Carbon Emissions Modeling of Caltech

Edward Lee

Mentor: Melany Hunt

Abstract:

It is no surprise that given the current state of the economy as well as the growing concern of carbon emissions and global warming, it is imperative for Caltech to model its own emissions and learn how to conserve energy. The first step for the Caltech community is to build a model that accurately determines our emissions as well as our projected emissions for the following years. Last year, this project began using the Clean Air-Cool Planet carbon emissions model, a model built specifically for the representation of a college or university's emissions. It is important now, to collect more data as well as add aspects to the model where assumptions were previously made such as embedded carbon in water transport, air travel, and the use of refrigerants and chemicals. Current results show that Caltech's emissions have started to level off with the 2008 emissions roughly the same as the 2007 emissions at around 90,000 MT of eCO_2. With more accurate and up to date data, Caltech's next step will be to look for places to cut back its use and ultimately lower its carbon footprint, an imperative goal with the many carbon emissions reduction plans currently enforced.

Text:

In the United States, California has been known to be the leading state in promoting environmental friendliness with its AB32 bill, which will set a mandatory cap on the carbon emissions of Californian companies and schools. This bill, passed in 2006, has initiated several more programs to reduce carbon emissions for the country. Recently, the "Cash for Clunkers" program has been started. This program rewards car owners with up to $4500 if they trade in their old, inefficient cars and buy a new, more fuel efficient car such as the popular Toyota Corolla or Honda Civic. Furthermore, the House of Representatives passed a bill introducing a cap and trade on carbon emissions with a goal being to reduce greenhouse gas emissions from 2005 by 17% by the year 2020 and 80% by the year 2050. The fact that the entire country has taken an initiative on reducing carbon emissions and not just California indicates how real and immediate the threat of global warming actually is. In order to meet these emissions caps, it is important for Caltech to start monitoring its greenhouse gas emissions. By modeling our emissions, we can get a projection of our future emissions as well as areas where we can cut back or make more efficient.

Last summer, another SURF student started Caltech's carbon emissions modeling using the Clean Air – Cool Planet model (CA-CP). This model was designed specifically for the modeling of campuses in the United States as opposed to homes and companies. The model looks at many aspects of the campus and determines the emissions by taking many inputs and running calculations to come up with a total emitted CO_2. In this model, there are three "Scopes":

1. Scope 1 views direct emissions from institute owned sources. The emissions from sources such as the On-Campus Co-Generation Plant, University Fleet vehicles, and Fertilizer Application fall into Scope 1.

2. Scope 2 views indirect emission from non-institute owned sources. Purchased electricity, steam, and chilled water fall into this category. While these emissions were not created on campus, it is counted under Caltech's emissions because Caltech is responsible for the use of the electricity, steam, and water.
3. Scope 3 looks at emissions that are not owned or operated by the institution but financed by the institution. For example, it looks at the commuting of faculty, staff, and students as well as the financed air travel of faculty. Often times these emissions are considered optional and looked over because they can be "de minimus" (of minimal) emissions.

For Caltech, the key contributors to the carbon footprint include the Co-Generation Electricity, Co-Generation Steam, and purchased electricity. The Co-Generation Plant works by taking in natural gas to run generators. However, the aspect of the plants that makes it more "green" is that it also captures the heat created as a by-product of electricity generation and uses it for more energy. There is also steam generation on campus that uses steam to produce electricity. These two forms of on campus generation provide clean electricity to the campus. Any additional power that may be needed would be purchased from the city of Pasadena. Since Pasadena gets its electricity from a variety of sources that are not as efficient as the Co-Generation system, purchased electricity yields an eCO_2 higher than if that electricity were produced on campus. In 2007, these three main contributors summed up to 68,366.3 MT eCO_2 and in 2008, they summed up to 73,790.9 MT eCO_2.

	Co-Gen Electricity	Co-Gen Steam	Purchased Electricity	MT eCO2
2007	16,202.90	33,273.50	18,889.90	68,366.30
2008	10,790.80	27,135.30	35,864.80	73,790.90

Figure 1: Major Emissions Contributors in 2007, 2008

When looking at the numbers, one notices that in 2008, Caltech purchased much more electricity and did not have as much of an emissions factor coming from the Co-Generation plants on campus. However, this anomaly is a result of the fact that the plants were down for part of the year for tune ups. To make up for the lack of electricity, Caltech had to purchase power from Pasadena and since purchased electricity isn't as clean as the electricity produced on campus, the total eCO_2 increased.

The numbers for the remaining fields such as Direct Transportation, Agriculture, Faculty/Staff Commuting or Student Commuting were roughly the same when comparing the 2007 and 2008 data. This data was obtained by contacting certain staff members and sorting through worksheets. Having filled in all the fields of the model that were filled in 2007, I have found that the total emissions for Caltech in 2008 were around the same as in 2007 at 90,467.5 MT of eCO_2. Figure 2 shows the graph of carbon emissions of Caltech since 1990 and the growth trends. We see that our emissions have hopefully leveled off and will start decreasing in the coming years now that there is a more conscious effort to lower emissions. The "hump" around years 2004 and 2005 are a result of the installation and testing of the new cogeneration plants as well as abnormally warm weather.

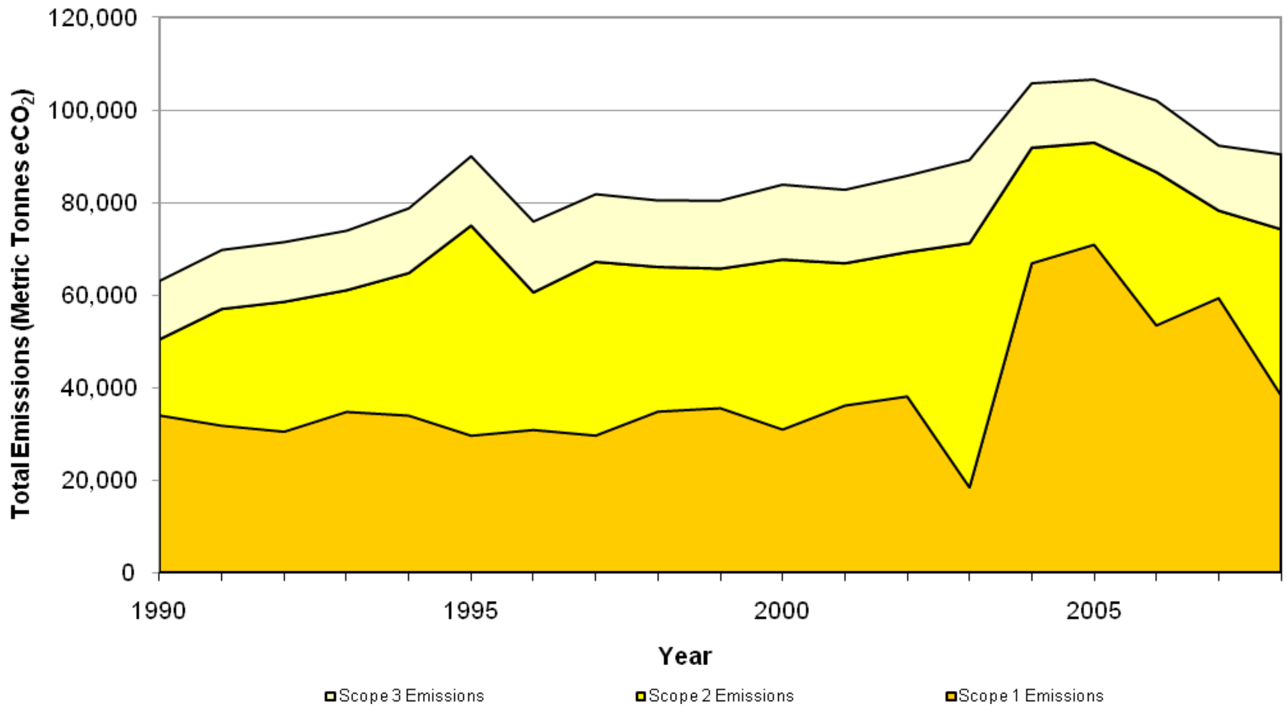

Figure 2: Total Emissions by Scopes from 1990-2008

With the data updated for 2008, the next step is to look into areas of carbon emissions that have not yet been covered in the model or are not in the model. The three areas of focus made so far have been in the use of Refrigerants and Chemicals, the transportation of water to and away from campus, and the emissions from the air travel of faculty as Caltech personnel. While these numbers did not overwhelmingly distort our carbon emissions, they do show that they contribute and in some cases significantly to our emissions. The data for 2008 has not been released yet, but for the year 2007, it has been calculated that the use of Refrigerants and Chemicals have added 312 MT eCO_2 to the total emissions. The emissions from pumping the 202 million gallons of water used on campus in 2008 was an additional 386 MT eCO_2. Lastly, of the three areas inspected, Air Travel seems to be the most significant with 797 MT eCO_2 for the 300 faculty members who answered the Air Travel survey. If this were extrapolated to the approximate 3000 faculty members, this could be a total of nearly 8000 MT eCO_2.

Methods

The research needed to determine the emissions from the use of refrigerants and chemicals was quite simple. Having received the data on refrigerant loss from 1995 to 2007, we could find the number of pounds used. The main chemicals we used were R-11, a trichlorofluoromethane with a Global Warming Potential (GWP) of 4000 and HCFC-22, a cholorodifluoromethane with a GWP 1700. Since the GWP is a measure of the equivalent mass of CO_2 released into the atmosphere per pound of chemical, we can simply multiply to find the net emitted CO_2 from our chemical usage. This total came out to 386 Metric Tons of eCO_2.

The delivery of water to campus originally worried us that it would increase our emissions significantly. Water is a heavy resource to carry and since Southern California is so dry, nearly all of our water supply is imported from the Metropolitan Water District (MWD), a collection of rivers from Northern California as well as the Colorado River. In 2008, Caltech used 202.5 million gallons of water. Using the water reports provided by the Pasadena Water and Power Department (PWP), 65% of this water came from the MWD and the remaining 35% was pumped from groundwater in local wells in 2008.[1] After contacting Brad Boman, an environmental engineer at the PWP, it was concluded that this year, the MWD pumped 35% of its water from Northern California and 65% of its water from the Colorado River. During the years of 2004-2005 however, the MWD pumped 70% of water from Northern California and 30% of the water from the Colorado River and before then, it was the opposite with 70% of the water coming from the Colorado River and only 30% coming from Northern California. These fluctuations between the sources of our water are due to pumping restrictions in one place or the other. For example, this year, there was a bill passed to pump less water from Northern California in order to preserve fish that were swimming in the rivers. To make up for this loss, more water had to be pumped from the Colorado River.

From the PWP, it was discovered that approximately $120 goes into pumping and treating an acre-foot of groundwater.[2] Since power is 11cents per kilowatt-hour, the power required to pump an acre-foot, equivalent to 326,000 gallons, of water is 1090kwh. As for the embedded energy in the MWD, a joint presentation given by the California Institute for Energy and Environment and Geotechnical Engineers, Inc had data on the energy intensity of pumping water to Southern California. The conveyance of water from Northern California along the California Aqueduct takes 2,500kWh/af while bringing water from the Colorado River only takes 2,000 kWh/af.[3] The water is then pumped to the Weymouth Treatment Plant in La Verne. There, the water is treated at the additional cost of 42.1 kWh/af.[4] Afterwards, it is assumed to flow downhill where the water is used at Caltech. Information on the distribution of wastewater has not been found yet. However, it can also be assumed that the water is treated once again at a similar energy cost where afterwards it flows downhill to the ocean.

Figure 3: California's Pumping System

Source	Water (Acre Feet)	Amount	Amount	Intensity	Energy
Nor.Cal Water	621.53 af	.65 MWD	.35 Norcal	2500 kWh/af	353,495.2 kWh
Col. Riv. Water	621.53 af	.65 MWD	.65 Col Riv	2000 kWh/af	525,192.9 kWh
Treatment	621.53 af	.65 MWD	-	42.1 kWh/af	17,008.2 kWh
Ground-Water	621.53 af	.35 GW	-	1090 kWh/af	237,331.23 kWh
Waste Water Treatment	621.53 af	1	-	42.1 kWh/af	17,008.2 kWh
Total					1,150,035.7 kWh

Figure 4: Total Embedded energy in Conveyance of Water

Following the calculations shown in Figure 4, we see that the total amount of energy used in transport is 1,150,035.7kWh. To find the resulting amount of carbon emissions from the use of this energy, we need to use California's custom fuel mix for generating power. This is the combination of coal, natural gas, nuclear, and renewable energy that is used in electric utility plants. Using this, the CA-CP model can calculate the net carbon emissions of using 1.15 million kWh. This equates to approximately 386 Metric Tons of eCO_2.

In previous years, the way we measured the carbon emissions from air travel has been by looking up the reports given by Protravel, Caltech's air travel booking agency. It takes in the total number of miles flown and then multiplies that by the average MMBtu per passenger mile and the kilograms of CO_2 per MMBtu of the jet fuel. By multiplying these numbers out, the calculator generates an approximate estimate of the emissions from air travel. However, after talking with faculty members, it seemed that most people did not travel using Protravel and the model seemed to make lots of assumptions and was not specific.

To alleviate this problem, I created a carbon calculator for Air Travel using a similar approach to Professor Kwan at UCLA. This calculation involves splitting up travel miles into short range, medium range, and long ranged flights.[5] These flights would then be assigned a "typical aircraft" such as the Boeing 737-700 for short ranged flights, Boeing 777-400 for medium ranged flights, and Boeing 747-400 for long ranged flights. The ranges were set up with short range as less than 3000miles, medium range as 3000-5500 miles, and long range as greater than 5500miles. Having looked up the specifications online, one can find the passenger capacity, load factor, landing and take-off emissions, and jet fuel efficiency per aircraft. With these numbers, one could multiply the miles by the fuel efficiency, add the CO_2 emitted from landing and take-off and divide it by the product of the passenger capacity and the load factor. By doing this, the emissions are more specific towards where the faculty member traveled.

Factor	B737-700	B777-400	B747-400
Range	<3000	3000-5500	>5500
Passenger Capacity	126	350	400
Load Factor	85%	85%	85%
Fuel Efficiency	1.9 GPM	4.38 GPM	6.48 GPM
CO2 emitted/LTO	3,150 kg	5,200 kg	7,900 kg

Figure 5: Airplane Specifications

To find out the quantity of trips faculty members made without using Protravel, I ran a survey with a small sample size of the faculty at Caltech consisting of the Mechanical Engineering Department, Aeronautics Department, GALCIT Department, Applied Physics

Department, and a few other faculty members from different departments. The survey consisted of questions regarding the number of trips that the faculty member has made as a Caltech representative in the past 12 months, if they used Protravel to book the flight, and the destination of the previous four trips. While layovers would affect the emissions slightly, it was decided that it would be too much to ask of the surveyors and that it would decrease the response rate. The targets of the survey were professors, assistant professors, associate professors, post docs, graduate students, and others such as visiting professors. Using this data, I could extrapolate the number of miles traveled by each faculty member to the total number of trips made the past year and would later be able to extrapolate the emissions to the entire faculty population. Of approximately 300 surveyors, there were 85 responses. After extrapolation for the number of trips made and entering it into the calculator based on short, medium, and long ranged flights, the 85 responses yielded a carbon emissions of 80.6 MT eCO_2. However, one must take into account the effect of radiative forcing. Radiative forcing measures the insolation change in the atmosphere and the fact that the airplane directly emits greenhouse gases into the atmosphere. This makes the gases 2.7 times worse than if it were emitted on the ground. Therefore, the final emissions for the 85 surveyors is 217.6 MT eCO_2. If we extrapolated to all 300 people who were asked to take the survey, the emissions would be 796.2 MT eCO_2. The next step to this research would be to take other small samples from different departments and see how the emissions add up. However, assuming that the 300 faculty members were representative of the 3000 faculty of Caltech, this could potentially yield an additional 8000 MT eCO_2 on Caltech's carbon footprint. The next step to this research would be to take other small samples from different departments and see how the emissions add up. Afterwards, we would get a detailed analysis of Caltech's carbon emissions and be able to begin reduction programs and see their effects.

References

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