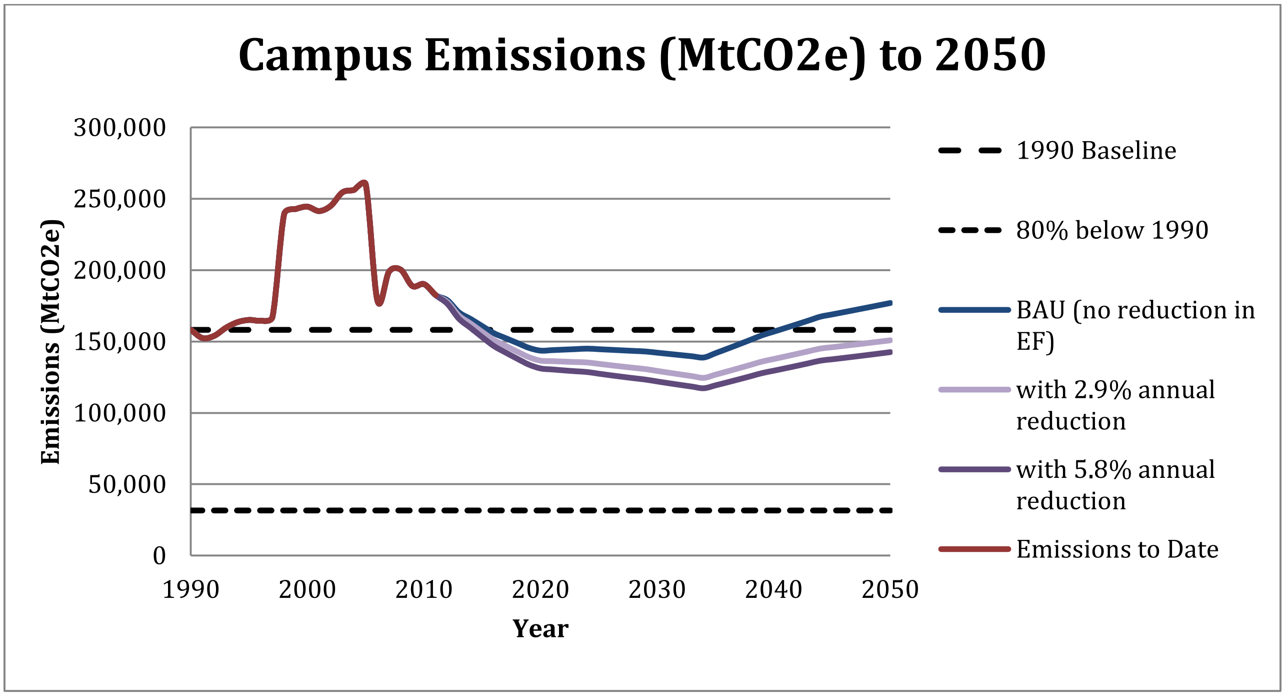

Figure 17. Reduction in Overall Emissions Due to Decarbonized Electricity

In this figure, the BAU scenario uses the Predicted model and assumes that PG&E's emission factor for electricity remains at its current value of 0.207 $MtCO_2/MWh$. The other two scenarios assume that PG&E reduces its emission factor by 2.9% annually and 5.8% annually, resulting in 2050 emission factors of 0.065 and 0.02, respectively. If PG&E is able to achieve the more aggressive reduction rate of 5.8%, this would result in 34,000 fewer metric tons of CO_2 emitted in 2050, relative to the BAU scenario. These savings represent 19% of the total GHGs emitted in 2050, under BAU conditions. If PG&E is only able to achieve a 2.9% reduction rate, this still results in 26,000 metric tons of savings, or 17% of the total.

One important take-away from this graph is the fact that decarbonization of our electricity supply can help us to reduce our emissions, but we cannot rely on it to achieve our goals. If our ultimate goal is to achieve 80% below 1990 levels, much deeper cuts will be needed. Under even the most optimistic scenario, we are still tens of thousands of metric tons away from the 80% below 1990 baseline.

A second key point involves the shift in campus' emission portfolio as a result of the decarbonization. Figure 18 below illustrates this point.

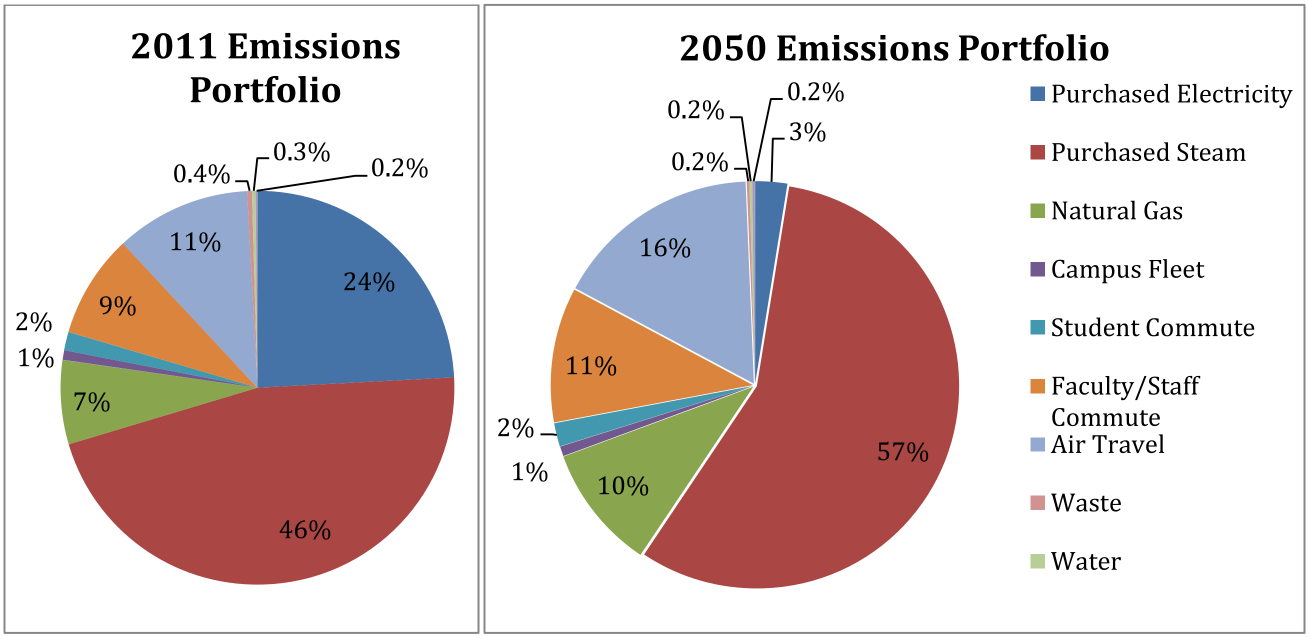

Figure 18. Change in Emissions Portfolio Between 2011 and 2050

As depicted above, if PG&E is able to achieve a 5.8% annual reduction in carbon intensity, by the year 2050 the University's emissions portfolio will demonstrate a dramatic shift. With all other emissions operating under business-as-usual conditions, electricity will drop from representing 24% of total emissions today to only 3% of total emissions in 2050. As a result, emissions from other sources such as steam now occupy a much larger percentage of the total emissions. This raises the question of whether the University could benefit from the electrification of other major emissions sources such as heating or transportation.

Uncertainty Assessment

There are several points that should be discussed regarding the reliability of data and uncertainties in the analysis. These can be broken down into uncertainties regarding the projections and uncertainties regarding electricity supply.

2050 Projections

One of the challenges in creating long-term projections is the development of reliable models of future consumption. The first area of uncertainty in these projections is the dependability of the data reported by the Department of Finance. These predictions are based off a number of factors including rates of fertility, mortality, and migration. There is no accompanying uncertainty analysis with the population projections, and it is curious that the projected population is reported with such precision (to the person!). In addition, age groups are reported in 5-year increments. In order to obtain values in the desired 18-24 range, it was assumed that the number of individuals in the 18-19 range is 2/5 of the number of individuals in the 15-19 range. There is some loss of accuracy in making this assumption. This result was added to the population in the 20-24 age range in order to obtain the number of individuals 18-24. In order to test the degree to which this assumption impacts the overall data, historical population was considered. In the year 2000, for example, the reported 18-24 population was 3,378,449.[44,45] Calculating the 2000 population from the age ranges using the method described above results in 3,374,464, for a percent error of only 1.2%.

Another assumption is the belief that the growth in California's college-aged population is an accurate predictor of campus population growth. In order to investigate this assumption, historical data was once again used.

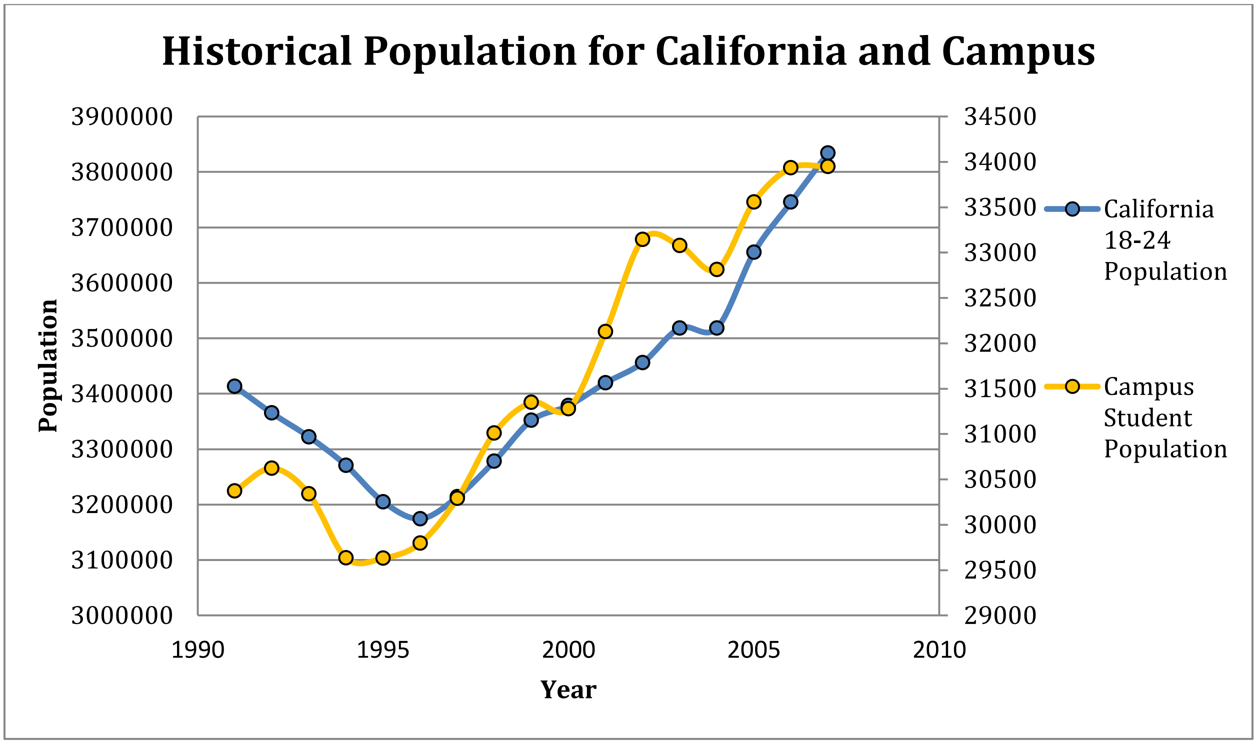

Figure 19. Growth in California's College-Aged Population as an Indicator for Student Population

While year-to-year growth may vary between campus and California as a whole, a least squares fit of the data yields very similar growth rates. Between the years of 1991 and

2007, the college-aged population of California grew at a rate of 0.84% per year. During this same time period, the student population on campus grew at a rate of 0.89% per year.

While campus population growth is closely correlated to the growth in California college-aged population, there are other factors involved that are difficult to predict. Among those are college participation rates, which can be influenced by such factors as tuition hikes. One of the reasons why campus growth was slightly greater than statewide population growth between 1991 and 2007 is likely the corresponding increase in college participation rates during this same time period.[41] Another factor that is difficult to predict is changes in the number of out of state students. It is plausible that if there is a lull in the in-state student population growth, the UC schools will simply accept more students from out of state.

An additional assumption is that an increase in campus population would result in higher levels of energy consumption. Past work relies on these same assumptions, but it is conceivable that in the future, the growth of building space, and subsequently emissions from electricity and heating, may not keep pace with the campus population growth, due to physical constraints on campus expansion.

Electricity Supply

In addition to those discussed in conjunction with the 2050 projection scenarios, there are a couple of uncertainties related to the reported PG&E numbers that should also be addressed. To begin with, emissions factors reported by PG&E report only CO_2, and not CO_2e. In their reporting, PG&E claims that other greenhouse gasses are negligible in comparison to CO_2.[5] In a state such as California, which is heavily invested in natural gas, such a claim is doubtful. Methane leaks during natural gas production are just one example of how PG&E's reported values may be misrepresenting our actual global warming impact. In addition, the numbers reported by PG&E do not reflect a life-cycle perspective, and therefore do not include such aspects as the extraction and delivery processes.

VII. FINAL PROJECTIONS AND FUTURE GOALS

A final projection was created which includes all current mitigation projects as well as the recommendations and industry trends discussed in the previous sections of this report. The results of the projection are shown below in Figure 20.

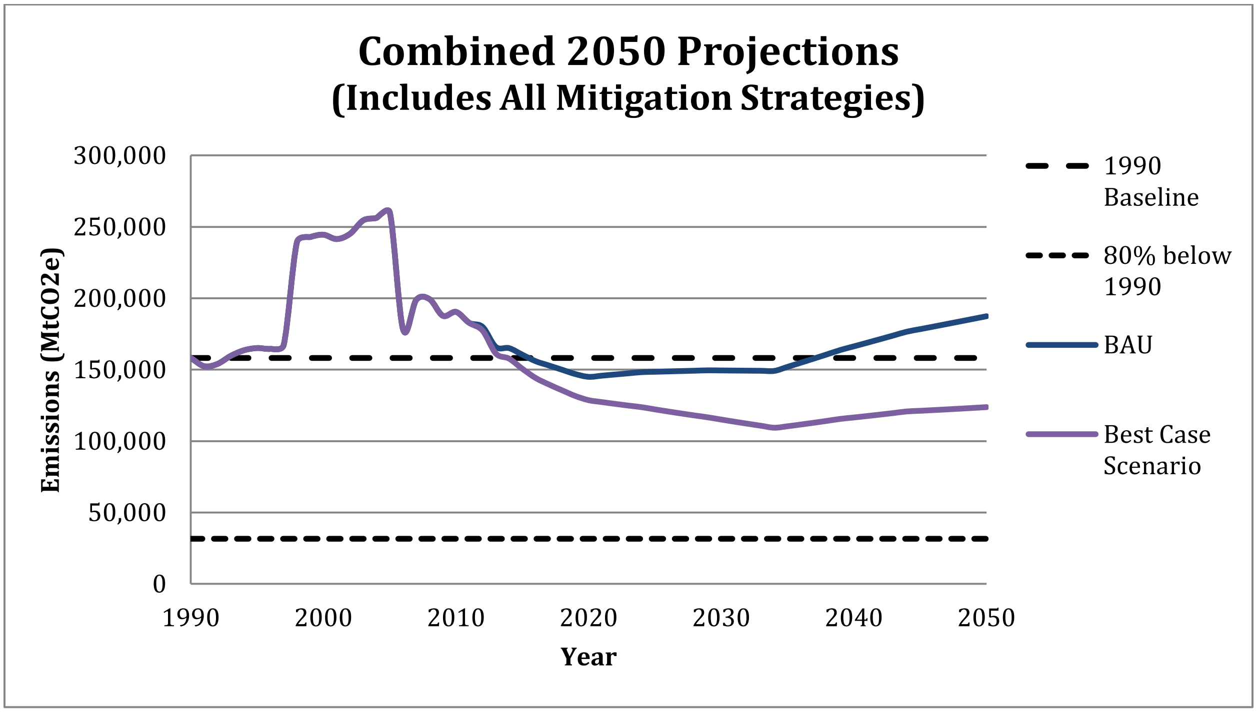

Figure 20. 2050 Projections Combining All Mitigation Strategies and Industry Trends

The "Best Case Scenario" represents a combination of the most optimistic outcomes in ground transportation, air transportation, energy efficiency, and electricity supply. Savings from water conservation was not included in this particular graph, as reductions in water usage proved to have a negligible impact on total campus emissions. The results from the combined 2050 projections are summarized in Table 14 below.

Year	**BAU**	**BCS**	**Change** (relative to BAU)
2035	152,000	110,000	-42,000 (30% below 1990)
2050	187,000	123,000	-64,000

Table 14. Summary of Emissions under Business-As-Usual and Best Case Scenario. (values in $MtCO_2e$)

The Best Case Scenario would result in a reduction of campus emissions to 110,000 $MtCO_2e$ by the year 2035. This value represents a 30% cut below 1990 emissions, which are estimated at 158,000 $MtCO_2e$. Setting the next campus goal at 30% below 1990 levels by

2035 would be appropriate because it is an ambitious goal, but not infeasible if the proper steps are taken.

VIII. CONCLUSION

There are many steps that campus can take to become more environmentally progressive. Focusing on energy efficiency and water conservation will reduce the University's environmental impact. Significant emissions of greenhouse gasses can be avoided through mitigation efforts aimed at decarbonizing transportation and limiting business travel through the increased use of teleconferencing. While certain industry trends such as the decarbonization of electricity can contribute to end goals, a reliance on such changes will inhibit progress and limit desired outcomes. A future emissions goal of 30% below 1990 levels is recommended, representing the most optimistic industry trends and aggressive mitigation approaches. Beyond 2035, however, emissions are projected to begin to rise again due to a boom in the student population of California. If the University's ultimate goal is to achieve 80% below 1990 levels, or even complete climate neutrality, deeper emissions cuts will have to be considered in the future.

DATA QUALITY ASSESSMENT

Data	**Acquisition Method**	**Independence of Data Supplier**	**Representativeness**	**Data Age**	**Geographical Correlation**	**Technological Correlation**
Vehicle Transport						
Commute Emissions	1	3	3	1	1	1
Fleet Emissions	1	2	1	1	1	1
Industry Trends	3	1	2	1	2	2
Parking Demand	2	1	1	1	1	1
Air travel						
Air Travel Demand	1	1	1	1	1	1
Aircraft Emissions	1	2	1	2	1	1
Industry Trends	1	2	1	2	1	1
Water use						
Campus Water Demand	1	1	1	1	1	1
Greywater/Rainwater Emissions	1	1	2	1	2	2
Industry Trends	2	1	1	1	1	2
Best Available Technologies	1	1	1	1	1	1
Water Emissions	2	1	2	2	1	1

Maximum Quality = 1
Minimum Quality = 5

Data	Acquisition Method	Independence of Data Supplier	Representativeness	Data Age	Geographical Correlation	Technological Correlation
Energy Efficiency						
Energy Intensity by Space Type	2	1	4	2	2	3
Energy Intensity by End Use	2	1	3	1	3	2
Technology Efficiency Predictions	1	1	2	1	1	2
Electricity Supply						
California Population Predictions	2	1	3	1	1	2
PG&E Emission Factors	2	5	4	1	1	1
California Historical Population	2	1	1	2	1	1

Maximum Quality = 1
Minimum Quality = 5

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