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Reducing Carbon Emissions on UCSC Campus Through Alternative Transportation

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Abstract.

In this project we explore the potential of implementing an electric bicycle program at the University of California Santa Cruz campus. UCSC suffers from a range of transportation issues from crowded busses to expensive parking passes. Simply riding a bicycle solves many of these issues and reduces Co2 emissions. However, the hills that make up much of the campus can make it a challenging environment for riding a bike. Because of this, we think an electric bike program at UCSC has the potential to be a great success. In this project, we explore different options for the implementation and design of an electric bike pilot program. We have established much of the necessary local contacts, funding sources, and design directions that would be needed to initiate this project. The bike specifications have been calculated and the most e-bikes will be suited for riding up the campus. Furthermore would e-bikes reduce the Co2 emissions by more than 90% and the students who drive, would be able to save more than $700 a year in transportation costs.

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Introduction:

The transportation sector accounts for a large portion of greenhouse gas emissions around the globe. Reducing these emissions through heightened vehicle efficiency and alternative fuel sources is essential if we want to lower our impact on the changing global climate. However, achieving the goal of a more carbon neutral society is something that cannot simply be accomplished through one “catch-all” solution. This will require a collective effort working towards a variety of alternatives to the oil-dependant transportation methods we are seeing today. On the large scale, shifting away from oil-based transportation will take our generation significant time and effort to change. But by at least initiating base changes at the local-level, we can begin to undertake this challenge in a smaller and more feasible scale.

The University of California Santa Cruz (UCSC) has a host of transportation issues that could benefit from a local-scale initiative of this sort. With a growing student population and limited space, busses over the past years have become noticeably crowded, making transport around campus a cumbersome and frustrating experience. Driving to and from campus also has its issues including limited parking spaces and expensive parking passes that can cost between $400 and $700 a year. Even with a parking pass, parking at any of the remote parking lots still involves taking a shuttle bus from the lot to the classroom areas. Many of these complications are solved simple by riding a bike. Biking allows you to bypass crowded busses, parking fees, and saves money on gas. In addition to these few obvious and immediate benefits, it also reduces transportation emissions and is a healthy source of exercise. However, biking at UCSC can be strenuous because of the hilly topography that makes up most of the campus. The bike ride down from campus is faster and much more enjoyable than waiting around for a crowded bus, but the ride up the hill can be a challenge. Because of this, we think UCSC makes a perfect campus for an electric bike program.

We are proposing the introduction of a small fleet of twenty electric bicycles available for day use among students and faculty at UCSC. Ideally, this project will help to alleviate some of the transportation issues at UCSC while simultaneously lowering the university’s carbon footprint. Through this pilot project we hope to show students and the public that sustainable solutions do not necessarily translate into inconvenience, but can be simple, effective, and even enjoyable.

Background

The electric bicycle, known by different terms including, light electrical vehicle, has no clear definition but is in general categorized as a bicycle attached an electrical motor powered by a battery. The border between an electric scooter and an e-bike can be unclear. In general e-bikes maintain their general characteristics such as pedals etc. Legislation is another concern, for example, in the US the different states have different laws when it comes to e-bikes. Some places they have to follow bicycles laws and other places they have to follow other rules.

In this report a small pilot project is proposed for introducing e-bikes into the UCSC campus transportation system. This project in general follows the principles of community bicycle programs in the sense that a fleet of e-bikes is available for UCSC students at a low membership fee.

Community bicycle programs are not a new idea. Back in 1965 the Dutch counterculture movement “Provo” introduced a project called “The White Bicycle Plan” in Amsterdam. The concept was simple: a couple of hundred bikes were painted white and distributed around Amsterdam for free usage for everyone. The project was not a success but can be considered the foundation of all modern community bicycle programs. Later projects, including a later version in Amsterdam, have turned out as successful. Other examples of successful projects are the two Danish community bicycle programs The Copenhagen City Bike, beginning 1995 and Aarhus City Bike beginning 2005. Both are non-profit projects financed by sponsors buying ad space on the bikes. Worldwide more than 30 cities have a community bicycle program.

Cases study: China

The modern e-bike has been around for roughly two decades and has got attention all over the world including China, Taiwan, Japan, Europe, and the US. China is the largest manufacture of e-bikes. The e-bikes are both exported and sold in the raising domestic marked (Muetze, & Tan, 2007). In China roughly 40.000 e-bikes were sold in 1998 and since then this number has doubled many times to more than 10 million sold units in 2005 (Cherry, & Cervero, 2007). Some studies of the e-bike usage has been conducted in China and this is why we have decided to take a closer look at China even that China and the US in many ways are very different.

China has been an upcoming economy for years with the result that the standards of living has improved but another and less favorable effect is that recently China took over the questionable spot as the world's largest greenhouse gas emitter. Besides pollution the main concern for many Chinese cities is the transportation systems (Fairley, 2005).

The e-bike mainly competes with scooters and public transportation but is still not competitive enough to make huge changes to the marked. Officially because of safety issues and pollution e-bikes have been banned in several cities, unofficially the reason is that some people will loose money if e-bikes takeover too large a marked share (Weinert, Ma, & Cherry, 2007).

E-bikes are limited in range and as a bicycle it is most suitable for short trips, for example, grocery shopping, campus transportation etc. This is both because of the nature of the e-bike but also the because of the capacity of batteries which continues to be one of the main technical issues. The tendency is that e-bikes are used for more and longer trips when compared to bicycles.

Politicians need to understand which people are using e-bikes and for which purposes to be better at planning sustainable transportation plans. Especially the flow in traffic is important because to increase the use of e-bikes they must prove to be effective. This can be accomplished by planning bike lanes without an significant amount of stop signs, red lights etc. to keep up momentum so the travel time can be kept down.

Biggest challenge for the e-bikes might be the roads as most roads are designed for cars and new city development planning often follow models based on car traffic. In many cities it can be quite dangerous to bike,

Overall, if e-bikes are successful in China this will be a big step for the concept to be migrated by other countries both developed and developing. Further it is the trend that more and more bike lanes are being created in the US, which is an important factor to get people on the bike.

The Grid

Today electricity already is an important energy source throughout the transportation sector for vehicles, scooters and probably the most notable, trains. In many countries trains and subways are purely or partly powered by electricity.

Even though electricity is seen as one of the most promising and important replacements of fossil fuels in the transportation sector, it must not be forgotten that the production of electricity is also a huge source of global emission. As more of the transportation section uses electricity an increased pressure will be added to the grid and the grid will be affected both on a long and short-term scale. Costs and emission from the grid will increase and this is an aspect that cannot be ignored. It can be difficult to calculate exactly how the increased demand from the transportation sector will impact the environment so more detailed studies must be performed. However it is clear that an impact on the grid must be considered and renewable sources must be used to make any real changes to the emission. Policy incentives can help maximizing the benefits (Yang, & McCarthy, 2009) and such virtual changes to something so fundamental in a society must be lead and supported by authorities. It as well seems clear that the existing renewable power plants not will be able to fulfill future requirements from the transportation section.

For this pilot project the e-bikes will be charged directly from the grid through UCSC. Currently the university is buying purely renewable electricity. In the vision for this project it is the plan to recharge the bikes using a renewable power source such as a local solar power grid.

Social aspects & mind set

Through the suggested pilot project we hope to be able to explorer several aspects that needs further investigations before a potential large-scale version can be implemented. This includes practical issues, technical issues and not least social issues. We also hope this pilot project can serve as a showcase of an alternative and sustainable transportation form which still is convenient. The intentions with this project it not only to decrease emission but also about making the users aware of sustainable transportation.

The idea is that it is not only about using one transportation form but rather provide sustainable transportation solutions that can serve as many people as possible while at the same time make the transportation options more convenient. Taking the bike rather than the bus will for some people provide some freedom and flexibility since they will not have to depend on a schedule. Also riding an e-bike provides a different experience than taking the bus.

To make sustainable transportation successful it is important that the convenience not is compromised. Rather than thinking of sustainable transportation as something that is just good for the environment, it is important that designers consider both the user experience and sustainability.

The Danish Ministry of Climate and Energy is currently running a campaign called ”One Tonne Less”. This is an awareness-raising campaign with the main mission of informing people that a lot of emission is caused by our lifestyle and we can all participate in reducing emission. The message is that everyone, no matter gender, age etc. can help reduce unnecessary emissions by taking often very simple actions. The official goal of the campaign is to have every Dane produce one tonne less of CO2 per year. This is an example of a campaign that informs and at the same time provide practical advices that might result in a tiny emission reduction and at the same time be an important step in changing the social understanding of energy usage and the global climate conditions.

By not only telling UCSC students about sustainable transportation forms but also provide a sort of hands-on experience and introduce e-bikes in the everyday life we believe this can be an eye opener and a first step towards a cultural change among the students.

Implementation and Project Design

Our Electric Bike pilot project is designed to start at a relatively small scale, and then grow and expend as time and funding allows. However, even at the initial small scale of the project, there is a range of variations and different designs into which the project could eventually evolve. Should we use bikes that have already installed electric systems? Or obtain bikes and batteries separately and install them ourselves at a potentially cheaper cost? Do we want to buy an expensive locker and bike check-out system? Or use regular bike racks and hire security and rental employees separately? These are just a few of the many questions that come up when attempting to realize the specifics of this kind of project. We have looked into a variety of alternatives for what bikes, lockers, and kind of membership systems to use for this project. Each option comes with its own inherent advantages and disadvantages. The ultimate decisions that we make will be largely contingent on how much funding we are granted, and which options make the most logistical sense during the time of implementation.

Electric Bike Options

Since our project is based around a fleet of electric bicycles, choosing a particular bike design and retailer is one of the most important aspects of this project. Initially, we looked at a variety of online sources for electric bicycles just to get an idea of different costs and models. In the end, we decided that buying the bikes from a local manufacturer would be a better option that purchasing them online or from and out-of-state location. Buying bikes locally has several obvious benefits over purchasing them on the Internet or elsewhere. Buying bikes from a local manufacturer establishes a relationship with a retailer that is nearby and available for help with bike maintenance and repairs. It also makes it easier to negotiate with the seller and get a discounted price for buying the bikes in bulk. This is critical to our project's success since funding is really our main limiting factor. Buying bikes locally also offers the advantage of supporting the local economy and serving as another potential depot or pick-up location for students looking to rent bikes.

So far, we have met with three separate suppliers of electric bikes in Santa Cruz. Of the three different potential electric bike suppliers we have spoken with, each offers its own advantages and disadvantages. We first met with the owner of Electric Sierra Cycles at the end of Pacific Avenue by the Boardwalk. Electric Sierra Cycles rents out a variety of bicycles (both electric and non-electric) and target their bike rentals primarily to tourists looking to bike along West Cliff or the Boardwalk. They have two types of bikes, both made by Synergy Cycles, available for rent as well as sale. They have an older model that runs on a 24-volt, 400-watt, lead acid battery. This model retails for around $800 and has a range of around 15-20 miles. Electric Sierra also rents another higher-end electric bike that runs on a lithium iron phosphate battery. This bike (Fig 1.) has a more powerful 600-watt motor and an increased range of 30-35 miles. However, this extra power comes with a hefty price tag. At $1,800, this option might be too costly for our purposes. The owner of Electric Sierra Cycles said he would definitely negotiate a discount for buying a bulk fleet of bicycles, but even with a price reduction this option is probably too costly. If we were able to get a discounted price of $1600, it would still cost us around $32,000 for 20 bikes which is out of our projected budget range. We were able to go on a test ride with the bike and it was powerful enough to accelerate quickly up a moderate hill. If funding allowed, this bike would be an excellent option for a bike, as it would climb up the UCSC hills without a problem. But for the purpose of our pilot project, we would probably have to opt for the cheaper and less powerful $800 model, or seek another alternative. Regardless of what bike we end up using, we got the owners contact information and established a good connection with Electric Sierra Cycles for the future of the project.

Figure 1: Electric sierra cycles

We explored some other electric bike model alternatives at Dave's Custom Bikes on Soquel Avenue. Rather than having one specific model of electric bike, Dave's simply has a variety of different battery kits that they both sell and install on bikes. This offers an interesting alternative to buying bulk electric bikes of the same model. For one, if the one model we buy in bulk has some serious design flaw down the road, the pilot program could suffer significantly. Pricing also becomes a little more flexible with the option of many different batteries. Dave's Costume Bikes has a range of batteries from lead acid to lithium iron phosphate, with some other options in-between. Even with more flexible pricing, however, some of the newer lithium iron battery kits alone are in the range of

$700-$900. Add in a bicycle and labor and Dave's Bikes estimated that we would be looking at costs in the $1000-1400 range for a decent bike set up.

Buying batteries individually could be an excellent option if we were able to obtain a large stock of non-electric bicycles for free (through donation) or at a very cheap cost. This may sound overly optimistic, but it may actually be a realistic option. The Bike Library organization on campus builds bikes as part of a quarterly class. They then donate and rent them out to students on campus through an application process. Through coordination with this group, it may be possible to obtain 20 bikes cheaply or at no cost at all. In this case, we could go through Dave's Costume Bike for batteries and installation and get optimum battery systems for a reasonable price.

Electric Bike Options:	**Est. Cost Per Bike**	**Est. Total Fleet cost**
Dave's Custom Bikes	~$1,200	~$24,000
Electric Sierra Bike 1	~$800	~$16,000
Electric Sierra Bike 2	~$1,800	~$36,000
Green Station	~$500	~$10,000

Table 1: Estimated bike costs

Bill Le Bon, the co-owner of a start-up sustainable transportation company, was a great contact to establish. We meet Bill at the Green Drink gathering downtown Santa Cruz. Bill is extremely interested in helping our cause and gave us a lot of great information. He is also interested in us because we can actually help him just as much as he can help us because he is a small business and needs growth in all directions. Bill specializes in bio-diesel (B99) and electric vehicles: cars, scooters, and bikes. The bike that he sells is called the Izip Urban Cruiser made by Currie. The Izip has a range of 15-20 miles and a top speed of about 15 mph. The battery is nickel metal hydride which offers a good power density. The Green Station has offered storage of bikes for an eBike hub which will help with the commuters from the east side of downtown (Green Station).

Storage

Since bike theft is one of the leading problems in the city of Santa Cruz, bike storage and security is extremely important to this pilot program. We have explored different options of bike 'hubs' or 'stations'. One hub could be located at the base of the UCSC campus on the parking lot near the University sign. The other hub could be located at the Green Station on the corner of Ocean Street and Soquel, downtown Santa Cruz. We had a great meeting with Larry Pageler, the director of taps, who said that the possibility of having a hub at the base of campus is actually something that taps would let us use. It is currently a childcare facility but will be decommissioned in the next year (Pageler). We also had a brief meeting with William Le Bon, owner of the Green Station, and he is interested in working with us to create a hub for downtown eBike users as well as promote his growing green business (Bon). For the hub at the base of campus we have found several different locking methods:

Figure 2: Bike Cage

BikeLinks, a company based out of Palo Alto, CA, offers a very secure system for bike lockers. The lock has a electronic system ideal for membership and security issues. Each member will have his or her on card and can check out bikes electronically.
Price: $50,000 US (20 cages)

Pros: Extremely secure and water resistant. Relatively small land use for storage. Electronic locking ideal for self check out

Cons: Extremely expensive. Limited mobility if hub site must change. (BikeLink)

Huntco, a company based out of Portland, Oregon, specializes in outdoor, urban structures that gives an alternative to bike cages. The POD's have proven to be relatively water resistant and have a good recorded for keeping thefts low. The city of Santa Cruz has similar units installed on the Wharf.
Price: $25,000 US (20 POD's)
Pros: Price is more applicable to a pilot project. Water resistance. Cons: Bike slightly exposed. Land use for POD's could cause problems. (Huntco)

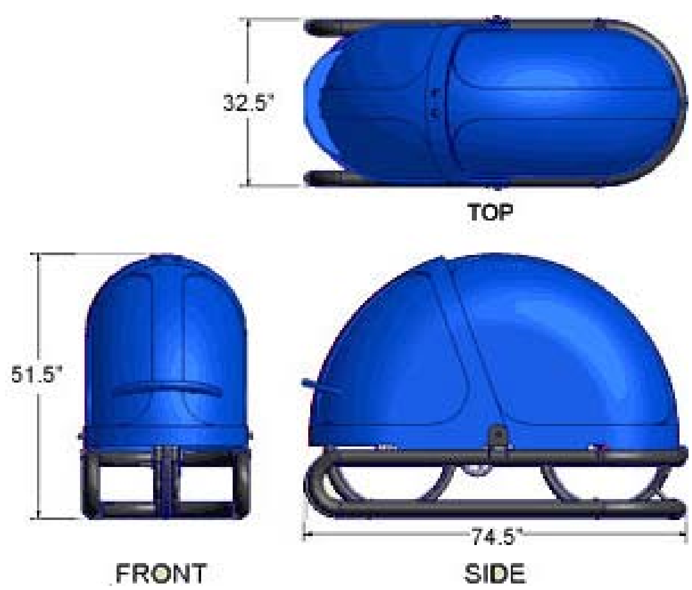

Figure 3: Bike POD

Storage Container

There are large storage containers that are typically placed on site to store bikes. monthly fee is attached to the container and will take up limited amount of space. Price: $4,000 US/year (20 bikes)

Pros: minimal land use. Not as expensive As the alternatives. High Security

Cons: not appealing to the eyes. Not individual containers.

Bike Racks

Normal bikes racks will still be able to suit our needs for storage. The problems highly outweigh the benefits. Huntco has many differing bike storage racks. Price: $2,500 US (20 bikes)

Pros: Extremely inexpensive. Great for pilot program to get started

Cons: Low security. Exposed to elements. (Huntco)

Ideally we will have 10 bikes at the base and 10 bikes at the Green Station hub, depending on storage options. For the Green Station hub, we would have access to garage space enough for 5-10 bikes and the rest will be locked in one of the ways explained. Having a campus location and a downtown location is ideal to promote alternative ways of getting to campus on a daily basis.

Bike Locker Options:	**Est. Cost for 20 lockers**	**Problems**
Huntco Bike Pod's	~$25,000	Moderately high expense
Bike-Link lockers w/ card swipe system	~$50,000	Extremely Expensive
Generic Storage Container	~$4,000 / yr	Eye sore in historic district of UCSC
Normal Bike Racks	~$2,500	Theft and security

Table 2: Estimated price for bike storage

Audience

We have aimed at two very specific groups of people to target for the UCSC eBikes pilot program which is why it would be ideal to have two different hub locations. First and most obvious is the eBike hub at the base of campus. A lot of UCSC students live in the areas between High street and Nobel. Most of them walk and take a slug bus and some of them even drive up to campus even though they are so close. We are encouraging students to walk/bike to the eBike hub at the base of campus and take an electronic bike up for their daily class needs. This will eliminate a lot of bus and car traffic but more importantly, reduce the university's overall carbon footprint (Appendix A). At the Green Station eBike hub, we are going after a whole different group of people. Most UCSC students that live on the east side/midtown area commute to class solely by car. This is a huge problem because car traffic on campus is among one of the leading problems. 19,700 cars per day commuted to campus in Fall of 2008 (Pageler). Taking one of our eBikes from midtown instead of taking a car will reduce the commuting time as well as reduce personal carbon emissions by 97%.

Part of the eBikes pilot program will have to require a great deal of outreach. One of the major market uncertainties is how we are going to push people to ride the eBikes instead of what they normally do. We have plans for an outreach campaign that would be in charge of promoting eBikes on and around campus. Some examples of outreach: flyers at bus stops, short pre-class talks, OPERS student groups, and KZSC radio (Appendix A).

Funding

Funding for this electric bike program will come from a variety of sources. Even with the budget issues we are facing in California and the rest of the nation, there still are abundant funding opportunities for alternative energy and efficiency projects. There is a growing market for green technologies in energy production and efficiency and more money is becoming available in these fields. Large portions of stimulus packages like the recent "American Recover and Reinvestment Act of 2009" are being directed towards increasing grants and funding for renewable energy projects, green jobs, and energy efficiency. One of the major objectives of this act is to "Revive the renewable energy industry and provide the capital over the next three years to eventually double domestic renewable energy capacity" (http://www.recovery.gov). Money exists for projects like the one we are proposing, it is simply a matter of finding the relevant grant sources an applying for them. Applying for grants from more than one source is also important not only to ensure that all project costs are met, but also because many grants at the state and federal level require a percentage of the project costs to be matched by local funding sources (Payne, 2002).

For our project, one of the most likely local sources or funding will be from the Campus Sustainability Counsel (CSC). This student run organization has funded other environmental organizations and projects across campus since their founding in 2005. Past projects funded by CSC have included topics dealing with green building, transportation, sustainable campus food systems, and student activism training. Funding for CSC comes from a quarterly fee of $6 per student, which translates into around $250,000 each year. CSC allocates around $75,000 to student-run environmental and sustainability organizations and projects. In the past, the amount of funding provided by CSC has varied from project to project but has been as much as $25,000. In addition to CSC, a variety of other possible funding sources exist for our project. Table 1 outlines some of the most relevant grant programs that could apply to our eBike project.

Table 3: Grants and funding

Relevant Grant Sources		***Funding Amount***	***Eligible Projects***	
Bicycle Facility Program (BFP) *The Bay Area Air Quality Management District's* **BFP** provides grant funding to reduce motor vehicle emissions through the implementation of new bikeways and bicycle parking facilities in the Bay Area. http://www.baaqmd.gov/Divisions/Strategic-Incentives/Bicycle-Facility-Program.aspx		Minimum - $10,000 Maximum - $120,000	• Bicycle lockers and racks • Secure bicycle parking • Bicycle racks on public transportation vehicles	

Bikes Belong Coalition (BBC) BBC is a Colorado based organization that works to put more people on bicycles more often. From helping create safe places to ride to promoting bicycling, they select projects and partnerships that have the capacity to make a difference. http://www.bikesbelong.org/		Up to $10,000 Per project	• Innovative pilot projects • Mountain Bike Facilities • Bike Parks • Projects that build coalitions for bicycling by collaborating the efforts of bicycle industry and advocacy.	
Community Based Transportation Planning (CBTP) grant program supports planning activities that encourage smart growth and livable communities. CBTP helps communities develop concepts or plans that promote an efficient transportation infrastructure and sustainable growth. *requires a match of local funding 20% http://www.caltrans.ca.gov/hq/tpp/offices/ocp/cbtp.html		Varies with project	• Projects that encourage transit oriented, mixed-use development • Expand upon available transportation choices	
Transportation Enhancement Activities Program (TEA) TEA provides grants for transportation projects that help enhance the travel experience through bicycle and pedestrian facilities. *Requires a match of local funding of 11.47% http://www.fhwa.dot.gov/environment/te/app_resc_ob.htm		Varies with project	• Bicycle lockers • Bike paths • Bike lanes • Bike racks on buses	

Environmental Enhancement and Mitigation Program (EEMP) EEMP provides grant funding for project that offset environmental impacts of modified or new public transportation facilities such as streets and transit stations.		Up to $250,000	• Development of roadside recreational facilities such as roadside rest stops • Bicycle facilities • Scenic overlooks • Parks and trailheads	
Campus Sustainability Counsel (CSC) The UCSC Campus Sustainability Counsel is a student organization that supports the development of other student environmental organizations and projects. They control approximately $250,000 each year and award around $75,000 to different projects each quarter.		Varies with project (has been up to $25,000 for past projects)	• Student environmental projects • Transportation • Energy Projects	

Technical specifications

The following section contains calculations determining the electrical motor needed, the battery size, the Co2 emissions of the ebikes compared to cars and busses and finally a short back of the envelope calculation of the costs difference for ebiking to school compared to driving a car.

Dimensioning of the electrical system

For estimation of the requirements for the ebikes, two different scenarios have been used, as mentioned earlier. One where the ebike is restricted only to go from lower to upper campus and one where the bike goes from the Green Station at the eastside of Santa Cruz, see appendix B for marked routes. After the power calculations for the ebikes, a comparison on Co2 emissions between a regular American car and the ebikes is carried out for the two scenarios.

The motor power needed depends on altitude difference, rolling resistance, air drag and efficiency of the electrical system. The power needed equivalent to the different losses has been calculated with the equations below. An average speed of 20km/h has been assumed and as the average wind speed is 1.5 m/s coming mainly from west or south west, this has been neglected (Wind). It has also been assumed that the electrical motor never runs going downhill.

Losses due to gravity: $$F_g = \mathrm{m} * \sin(\frac{\mathrm{h}}{\mathrm{d}}) * \mathrm{g} * \mathrm{v} \qquad \text{Eq. 1}$$

Losses due to air drag: $$F_W = 0.5 * \mathrm{v}^3 * \rho * a * c_v \qquad \text{Eq. 2}$$

Losses due to rolling resistance: $$F_g = \mathrm{f} * \mathrm{m} * \mathrm{v} \qquad \text{Eq. 3}$$

Where *m* is the mass of bike with rider, set to 100 kg. *g* is the gravity 9.82 kg/(m*s), *h* the altitude difference, *d* the distance driven. *v* is the velocity, set to 20 km/h, *ρ* is the density of air at 20 C° and 1 atm pressure, *a* is the cross sectional front area of biker and bike, set to 0.3 m^2. f is the friction factor between the wheel and the road and it is found to be 0.085. The total amount of energy needed in both scenarios to drive the bike under the above conditions and with an efficiency of 85% in the electrical circuit, is P = 413W. With a 450W motor the trip up will take about 8 minutes and 15 seconds from bottom campus to top Science hill, this will be faster if the biker help pedaling.

When going from the Green Station trip will take about 20 minutes with a 450W electrical motor.

The power capacity of the battery depends on the current hours (Ah) and the voltage (V), the two most common specifications for a battery is either 24V or 36. The current hours are very different depending on the battery type and size. The table below shows the needed required current hours depending on the two different voltages. The bikes should be able to from bottom campus to Science hill 3 times without charging and from Green Station to Science hill 2 times without charging.

	Bottom Campus (Ah)	Green Station (Ah)	3 trips Bottom Campus (Ah)	2 trips Green Station (Ah)
24V	2.368	4.292	7.105	8.584
36V	1.579	2.861	4.627	5.722

Table 4: Battery requirements

For all calculations the program EES has been used and program and results can be found in appendix B.

Carbon emissions

As the main goal for this project is to lower the emissions at campus it is essential to look at the carbon difference driving a car or riding an electric bike up the hill. The carbon emissions compared is the emissions of producing the electricity compared to the amount used by an average American car going up to science hill and the average emission for a bus passenger. The assumptions made for the bike when calculating the power requirements are still valid. As the car and bus are going both up and down the hill, it is assumed that the average emission can be used as an average for the whole trip.

The ebike uses 0.054kWh going up and down from lower campus to Science hill and 0.1kWh going from the Green station to Science hill. The Co2 emissions of producing a kWh can be seen in the table below:

Electrical Generation Technology	**Grams of CO_2 per kWh (reference - PDF)**	**Percent of U.S. Generating Capacity (from EIA)**	**Contribution (Grams)**
Coal	1000	49%	490.0
Oil	650	3%	19.5
Natural Gas	500	19%	95.0
Solar	150	0.5%	0.75
Wind	23	1.5%	0.35
Hydro	5	7%	0.35
Nuclear	5	20%	1.0
Total		**100%**	**607**

Table 4: Co2 Emissions producing 1 KWh

The carbon emission for an average car is 162 g/km and the emission for an average bus passenger is 56 g/km (M.J. Bradley & Associates). The bar plot below shows the emissions for one trip back and forward, assumed there is 1 person in the car.

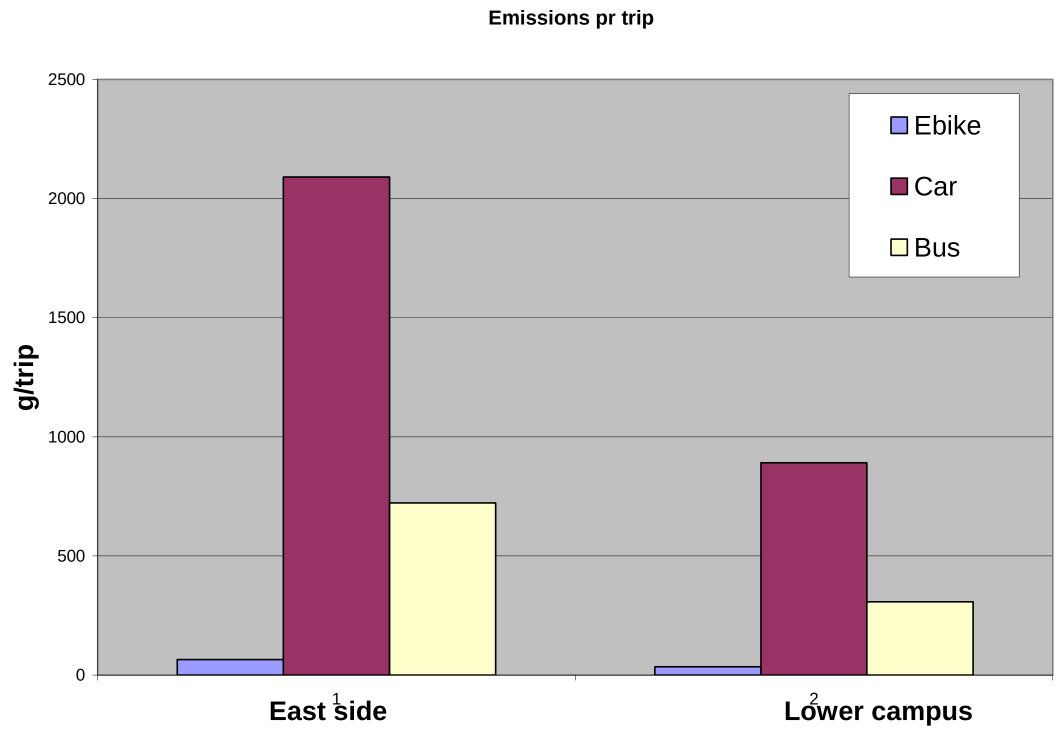

Figure 4: Co2 emissions from different transportation

On a percentage basis the Co2 reduction when using the ebike is around 96% compared to cars and around 90% compared to buses. AS UCSC buys purely renewable energy, the emissions are in principle nothing from the bikes, but since the renewable energy is produced outside Santa Cruz the emissions is still there. Furthermore the idea of buying 100% renewable energy is only an idea, as the energy used comes from the same grid as the large power plants are producing at, that is why the C02 calculation has been done. The total amount of Co2 reduction for a year can be seen in the appendix in both the bar plot and in the result table where the most important results are gathered.

Cost comparison on ebikes and cars

Another important factor and motivation for students to get on the ebikes is the savings by taking the ebike instead of the car. This is only interesting for the people talking the ebike from the Green Station, as the people taking the bikes from lower campus should be walking up there.

The price for the cheapest parking lot is 110$ a quarter, so 440$ a year (Pageler). The gas price is around 3.2 $/gal and the average mileage is 27 miles a gallon, converting this into SI units gives 0.85$/l and 11.5km/l. Driving 200 days to top campus and back a year then gives a total minimum cost of: 710$/year + maintenance. The electric bike costs 500$ (Green Station) and the yearly charge for going to and back from science hill is 20kWh, one kWh costs 0.18$ (PG&E) this would give a total of 3.7$. Total costs for a year plus purchasing the ebike is 503.7$/yearly + maintenance.

Amount of PV's needed to charge a fleet of 20 bikes

The sun has an intensity of around 1000W/m^2 at the surface of the earth. A good retail system for PV has an efficiency of 18% (Kubby). The PV's are placed facing south so they always have the sun onto the surface during the day, but without a tracking system. The bikes are able to charge 4 hours a day randomly. Each bike should be charged with 200 Wh, this means that they are charging with 50Wh/h. A PV installation of 1.8m^2, will when it is positioned best possible to the sun, deliver 250W. On an average over the day it might only be 150W, so for every 0.6 m^2, one bike can be charged. So in order to charge a fleet of 20 bikes, at least 12m^2 of PV's needs to be installed at suitable locations.

Membership and rental options

Although it is subject to some degree of change, a preliminary goal for our pilot project is to introduce the initial fleet of 20 electric bicycles in the spring quarter of 2010. This first quarter will serve as a kind of test-run for the bike fleet. At this point, there will be no membership or rental fee, but there will be a mandatory electric bike safety workshop and a process involving all the necessary release forms. With a little advertising about the project through flyers at bus stops and announcements across campus we should have no problem getting twenty students interested in testing the bikes. The summer after this initial test run will serve as a time to revise the program based upon the eBike performance in the spring test run. At the start of the 2010 fall quarter, we will continue the program and ideally at this point introduce more bikes to the program and a small membership and or rental fee for using the bikes.

There are a few different directions in which a membership and rental program could go. Since the program will be non-profit and through the university, a membership for bike rentals could be as easy as adding on a small membership fee to the student portal's quarterly fee's and tuition. The majority of funding for our project will be through grants at first, but ideally some revenue from a membership and rental program will provide the funds for sustaining and expanding upon the eBike project. When we do implement the membership program we would like there to be several different rental and buying options available.

There will be a day rental system much like the one Electric Sierra Cycles has set up. Their rates are $35 per day for electric bike rentals, but we would charge considerably less, ideally between $5-10 a day. There would also be the option of renting out an eBike for a full quarter for between $50 and $100. Lastly, there could be an option actually buy your own electric bike at a discounted price through a rebate program that we could set up. In the past, Ecology Action has sponsored incentive programs that rebate up $200 for buying an electric bike and taking a biking safety class (http://www.ecoact.org/). Unfortunately the program has since been discontinued, but we could do one of two things to reinstate a similar program. We could either get Ecology Action interested in starting up this program again, or introduce our own rebate program using grant funding. In either case, we could set up an attractive incentive system to increase the number of electric bikes used in campus transportation.

Future Expansion

Since this is only a pilot program we have a large vision for expanding into a large scale operation. Ideally we see the eBike project to be charged completely by solar PV panels reducing the carbon emissions be even more, which is our over all goal. Solar PV will not only charge the bikes but when people visit and see the panels they will see how the UCSC campus promotes renewable technologies. Not a lot of places in the United States have a fleet of eBikes and UC Santa Cruz would receive a lot of recognition for being one of the first. Part of having the eBikes on the university is the program could be used as an educational tool to do research on or teach students about sustainability. For example, Electrical engineering students could manage and work on the solar PV charging stations or the Environmental Studies students could evaluate the environmental impact the program has on the surrounds community. With the addition of 20 new bikes every spring, the young pilot program will expand into a vast network of charging hubs and eBike lanes around Santa Cruz. The pilot program will not run by itself and eventually the program will need a team of volunteers along with certain paid positions to keep the program running (Appendix A).

There are several issues that the eBikes program could encounter through expanding the pilot program. First of all, who is going to own the eBikes and who manages them? We have talked to a number of sources and came up with a few options. The bike library has an interest taking part in the ownership and could perhaps help run regular maintenance on the eBike fleet. Also, the Green Station has posed some interest in housing the bikes and offering discounts to university students. Another difficulty to the expansion of the program would be acquiring sufficient funding for the program because it is reasonably expensive. With the economy in a recession and budget cuts all over the nation, it might very difficult to get our program noticed. Showing that this program is beneficial and feasible will aid our cause.

Conclusion

As DuPuis mentioned during her lecture about sustainable design: you need to know your user. This pilot project is a good example of a project that easily can fail if the user is forgotten. If the solution does not satisfy the needs of the users they will not change to this transportation form. Identifying user needs is just as important as solving technical challenges.

Worldwide more and more non-green vehicles are being banned within city centers. With e-bikes as a rather cheap alternative for short distance traveling and with an exponential raise in the Chinese market for ebikes. It is fair to estimate that the marked for e-bikes have far from peaked yet. We are still observing what is an early stage in a new market. Studies of use of e-bikes in China have indentified clear legislation and support from authorities as some key aspects for a successful future of e-bikes. When it comes to actual implementation safety is a key concern. If the user does not feel safe other and safer transportation forms will be chosen.

Global GHG emission has been identified as a threat to the entire globe. Reducing GHG emission requires a global effort and everyone are responsible for doing their own little part in bringing down the GHG emission.

Besides reducing GHG emission the e-bike fleet should also function as an awareness campaign to the students and the public. As Muetze & Tan (2007) points out: “More publicity is needed to introduce the public to electric bicycles.”

Despite the obstacles that exist for our electric bike pilot project, there is still great potential for this program to see actual implementation. We have established many of the necessary contacts and design outlines for this pilot program, and it could easily be implemented in the near future. We plan to continue refining the project logistics and securing funding this next fall and winter. Ideally, by the spring quarter of 2010 we could have the first test run on 20 electric bicycles. Based on our estimates, eBikes could reduce individual Co2 emissions by more than 90%, and the students who drive would be able to save more than $700 a year on transportation. With both environmental and economic benefits, we are confident that this program will be a success at UCSC. The foundations for this program are set in place and it could be a great example of a sustainable alternative transportation program for the University and the Santa Cruz community, all it needs now is implementation.

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Appendix

Appendix A

- Timeline
- Blueprint

Appendix B

- Google maps meausrements
- Program and solution for ebike calculations
- The most important results in a table
- Bar plot of CO2 emission reduction

Appendix A

Timeline

2009

July 30- LoCal-RE eBikes project group created.

-Goal: To reduce the emissions on UCSC campus through the use of alternative transportation

-Original Members: James Hoffner (UCSC-Environmental Studies)
Nis Bornoe (University of Copenhagen- Computer Science)
Erasmus Rothuizen (DTU-Mechanical Engineering)
Levi Patton (UCSC-Environmental Studies)

August 3 - First group meeting with LoCal-RE project advisor:
Joel Kubby (UCSC- Electrical Engineering)

August 21- LoCal-RE project proposal presentations.
-Explanation of Pilot Project and Future Expansion

September 25 – UCSC Fall Quarter 2009/2010 begins.

- James Hoffner and Levi Patton continue project steering
- Project Funding
  - Grants from Campus Sustainability Counsel through SEC
    - Funding rounds 8th week of every quarter.
  - Grants from Bikes Belong – Transportation Enhancement
- Project Team Growth
  - Seek project involvement through Student Environmental Center, The bike co-op, and Bike Library
  - Outreach campaign-gaining interest in using eBikes on campus
- Explore eBike designs and purchasing possibilities
- Coordinate with University and TAPS
  - Negotiate facilities for storage and general use
  - Work with TAPS and METRO to organize bus routes and schedules

2010

January 5 – UCSC Winter Quarter 2009/2010

- Continue Project Funding
  - Apply for grants and seek alternative funding sources
- Finalize bike design
  - Offer bids for Pilot program fleet
  - Finalize locking facility
  - Maintain relationship with University and TAPS
  - Discuss membership opportunities and car tax
- Outreach to Increase interest for using eBikes to get on campus

March 29 – UCSC Spring Quarter 2009/2010

- Deploy eBikes Pilot Program
- Continue Outreach
    - Flyers, class raps, advertisements
    - Develop feedback data from eBike users

June 20 – eBikes Summer Steering

- review success of Pilot Program
    - feed back from users
    - damage reports and maintenance
- prepare budget and explore granting opportunities

September 28 – UCSC Fall Quarter 2010/2011

- Plans for expansion
    - Solar power charging capabilities
    - Adding second generation fleet
        - Storage and lockers
        - New eBike locations
        - East and west remote
- Granting Process
    - Apply for funding to second generation

2011

January 5 – UCSC Winter Quarter 2010/2011

- Expand fleet
- Solar Charging
    - Site analysis
    - Calculate charging requirements
- Outreach to promote growth

March 30 – UCSC Spring Quarter 2010/2011

- Deploy Second Generation eBikes
    - Continue to gather feed back
    - Maintenance
- Continue to work with solar capabilities

June 15 – Summer Steering

- Review feedback and maintenance issues
- Research and funding for solar array for charging
    -

Transportation- Moving people and things

Stakeholders
Students, faculty, staff, TAPS, Crown Student Services, UCSC Biofuels CO-OP, Santa Cruz Metropolitan Transit District, bicyclists, PPC, bus drivers, community members, Food Systems delivery, transit riders, low income.

Where Are We Now?
Much has been done with regards to MANY specific programs, i.e.…

- biofuels production facilities
- why students aren't walking
- carshare
- educate
- post more signs, etc, etc

UCSC students are 20% of county-wide Metro riders.
Biofuels Coop working on pilot study: Small scale biodiesel processor to power farm equipment and beyond (loop busses, etc.). TAPS shuttles carry 10-12K people/day, they use biodiesel formulation B20.

ESLP action research team to build processor. Need a location! Working on logistics

Env. Studies class 158: Campus dining hall used cooking oil- How much are we purchasing? Where does it go?
TAPS burns 60K gallons of diesel/year. The biodiesel comes from Richmond. Pacific Biodiesel? Biodiesel approx. $1/gal. more than regular.

Bicycle plan is under development: This would include bike storage and parking, showering services for cyclists and ebike users but not gas-powered cycles, 'EGO' electric scooter would be able to park on campus w/o a parking permit (A draft plan is available on TAPS website, but is still waiting formal approval)
Car pooling education. The average rider per vehicle is increasing, what can we do to encourage this to continue?
Car-share program (car ownership/rental program): This proposal is a co-op like system where you reserve a car online, user's pay hourly fee (projected cost- $7.50-8 per hour or about $60/day) or pre-pay. Drivers currently need to be 21 or over, eventually the age will drop to 18 and over. Cars may be hybrid gas/electric. Program costs approx. $70-75K/year. Funding from student groups? (Ask Teresa Buika at TAPS . . sounds like it will happen by the end of the quarter for 18+ . . CSC pitched in $15,000 for pilot program)

Minimize impact, every square foot costs! Work toward a pedestrian-core campus, no 'kiss-and-runs'

- **Move UC: Statewide sustainability policy worked to get passed**
  - Transportation and greenhouse gas emissions recently brought to table
  - UCOP- if requirements come into effect, money will be an issue. One natural gas bus- $350K! Need money! Increasing requirements for the fleet vehicles.
  - UC campus system, with huge purchasing power can demand more efficient and environmentally friendly vehicles.

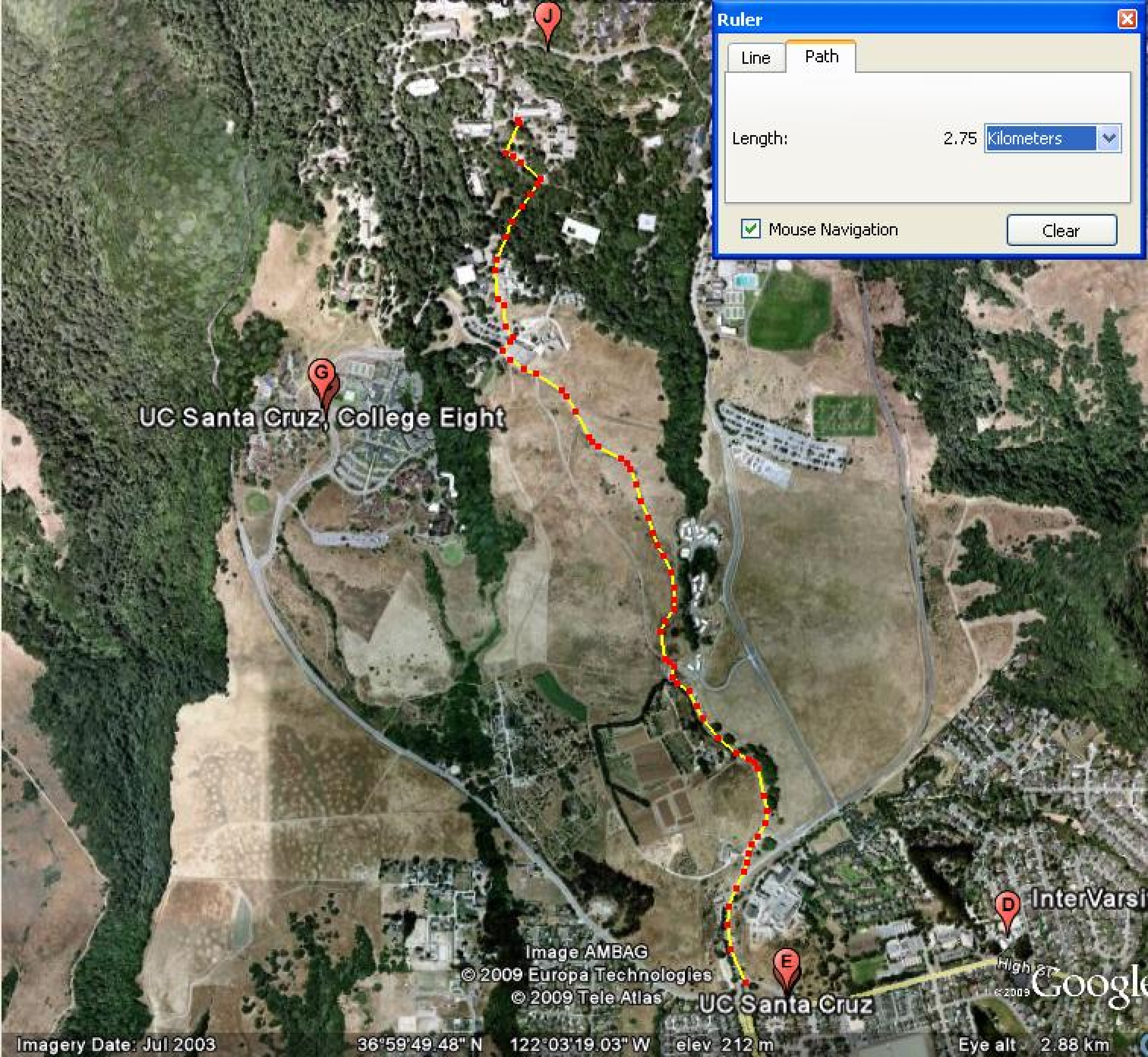
Action Steps

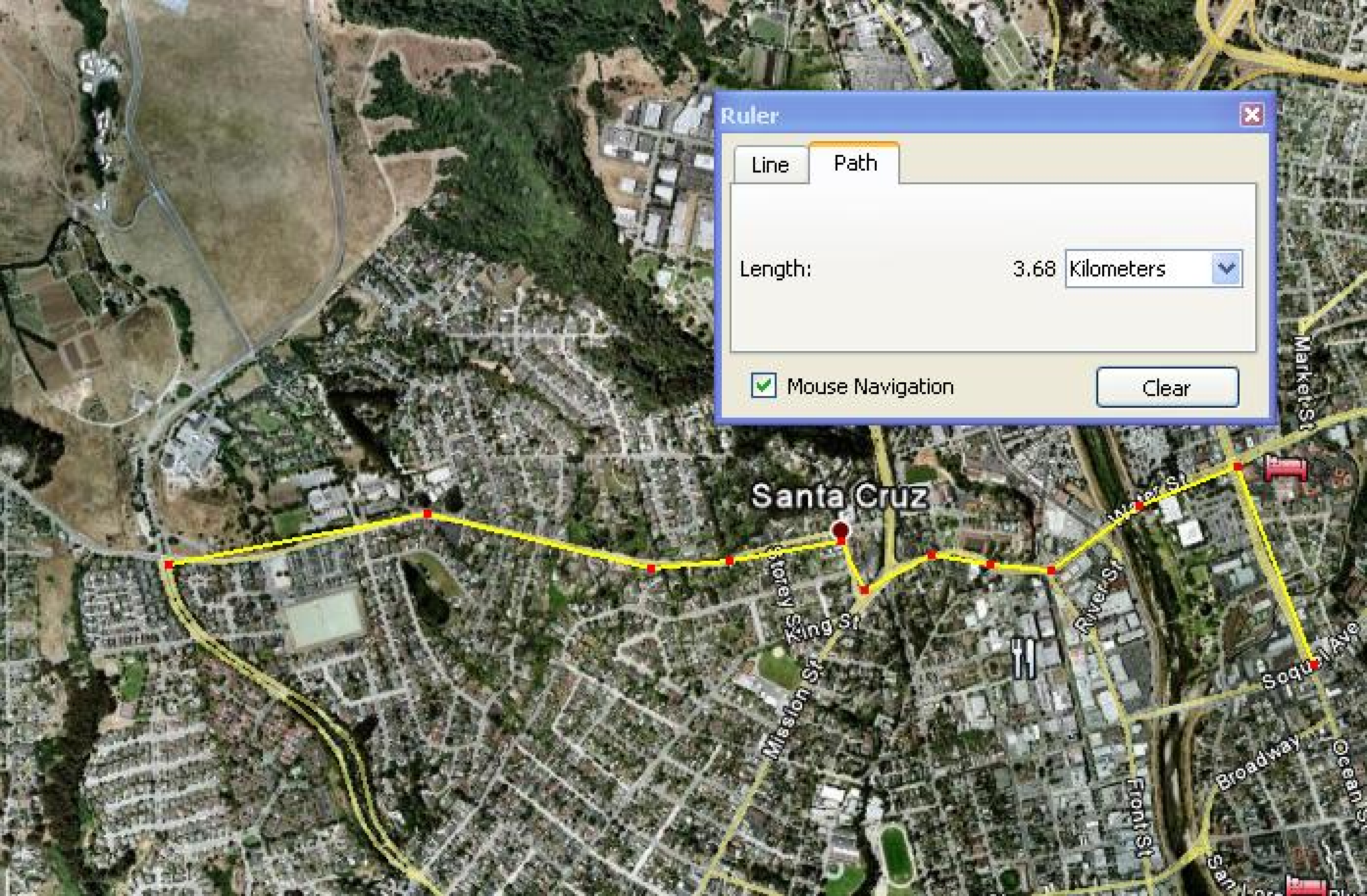
- Add incentives to make sustainable transportation more desirable
- Biodiesel production facilities at central campus and base of campus need to happen!
- Create more effective use of waste oils from dining halls and cafes
- Discourage cars on campus
- Education and outreach: what other options are available aside from parking permits? (in car parking meters are coming . . a new way to pay and influence demand)
- Maybe a regular bulletin/news letter, reach out to others- CRE's
- Implement carshare
- Late night escort services for students, safety around McHenry
- More funding from State and/or UCOP needed
- More direct shuttle routes with fewer stops. Currently it is more convenient to use busses
- Need more east side transit service.
- Need walking maps at bus stops, they could include walking times.
- Ride-bike to work/school day, more promotion, better safety and security for bikers
- Work with our Chancellor

What's Next?

- Develop an event
- Newsletter, possibly
- Possible internships through TAPS
- More transportation group meetings would be helpful
- Need to make 'spirit' of the Earth Summit last throughout the year
- UC/CSU Sustainability Conference June 25-27
- Student Union Assembly (SUA) - meeting 6-8pm; conference room D; Baytree Bookstore
- ESLP…build on ideas to make things more public
- Need more education and student involvement of transportation issues
- TAPS website includes minutes from past meetings
- Did you know? Monthly bulletin would be helpful. Make it a consistent color scheme so easily identifiable.
- Ties to other sustainability committees on campus
- Bike lane improvements on Bay and High Streets, more bicycle security on campus, i.e. lockers?

Appendix B


Ruler
Line
Path
Length: 2.75 Kilometers
Mouse Navigation
Clear
J
G
UC Santa Cruz, College Eight
D
InterVarsi
E
UC Santa Cruz
High St
Image AMBAG
© 2009 Europa Technologies
© 2009 Tele Atlas
©2009
Google
Imagery Date: Jul 2003
36°59'49.48" N
122°03'19.03" W
elev 212 m
Eye alt 2.88 km



Ruler
Line
Path
Length:
3.68
Kilometers
Mouse Navigation
Clear
Santa Cruz
Market St
Water St
River St
Storey St
King St
Mission St
Soquel Ave
Broadway
Front St

```
"Program made for the course Renewable Energy in Pracsis, it calculates the power needed to drive an electrical bike a certain
distance and between different altitudes It is also able to calculate CO2 emissions for the ebike and compare it to cars, the last part is
 a short cost program comparing the energy prices between ebikes and cars"


"The following procedures are mathematical formulaes set up in order to calculate the necessary data for the ebike project"
"Below the procedures the requests for calculting for the given data given at the bottom of this program"

"Calculation of the resistances going up the hil"
procedure power(h,d,f_r,m,v,c_v,g,rho_air,a,e_m,e_t,Vol: P_m)

"Losses due to gravity"
c=sqrt(h^2+d^2)
if h=0 then
F_g=0
else
F_g=m*(h/c)*g*v
endif

"losses due to wind resistance"
F_w=0.5*v^3*rho_air*a*c_v

"Losses due to rolling resistance"
F_f=f_r*m*v

"Losses in the transmission - Not relavant when looking at electrical motor size as it is the loss in the human paddling part of the bike"
F_t=(F_g+F_w+F_f)-(F_g+F_w+F_f)*e_t

"Total power needed at the wheel"
"P=(F_g+F_w+F_f+F_t)"

"The power of the electrical motor needed "
P_m=(F_g+F_w+F_f)/e_m

End


Procedure CO2(d,v,P_m,CO2_vkm, CO2_kWh : CO2_ekm, CO2_v, CO2_e,P_trip_kWh,t_1) "Calculations of CO2 emissions for
 vehicles vs. ebikes"


"The emissions from 1 trip on an ebike, both up and down the hill, assumed motor is only used uphill"
"The emissions can be found by comparing the energy used for a trip with the time"
"The time used for one up trip is"
t_1=(d/v)
P_trip_kWh=(P_m*t_1)/(1000*3600)
P_km_kWh=(P_m*t_1)/(1000*3600)/(d/1000)
"The CO2 emission pr. kilometer"
CO2_ekm=CO2_kWh*P_trip_kWh/(d/1000)
CO2_e=CO2_ekm*d/1000

"The emmsions from a car going up and down, the engine can not be turned off going downhill"
CO2_v=CO2_vkm*(d/1000)*2
"Assuming there are 5 in the car the CO2 emission pr. person is"
people=5
CO2_1=CO2_v/people
```

```
"Emissions on a yearly basis"
CO2_year=200*2*(CO2_v-CO2_e)/1000
emmit_e=200*2*(CO2_e)/1000
emmit_v=200*2*(CO2_v)/1000
"percentage reduction by using ebike instaed of car for one person"
Reduction_%=emmit_e/emmit_v


"Bus 1600 g/km, eng gov."

End

"Power needed in battery"
procedure battery(t_1, d,v,P_m,Vol: Amph_t)

"The battery should be able to last for a minimum of 4 trips before being disharged"
"that gives a total battery time on one charge of"
t_t=t_1*4

"Assuming a voltage of 36V from the battery the amph should be"

Amph=P_m/Vol
"The Amph needed for the 4 trips would then be"
Amph_t=t_1*Amph/(3600)

End


"Savings by using the bike instead of car going back and forward from lower campus to science hill"
Procedure costs(avg_pr_gallon,mile,gallon,Price_pr_gal,d,P_parking, trips_a_year, Total_kWh_year_east,P_trip_kWh,price_kWh:
Price_vtotal, Price_etotal_east)

km_liter=(avg_pr_gallon*mile)/(gallon)
P_gas_liter=Price_pr_gal/gallon
"total price of driving a car back and forward campus"
Price_vtotal=P_parking+2*trips_a_year*((d/1000)/km_liter*(P_gas_liter))

"Electricity price for using the electrical bike a year"
"East side"
Price_etotal_east=Total_kWh_year_east*price_kWh
"Lower campus"
"Price_etotal_lower=0"

End

"-------------------------------------------------------------------------------------------------------------------------------------------"
"Calling the diferent functions - asking the program to calculate"
call power(h,d,f_r,m,v,c_v,g,rho_air,a,e_m,e_t,Vol: P_m)
call power(h_2,d_2,f_r,m,v,c_v,g,rho_air,a,e_m,e_t,Vol: P_m2)
call power(h_3,d_3,f_r,m,v,c_v,g,rho_air,a,e_m,e_t,Vol: P_m3)

call CO2(d,v,P_m,CO2_vkm, CO2_kWh: CO2_ekm, CO2_v, CO2_e,P_trip_kWh,t_1)
call CO2(d_2,v,P_m2,CO2_vkm, CO2_kWh: CO2_ekm2, CO2_v2, CO2_e2,P_trip_kWh2,t_1_2)
call CO2(d_3,v,P_m3,CO2_vkm, CO2_kWh: CO2_ekm3, CO2_v3, CO2_e3,P_trip_kWh3,t_1_3)

call battery(t_1, d,v,P_m,Vol: Amph_t1)
```

```
call battery(t_1_2, d_2,v,P_m2,Vol: Amph_t2)
call battery(t_1_3, d_3,v,P_m3,Vol: Amph_t3)

call costs(avg_pr_gallon,mile,gallon,Price_pr_gal,d,P_parking, trips_a_year,Total_kWh_year_east,P_trip_kWh,price_kWh:
Price_vtotal, Price_etotal_east)
call costs(avg_pr_gallon,mile,gallon,Price_pr_gal,d_2,P_parking, trips_a_year,Total_kWh_year_east,P_trip_kWh,price_kWh:
Price_vtotal2, Price_etotal_east1)
call costs(avg_pr_gallon,mile,gallon,Price_pr_gal,d_3,P_parking, trips_a_year,Total_kWh_year_east,P_trip_kWh,price_kWh:
Price_vtotal3, Price_etotal_east2)

"--------------------------------------------------------------------------------------------------------------------------------------"

Total_CO2_etrip=CO2_e+CO2_e2+2*CO2_e3
Total_CO2_vtrip=CO2_v+CO2_v2+CO2_v3
TOTAL=P_trip_kWh+P_trip_kWh2+P_trip_kWh3
Total_Amph=Amph_t1+Amph_t2+Amph_t3
Total_Amph_4trips=Total_Amph*4
Total_costs=Price_vtotal+Price_vtotal2+Price_vtotal3-800
Percentage_CO2_reduction=Total_CO2_etrip/Total_CO2_vtrip
Total_CO2_ekm=Total_CO2_etrip*1000/(d+d_2+d_3)
Total_kWh_year_east=(P_trip_kWh+P_trip_kWh2+P_trip_kWh3)*200


"--------------------------------------------------------------------------------------------------------------------------------------"
"The data used for calculating motor power and battery power"
h=135[m] "The altitude difference from entrance to scince hill measured with google earth"
d=2750[m]  "From entrance to science hill, measured with google earth"
f_r=0.085 "f_r rolling resistance - wiki 0.05"
m=100 [kg] "m mass of bike + biker. Bike around 30kg (typical elctric bike found by comparisons on the internet) and biker 70 kg"
v=(20/3.6)[m/s] "v the average speed wanted"
h_%=h/d "Steepness of the hill"
c_v=1.2 "c_v drag coefficient"
g=9.82 [kg*s/m]"gravity"
rho_air=Density(Air,T=20,P=1)
a=0.3 [m^2]"a area front area of bike + biker"
e_t=0.90 "e_t the efficiency of the transmission"
e_m=0.85 "e_m is the efficiency of the motor reference: Keith, sierra electricbikes SC"
Vol=36[V] " The voltage of the battery"
"--------------------------------------------------------------------------------------------------------------------------------------"
"The CO2 emissions for ebikes and cars going from lower campus til upper campus"
CO2_vkm=162 "CO2_v is the CO2 emission pr. kilometer for an average american car, set to 162g CO2/km. "
CO2_kWh=607 "Emmssions from producing one 1kWh in a power plant"

"--------------------------------------------------------------------------------------------------------------------------------------"
"Cotst of using the car from lower campus to upper campus"
P_parking=440 [$/year] "-700" "Parking fee a year for parking at campus, varies from 400-900$: reference UCSC homepage"
gallon=3.785[l/gal] "liter pr. gallons "
mile=1.609[km/mile] "kilometers pr. mile"
avg_pr_gallon=27[mile] "average milage for a US car, reference: http://en.wikipedia.org/wiki/Fuel_efficiency"
Price_pr_gal=3.2 [$/gal] "Price pr. gallon of gas"
trips_a_year=200 "The average number of trips to top campus for a car"
Price_kWh=0.18 [$]

"--------------------------------------------------------------------------------------------------------------------------------------"
"Data for going from east side Santa Cruz on electrical bikes to lower campus. The start point is at the greenstation at the corner of
Soquel Ave. and Ocean st."
```

"Distances"
d_3=1000 "No incline or decline on route"
d_2=2700 [m] "incline h_2, no decline"
h_2=87 [m] "the altitude difference for d_2"
h_3=0 "Altitude difference for d_3, assumed neglected"

";) by Erasmus Rothuizen ;)"

SOLUTION
Unit Settings: [kJ]/[C]/[bar]/[kg]/[degrees]

a = 0.3 [m^2]	Amph_t1 = 1.579 [Ah]
Amph_t2 = 1.145 [Ah]	Amph_t3 = 0.1371 [Ah]
avg_pr_gallon = 27 [mile]	CO2_e = 34.5 [g]
CO2_e2 = 25.03 [g/trip]	CO2_e3 = 2.996 [g/trip]
CO2_ekm = 12.55 [g]	CO2_ekm2 = 9.269 [g/km]
CO2_ekm3 = 2.996 [g/km]	CO2_kWh = 607 [g/kWh]
CO2_v = 891 [g]	CO2_v2 = 874.8 [g/trip]
CO2_v3 = 324 [g/trip]	CO2_vkm = 162 [g/km]
c_v = 1.2	d = 2750 [m]
d_2 = 2700 [m]	d_3 = 1000 [m]
e_m = 0.85	e_t = 0.9
f_r = 0.085	g = 9.82 [kg*s/m]
gallon = 3.785 [l/gal]	h = 135 [m]
h_% = 0.04909	h_2 = 87 [m]
h_3 = 0 [m]	m = 100 [kg]
mile = 1.609 [km/mile]	Percentage_CO2_reduction = 0.03135
Price_etotal_east = 3.708 [$/year]	Price_etotal_east1 = 3.708 [$/year]
Price_etotal_east2 = 3.708 [$/year]	price_kWh = 0.18 [$]
Price_pr_gal = 3.2 [$/gal]	Price_vtotal = 521 [$]
Price_vtotal2 = 519.6 [$]	Price_vtotal3 = 469.5 [$]
P_m = 413.4 [W]	P_m2 = 305.4 [W]
P_m3 = 98.71 [W]	P_parking = 440 [$/year]
P_trip_kWh = 0.05684 [kWh]	P_trip_kWh2 = 0.04123 [kWh]
P_trip_kWh3 = 0.004935 [kWh]	rho_air = 1.188 [kg/m^3]
TOTAL = 0.103	Total_Amph = 2.861 [Ah]
Total_Amph_4trips = 11.45 [Ah]	Total_CO2_ekm = 10.16
Total_CO2_etrip = 65.52 [g/trip]	Total_CO2_vtrip = 2090 [g/trip]
Total_costs = 710 [$/year]	Total_kWh_year_east = 20.6 [kWh/year]
trips_a_year = 200	t_1 = 495 [s]
t_1_2 = 486 [s]	t_1_3 = 180 [s']
v = 5.556 [m/s]	Vol = 36 [V]

49 potential unit problems were detected.

Local variables in Procedure power (5 calls)

a =0.3 [m^2]	c =1000 [m]	c_v =1.2
d =1000 [m]	e_m =0.85	e_t =0.9
F_f =47.22 [W]	F_g=0 [W]	f_r =0.085
F_t =8.39	F_w =36.68 [MWh]	g =9.82 [kg/m*s^2]
h =0	m=100 [kg]	P_m =98.71 [W]
rho_air =1.188 [kg/m^3]	v =5.556 [m/s]	Vol =36 [V]

Local variables in Procedure CO2 (5 calls)

CO2_1 =64.8 [g/km]	CO2_e =2.996 [g/trip]	CO2_ekm =2.996 [g/km]
CO2_kWh =607 [g/kWh]	CO2_v =324 [g/trip]	CO2_vkm =162 [g/km]

CO2_year =128.4 [kg/year]	d =1000 [m]	emmit_e=1.198 [kg/year]
emmit_v=129.6 [kg/year]	people=5	P_km_kWh=0.004935 [kWh]
P_m=98.71 [W]	P_trip_kWh=0.004935 [kWh]	Reduction_%=0.009246
t_1 =180 [s]	v =5.556 [m/s]	

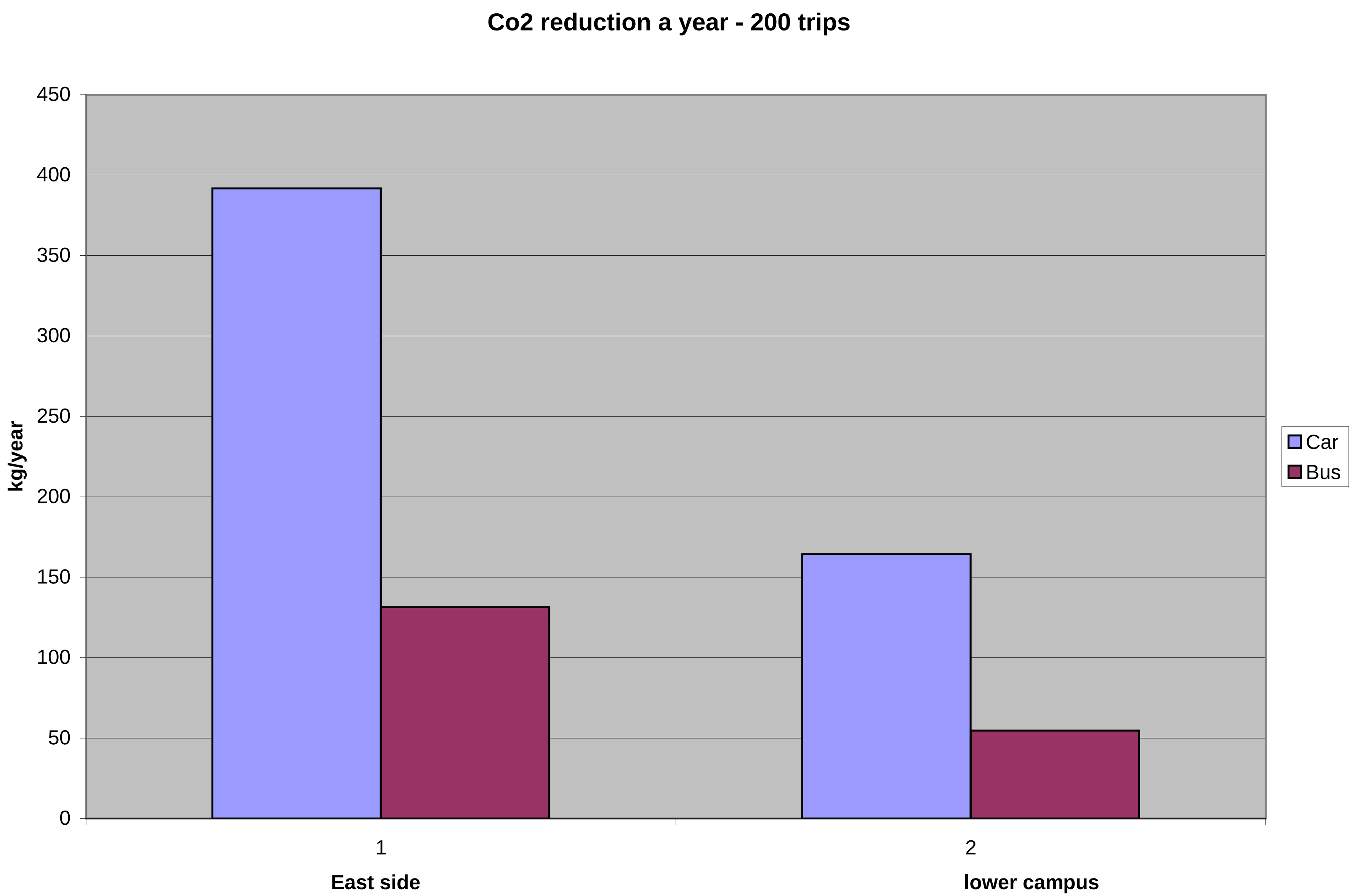
Local variables in Procedure battery (5 calls)

Amph=2.742 [Ah]	Amph_t=0.1371 [Ah]	d =1000 [m]
P_m=98.71 [W]	t_1 =180 [s]	t_t=720 [s]
v =5.556 [m/s]	Vol =36 [V]	

Local variables in Procedure costs (5 calls)

avg_pr_gallon =27 [Mile]	d =1000 [m]
gallon =3.785 [l/gal]	km_liter=11.48 [km/l]
mile =1.609 [mile/km]	Price_etotal_east=3.708 [$]
price_kWh=0.18 [$/kWh]	Price_pr_gal=3.2 [$/gal]
Price_vtotal=469.5 [$]	P_gas_liter =0.8454 [$/l]
P_parking =440 [$]	P_trip_kWh=0.05684 [kWh]
Total_kWh_year_east =20.6 [kWh/year]	trips_a_year=200

	Eatside	Lower campus	Notes and references
Distance in (m)	6450	2750	ref: Google earth
Altitude difference (m)	222	135	ref: Google earth
Average Co2 emission g/kWh electricity	607	607	ref: Postnote and EIA
Mass of bike and driver (kg)	100	100	
Speed ebike (m/s)	5.56	5.56	equivalent to 20km/h
Max Power needed ebike (W)	413	413	
Voltage of battery (V)	36	36	ref: Keith - sierra ebikes
Co2 pr km ebike (g/km)	10.16	12.55	
Co2 pr km car (g/km)	162	162	ref: Wiki
Co2 per km bus (g/km per passenger)	56	56	ref: M.J. Bradley & Associates
Co2 per trip ebike (g/trip)	65.52	34.5	
Co2 per trip car (g/trip)	2090	891	
Co2 per trip bus (g/trip per passenger)	722.4	308	
Amph per trip for ebike	2.861	1.579	
Co2 savings ebike vs. Car pr km (g)	151.84	149.45	
Co2 savings ebike vs. Car pr trip (g)	2024.5	856.5	
Co2 savings ebike vs. Car a year (kg)	391.79	164.4	Assumed 200 trips a year
Co2 savings ebike vs. bus pr km (g)	45.84	43.45	
Co2 savings ebike vs. bus pr trip (g)	656.88	273.5	
Co2 savings ebike vs. bus a year (kg)	131.38	54.7	Assumed 200 trips a year


Co2 reduction a year - 200 trips
kg/year
450
400
350
300
250
200
150
100
50
0
1
2
East side
lower campus
Car
Bus