Appendix D: Carbon Model

Carbon Model

Dave Erickson, Climate Protection Campaign, September 2009

The Carbon Model is a mathematical representation of all of the significant sources of direct and indirect carbon dioxide emissions in Napa County, and the quantity of emissions from each source. This model also incorporates a representation of ”opportunities for intervention” (OFI). The OFI are a means for quantifying emissions reduction from a particular measure or set of measures. The OFI are sector specific and refer to a range of reduction measures, both on the energy supply side, and on the energy demand side.

The Carbon Model gives us a mathematical way for quantifying the effect of emissions reduction measures in various sectors. It allows us to answer questions regarding “how much will be achieved” by a possible measure. It also allows us to answer questions of scale, i.e., “what is the necessary scope of the measures” to reach the overall target. If a cost can be associated with a particular measure, we can evaluate the cost effectiveness, i.e., the amount of carbon reduction per dollar invested.

The model is organized in a fashion similar to a standard emissions inventory. In fact, it is built using inventory source data.[1] The model includes baseline data for electricity use, natural gas use and transportation in Napa County for the years 1990 and 2005. The model also contains projections for “business as usual” levels in each sector for the year 2020.[2] The model was developed using statistics from the California Energy Commission studies on end use of electricity and natural gas in the residential and commercial sectors. The transportation statistics come from Metropolitan Transportation Commission studies of Bay Area travel forecasts. As much as possible, statistics that are local to Napa County were used. In some cases, statewide or national averages were used.

Electricity and natural gas sectors are divided into residential and commercial subsectors. Industrial and agricultural sectors are not included in carbon reduction evaluation. This is due to the fact that there is no general energy end use data for these sectors. The data that is available tends to be specialized and difficult to use to make estimates of reduction measures. The simplification of end use to include only residential and commercial subsectors was considered to be usable because these subsectors account for the majority of energy use in Napa County.

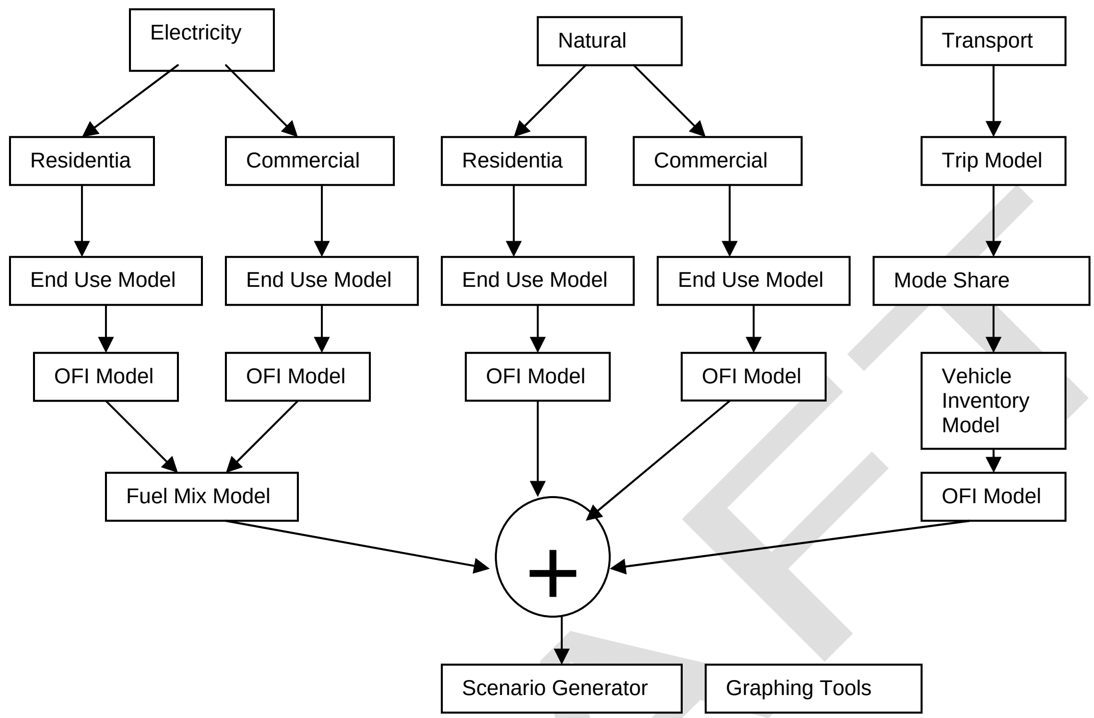
---

[1] Data were obtained from the California Energy Commission, and the Metropolitan Transportation Commission. Population data were obtained from the California Department of Finance, and from the County of Napa.

[2] Projection and estimation methodology is described in “PG&E LTPP Analysis” developed as part of the Sonoma County Community Climate Action Plan and available online (www.coolplan.org).

Structure of the Model

Figure 1



The electricity and natural gas elements of the model are identical in their structure. The model uses historical data from the California Energy Commission. These data are organized into total megawatt-hours and therms for Residential, Commercial, Industrial and Agriculture and Water Pumping.

The transportation element of the model uses data from the Metropolitan Transportation Commission 2005 Travel Forecast. These data are organized into:

- Total passenger trips
- Average trip length for each trip type
- Share of total trips for each trip type
- Mode share distribution for each trip type

In addition, the transportation element uses vehicle inventory distribution data. The vehicle inventory is estimated using an “On Road Stock Turnover” model, supplied in this case from the Oak Ridge National Laboratory. The total fuel use is estimated using average vehicle fuel efficiency for each of the vehicle types in the On Road Stock Turnover model.

Electricity and Natural Gas Elements

The total consumption figures for Residential and Commercial electricity and natural gas subsectors are input to the End Use model. This model is derived from data from various CEC-sponsored end use studies. This model uses a climate-zone specific percentage breakdown of energy end use in the residential and commercial sectors.[3,4,5]

The output of the End Use model is a set of consumption numbers (kWh and therms) that correspond to each end use in the residential and commercial electricity and natural gas sectors.

The OFI model for each sector takes as input an efficiency improvement figure for each end use, and a "penetration" or "uptake" figure. This represents the percentage of the total number of end use application types that would be upgraded. For example, a 50 percent uptake rate on a high efficiency refrigerator means that 50 percent of the households in the service territory have installed one.

As an example, Table 1 shows the OFI table for the residential electricity sector. It shows the results of a theoretical efficiency upgrade program that upgrades the electric water heaters to solar water heaters and upgrades clothes dryers, freezers and dishwashers to super-high-efficiency models. The existing units in 80 percent of the residences are replaced with units that use 80 percent less energy. The solar hot water heater uses 95 percent less energy than an electric model (hypothetical). This will reduce the annual projected residential electric energy use in Napa County from 367 GWh to 314 GWh, an approximate 15 percent reduction in total residential electricity use.

[3] California Statewide Residential Appliance Saturation Survey, Kema-Xenergy/Itron, 2004-2006.
[4] California Commercial End Use Study, Itron, 2006.
[5] California Statewide Commercial Sector Natural Gas Energy Efficiency Potential Study, Kema-Xenergy, 2003.

Table 1

End Use	percentage of total use	Cumulative percentage	2005 GWh	Penetration	% improvement	2005 after retrofit
Refrigerator	**13.7**	**13.7**	**50.4**	**0%**	**0%**	**50**
A/C (central & room)	**16**	**29.7**	**58.8**	**0%**	**0%**	**59**
Space Heat	**10.1**	**39.8**	**37.1**	**0%**	**0%**	**37**
Water Heat	**9.1**	**48.9**	**33.4**	**80%**	**95%**	**8**
Lighting	**8.8**	**57.7**	**32.3**	**0%**	**0%**	**32**
Residual	7.3	65	26.8	**0%**	**0%**	**27**
Clothes dryer	**5.8**	**70.8**	**21.3**	**80%**	**80%**	**8**
Freezer	**3.5**	**74.3**	**12.9**	**80%**	**80%**	**5**
Furnace Fan	3.3	77.6	12.1	**0%**	**0%**	**12**
Television	2.9	80.5	10.7	**0%**	**0%**	**11**
Electric Range Top	2.8	83.3	10.3	**0%**	**0%**	**10**
Dishwasher	**2.5**	**85.8**	**9.2**	**80%**	**80%**	**3**
Electric Oven	1.8	87.6	6.6	**0%**	**0%**	**7**
Microwave Oven	1.7	89.3	6.2	**0%**	**0%**	**6**
Personal Computer (Desk Top)	1.5	90.8	5.5	0%	**0%**	**6**
Other	9.2	100	33.8	0%	**0%**	**34**
Total	100		367.6			**314**

Natural gas OFI is treated in the same way. Shown below is the OFI table for residential natural gas use. This particular OFI models the effect of the installation of solar hot water heaters on 80 percent of the residences in the county. 2005 use and the result are given in therms.

Table 2

Residential Natural Gas End Use	**Percent of total**	**Cumulative**	2005	Penetration	% improvement	Result
Space Heating	44%	44%	9,395,724	0%	0%	9,395,724
Water Heat	44%	88%	9,395,724	80%	95%	2,254,974
Cooking	7%	95%	1,494,774	0%	0	1,494,774
Dryer	3%	98%	640,618	0%	0%	640,618
Pools, Spas, misc	2%	100%	427,078	0%	0%	427,078
Total	*100%*		21,353,919			14,213,168

The program modeled in Table 2 results in a decrease of approximately 7 million therms from business as usual residential natural gas consumption, a 33 percent reduction.

Electricity GHG Evaluation

The output of the OFI model for electricity is used as input to the Fuel Mix Model. This model represents the mix of generation resources used to supply the grid electricity used in the county. Table 3 shows an example of a fuel mix. The format for the first two columns is the same as the familiar “Power Content Label” required by the CPUC for electricity retailers. The third column entries are the average emissions intensity for that generation type. There are various sources for these numbers, but the one used for this model is eGRID from the EIA.[6] The fourth column calculates the total emission factor for that particular “portfolio” or mix of resources.

[6] From the EPA website: “The Emissions & Generation Resource Integrated Database (eGRID) is a comprehensive inventory of environmental attributes of electric power systems. The preeminent source of air emissions data for the electric power sector, eGRID is based on available plant-specific data for all US electricity generating plants that provide power to the electric grid and report data to the US government. eGRID contains air emissions data for nitrogen oxides, sulfur dioxide, carbon dioxide, and mercury.”

The purpose of the fuel mix model is to enable the evaluation of different portfolios of electricity generation resources in terms of their effect on the GHG emissions due to electricity use. The model shown in Table 3 shows the emissions factor from a portfolio consisting of 43 percent natural gas fired generators and 4 percent coal fired generators. The gray area on the model indicates non-emitting resources.[7] The combined emission factor from this resource mix is 0.56 lb eCO2/kWh. This result is then used, along with the electricity OFI model output, to calculate the combined effects of efficiency and varying levels of renewables on the total emissions due to electricity use.

Table 3

Energy Resources	Power Mix	Resource lb/kWh	Combined Emission Factor
Eligible Renewable	67%		
Biomass and waste	14%		
Geothermal	32%		
Small hydroelectric	3%		
Solar	7%		
Wind	11%		
Nuclear	0%		
Large Hydroelectric	14%		
Natural Gas	19%	1.05	0.20
Coal	0%	2.73	0.00
Other			
TOTAL	100%		0.20

Natural Gas GHG Evaluation

The output of the OFI tables for residential and commercial natural gas use are evaluated directly for their GHG emissions levels.

For natural gas, there is a fixed emission factor of 12.3 lbs eCO2/therm. This figure is an average of the suggested EPA factor for natural gas combustion (11.7 lb CO2/therm) and the suggested IPCC factor (13.0 lb CO2/therm).

Transportation Element

The Transportation Element has four components:

1. Total trips, trip type, average trip length and trip modal distribution table
2. Vehicle inventory and fuel efficiency table
3. Total fuel use and GHG calculation

[7] Although there are emissions from geothermal, large hydroelectric (methane emissions), and nuclear (from energy used for fuel mining, milling and refining) the State of California considers these generation types to be non-emitting.

4. OFI table

The first element is used to compute total Vehicle Miles Traveled (VMT). The data used in this element come from the Metropolitan Transit Commission Travel Forecast Survey 2005. The best way to visualize the organization of this table is as a two dimensional matrix. The rows of the matrix represent the trip generation model. The columns represent mode choices.

The trip generation model used in this Travel Forecast is composed of the following types:

1. Home-based work
2. Home-based shop
3. Home-based Social/Recreation
4. Non-home-based
5. Home-based grade school
6. Home-based high school
7. Home-based college

Each of these trips types is assigned a share of the total number of trips. There is an average trip distance associated with each of these trip types.

The mode choices for each trip type are as follows:

1. Drive alone
2. Drive 2
3. Drive 3+
4. Transit
5. Walk
6. Bicycle

For the purposes of our transportation OFI, we have simplified modes 1-3 to

1. Car driver
2. Car passenger

The output of this table is total VMT. The input to this table is “daily person trips.” This is the total number of trips made each day in Napa County for all purposes, in all modes. This number is converted into passenger miles, which is then converted to vehicle miles using a “loading factor.” The loading factor is the number of passenger miles achieved for each mile of vehicle movement. For Napa County transit, the loading factor used was four. That is, an average of four passengers per transit vehicle was assumed for this model.

The calculated annual VMT based on daily person trips for year 2005 is then calibrated to match VMT obtained from the MTC for year 2005. This step is necessary to insure that the input to the vehicle inventory is accurate.

The total calculated VMT is input to a vehicle inventory, which is based on the On Road Vehicle Turnover model mentioned above. This is a national average of the vehicle types and the average fuel efficiency for each vehicle type on the road. The output of this table is the total number of gallons of gasoline and diesel fuel used for the year. These fuel amounts are then converted to (metric) tonnes of GHG, using the factors 21.1 lbs eCO2/gallon for gasoline and 22.1 lbs eCO2/gallon for diesel.

The OFI table (shown below in Table 4) has six categories of opportunities to reduce emissions:

1. Transit share increase
2. Non-motorized share increase
3. Non-emitting vehicle
4. Trip (number) reduction
5. Carpool/Vanpool increase
6. Trip length reduction

Table 4

Measures	Transit Share Increase	Non Motorized Share Increase	Non-emitting vehicle	Trip reduction	Carpool/Vanpool Increase	Average Trip Length Reduction
	Free transit pass	Full Path System	Biofuel	Gas tax	Employee Commute Program	Walkable Facility
	Increase bus service	Walkable Facility	Plugin Hybrid	Congestion Price	Rural Service Network	Land Use
	Other public transportation	Land Use	Other	Land Use	Car Share	Other Reg
	Rural Service Network			Delivery Service	Ride Auction	
	Tax Policy			Online shopping	Tax Policy	
				Other Tax Policy		
				Telecommute		
Totals	5%	9%	15%	5%	4%	3%

Opportunities 1, 2 and 5 use the desired percentage shift (entry in the table) to reduce the Car Driver mode share assignment and increase walking and biking, Drive 2/3+ or transit mode share. The non-motorized share increase decreases vehicular modes according to the loading factor. The non-emitting vehicle decreases the share of each standard vehicle type in the vehicle inventory. Trip reduction reduces total daily trips by the entered percentage and trip length reduction reduces average trip length of all trip types by the entered percentage.

Likely and realizable mode share shifts for transit, walking and biking, as well and trip number and length reduction were obtained from the Napa County Transportation Planning Authority.

Non-emitting vehicle increase amount was used to model the effect of a plug-in hybrid or electric car share fleet.

OVERALL IMPACT SUMMATION AND SCENARIOS

The final step in producing the output of the carbon model is to convert the energy use numbers to GHG emissions and compare those to the target levels.

Table 5 and Table 6 below show the target reference numbers for electricity and natural gas. The total Napa County use in each subsector in 1990 is shown with its corresponding GHG emission level. The GHG emission level for electricity for PG&E for 1990[8] is calculated using the carbon intensity factor of 0.566 lb eCO2/kWh. Below the 1990 level is the target level for each subsector. The emission level for natural gas in each sector is calculated using the emission factor mentioned above.

Table 5

Year	Residential	Commercial	Industrial	Agriculture & Water Pumping	Total	GHG (tonnes)
Electricity						
1990 (million kWh)	*291*	*234*	*96*	*13*	*634*	
tonnes ghg (1990 PGE mix)	74,613	60,172	24,546	3,362		162,694
Target GHG Electricity	74,613	60,172	24,546	3,362	-	162,694

Table 6

Natural Gas						
1990 (million therms)	**23.1**	**13.3**	**3.8**	**0.2**	**40.4**	214,265
Target GHG Natural Gas (tonnes)	**122,608**	**70,761**	**20,071**	**825**	**214,265**	**214,265**

Table 7 below shows typical results from the electricity model. The blue rows show the projected consumption for 2020 in each subsector, along with the projected total emissions level based on the PG&E Long Term Procurement Plan.[9] This is also known as "the business as usual level." The next rows in orange show three scenarios:

1. The resulting GHG emissions if just the emission factor from the Fuel Mix Model is used (CCAP Fuel Mix GHG).
2. The GHG emissions if only the effects of the Residential and Commercial efficiency models are considered, using the business as usual electricity emission factor (CCAP Efficiency GHG).
3. The combined effect of both the fuel mix and the efficiency models. Residential and Commercial subsector efficiency improvements only are considered in the scenarios. The Industrial and Agriculture & Water Pumping subsectors are modified by the fuel mix model (Fuel Mix GHG and Combined).

Table 7

Year	Residential	Commercial	Industrial	Agriculture & Water Pumping	Total	GHG (tons)	% below 1990
2015 (million kWh)	***1,406***	***1,289***	***405***	***129***	***3,230***		
Electricity BAU (tons)	***254,530***	***233,338***	***73,344***	***23,418***		***584,630***	***5%***
CCAP Fuel Mix GHG	140,273	128,594	40,420	12,906	322,193	322,193	48%
CCAP Efficiency GHG	217,704	193,374	73,344	23,418	507,840	507,840	18%
Combined Efficiency & Fuel Mix	121,816	106,569	40,420	12,906	281,711	281,711	54%

The last two columns of the model show total GHG emissions and percentage reduction below 1990 levels. From this example output it can be seen that the modeled efficiency programs

[8] The California Climate Action Registry: Development of Methodologies for Calculating Greenhouse Gas Emissions from Electricity Generation. Environmental Energy Technologies Division, Ernest Orlando Lawrence Berkeley National Laboratory, August 2002.

[9] Pacific Gas and Electric Company 2006 Long Term Procurement Plan, filed with the California Public Utilities Commission, March 2007.

alone result in an 18 percent reduction below 1990 levels. The fuel mix alone results in a 47 percent reduction, while the combined effect of the modeled fuel mix and efficiency results in a reduction of 54 percent below 1990 levels. For comparison, the business as usual reference results in a 5 percent reduction below 1990 levels.

Table 8 below shows example output from the natural gas model. As in the electricity model, the rows in blue show the business as usual projection for natural gas use in 2015. The rows in orange show the results of two scenarios:

1. The effects of residential an commercial natural gas efficiency programs;
2. The results of a natural gas replacement program in which natural gas space heating is replaced with heat pumps and natural gas water heaters are replaced with solar water heaters.

Table 8

Year	Residential	Commercial	Industrial	Agriculture & Water Pumping	Total	GHG (tons)
2015 projected (million therms)	***81.8***	***39.1***	***7.0***	***1.1***	***129.0***	
Natural Gas BAU (tons)	**478,561**	**228,599**	**40,775**	**6,716**		***793,350***
CCAP Efficiency Rollout	312,105	208,291	40,775	6,716		567,886
CCAP Geothermal Rollout	334,865	107,664	40,775	6,716		490,019

Table 9 shows the output from the transportation model. The Transportation Scenario line shows the aggregated reduction of all measures in the Transportation OFI table. A negative “percentage below” means “percentage above.” In the table below, the 2015 projected level is 19.2 percent above 1990.

Table 9

Transportation	Annual VMT	tons eCO2	% below 1990
1990 Level	**3,007,965,000**	**2,340,667**	**0.0%**
Target Level (25% below 1990)		**1,755,500**	**25.0%**
2015 Projected Level	**4,440,902,008**	**2,788,992**	-19.2%
CCAP Transportation Scenario		2,049,542	12.4%

Table 10 below shows the total model output summation. There are four scenarios that have been defined showing the aggregate effects of actions in each sector. The first two columns show the “Business as Usual” scenario. This is the scenario in which there is no action taken in any sector at the local level. The projected emissions for each scenario are shown in the first column and the percentage below 1990 levels in the next column for each sector.

The scenarios are as follows:

1. Residential and Commercial electricity end-use efficiency programs only
2. Residential and Commercial electricity end-use efficiency and renewable grid fuel mix
3. Residential and commercial electricity efficiency, renewables and natural gas replacement

4. All of the above plus required transportation OFI

Table 10

Sector	BAU	below 1990	Scenario 1	below 1990	Scenario 2	below 1990	Scenario 3	below 1990	Scenario 4	below 1990
Electricity	584,630	5.5%	474,031	23.4%	263,476	57.4%	263,476	57.4%	263,476	57.4%
Natural Gas	793,350	-18.5%	793,350	-18.5%	793,350	-18.5%	490,019	26.8%	490,019	26.8%
Transportation	2,788,992	-19%	2,788,992	-19%	2,788,992	-19%	2,788,992	-19%	2,049,542	12%
Total	4,166,972	-15%	4,056,373	-12%	3,845,818	-6%	3,542,487	2%	2,803,037	23%
1990 Total	3,628,880									
Target Total	2,721,660									

Example Outputs

The model is implemented as an Excel spreadsheet. As such, the output of the model can be represented in either tabular or graphic form, using the capabilities of Excel. The model enables us to project the effects of efficiency programs and different renewable generation portfolios on emissions in the electricity and natural gas sectors. For the transportation sector, we can project the effects of programs designed to shift mode share, reduce the number of trips, or reduce average trip length. We can also project the effects of using “non-emitting” vehicles such as EVs.

Figure 2 shows the effect on emissions in the residential electricity sector from the rollout of six different levels of energy efficiency improvement programs. Each curve in the figure corresponds to a particular uptake rate, from 70% adoption to 95% adoption. The X axis is the overall percentage improvement in efficiency, from 20% to 80%. For example, the top blue line shows the change in GHG emissions if a program is implemented where the adoption rate is 95%, and the level of efficiency improvement is varied between 20% and 80%. This graph assumes a package of end use electricity upgrades that include the top eight residential electricity using appliances:

1. Refrigerator
2. Air conditioner
3. Space heater
4. Water heater
5. Lighting
6. Clothes dryer
7. Freezer
8. Dishwasher

Note: The fuel mix used for these results was assumed to be the same as the 2006 PG&E mix.

This chart shows that emissions from electricity use in the residential sector will be reduced by 25 percent below 1990 levels (target level) if 95 percent of the residences in Napa County install a package of upgrades to the listed end uses that has an overall 65 percent efficiency improvement. At the other end of the range, a minimum of 75 percent of the residences would have to adopt a package of upgrades that has an overall 80 percent improvement in efficiency in order to achieve the target level.

Figure 2

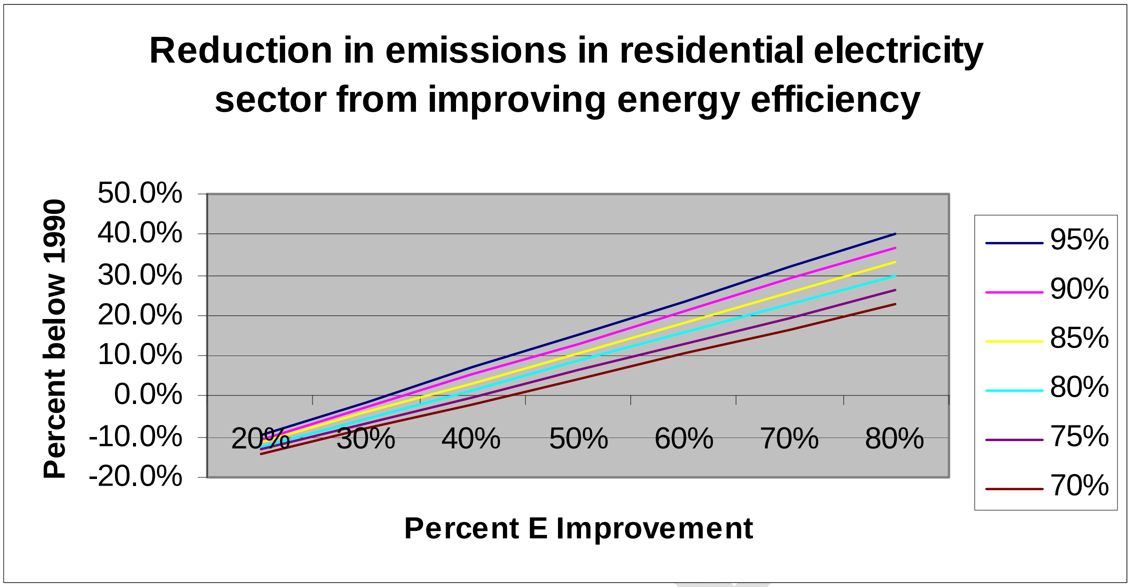
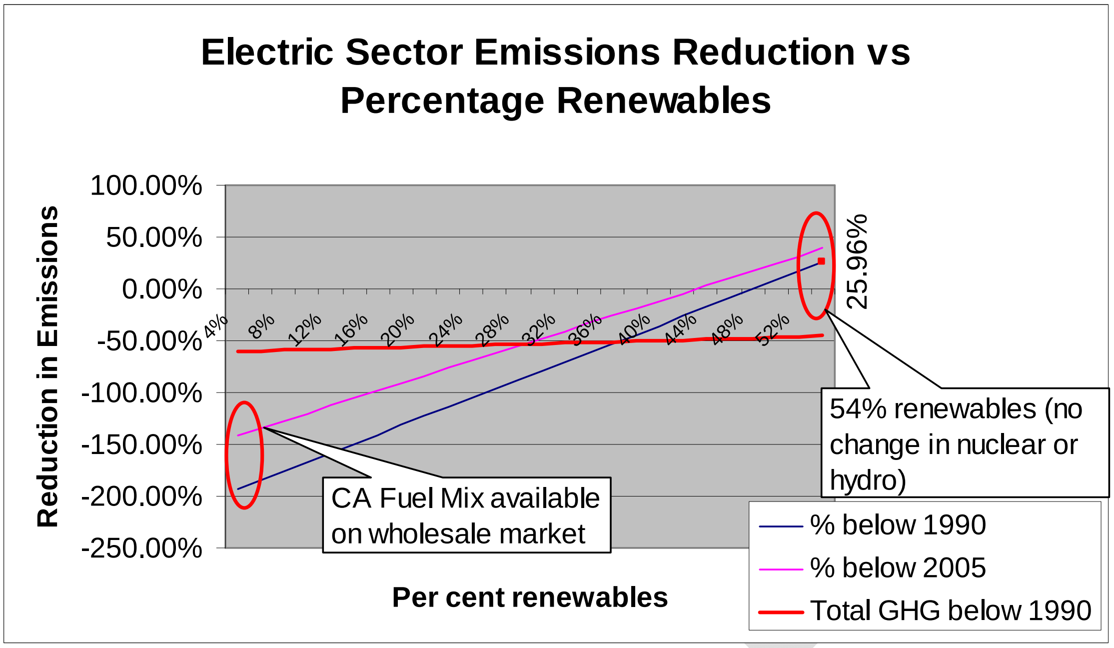


Figure 3 below shows the reduction in total carbon emissions in the electricity sector as the percentage of eligible renewables is increased. The starting point on the curve is the emissions from the "California Mix" which is the fuel mix of the wholesale power market. 25 percent reduction below 1990 levels in the electricity sector occurs at 54% renewables. The red curve shows the effect on overall (total) emissions from increasing renewables only, and keeping all other emissions sources (in all sectors) constant. This experiment shows how we can vary the effect of a single emissions reduction measure and track the effect on total emissions, as well as the effect within a single sector.

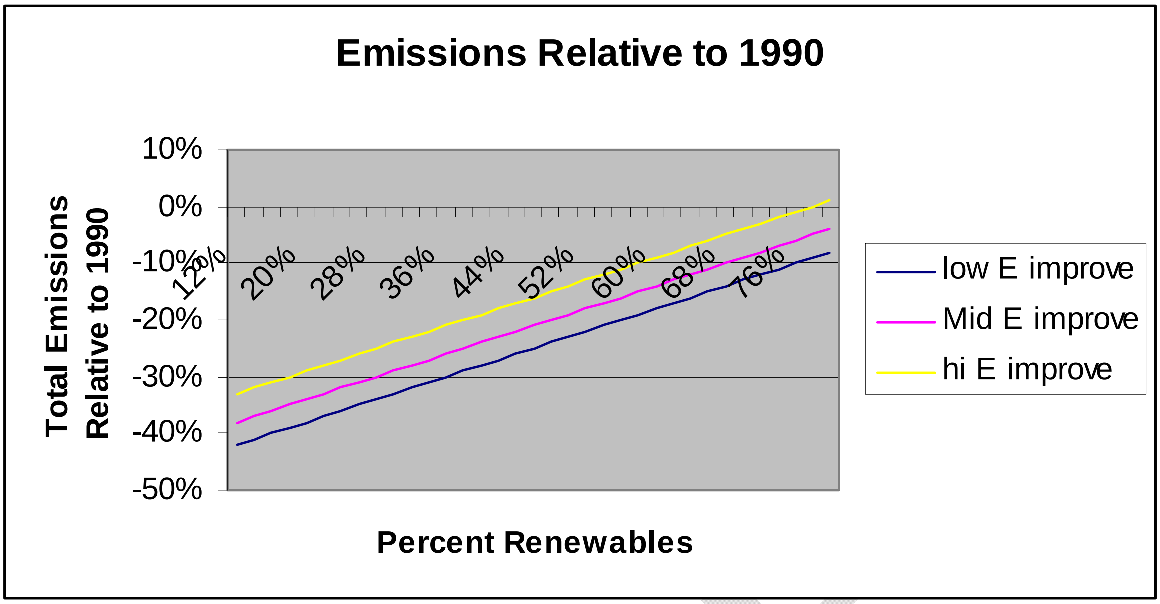
Figure 3



Finally, we can plot the effect on emissions of multiple reduction programs at varying levels of effectiveness. The curves for reductions in total emissions relative to 1990 due to efficiency improvement and increase in the percentage of renewables combined are shown in Figure 4 below.

This experiment shows the level of renewables and efficiency that would have to be implemented in order to reach the Napa County overall emissions target. The curve labeled “low E improve” is from a “low adoption rate” residential electricity efficiency program (70%) with “low” overall efficiency improvement (20%). The curve labeled “hi E improve” is from a very high adoption rate residential electricity efficiency program (95%) with a very high efficiency improvement (80%). A high efficiency improvement was included in the commercial electricity sector. This graph assumes no change in the transportation sector, or in natural gas use. This graph shows how the effects of multiple variables on total emissions can be modeled.

Figure 4



Summary and Conclusion

This report describes the “carbon model” used in the CCAP to estimate the effects of emission reduction measures on the overall emissions of GHG from Napa County. The model can be used to determine the necessary reductions from measures in each subsector. “Opportunities for intervention” represent the categories of actions that can be taken to reduce emissions in each sector. This model can be used to both quantify the effects of specific measures and to estimate the optimum level of reduction from each set of measures required to reach the overall reduction target.