ASSESSMENT OF THE EMISSION REDUCTIONS ACHIEVED IN TEXAS NONATTAINMENT AREAS BY UTILIZING ELECTRIC VEHICLES TO COMPLY WITH SENATE BILL 200

THESIS

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………to my loving wife Lisa

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CHAPTER 1

INTRODUCTION

Technological and regulatory solutions to the air quality problem in our nation's nonattainment areas have been proposed, and now is the opportune time to integrate the two. One attempt by the federal government to improve air quality in our nonattainment areas is the Federal Clean Fuel Fleet (FCFF) program, which was established by the 1990 Federal Clean Air Act (FCAA) Amendments. This program is directed at private and public owners of fleet vehicles, and requires them to convert their fleets to vehicles with fewer emissions. The FCFF program affects federal, state, local government, and private fleets in nonattainment areas. These are areas classified by the Environmental Protection Agency (EPA) as being in serious, severe, or extreme nonattainment of the National Ambient Air Quality Standards for ozone and carbon monoxide (TNRCC 1996). States are required to either adopt this program or implement one that demonstrates equivalent emission reductions.

Texas made the decision to opt out of the federal program. The Texas Natural Resource Conservation Commission (TNRCC) proposed rules for Senate Bill 200 (SB 200) in 1995, creating the Texas version of the FCFF program. The intent of the bill was to achieve compliance with the FCAA by reducing vehicular emissions in the state's nonattainment areas.

SB 200 established a schedule in which fleet owners must replace their current vehicles with "clean-fuel" vehicles that meet certain emission standards established by the EPA. Following are the categories of clean-fuel vehicles listed in order of pollution prevention:

- Zero emission vehicles (ZEV)
- Inherently low emission vehicles (ILEV)
- Ultra low emission vehicles (ULEV)
- Low emission vehicles (LEV)

The LEV is the baseline vehicle for compliance with SB 200. ULEV, ILEV, and ZEV do more to reduce pollution and therefore fleet owners receive additional credit if they choose to purchase them. The EPA has established emission standards for conventional vehicles (Tier 1 vehicles). The credits given the clean-fuel vehicles are based on the difference in emissions between Tier 1 vehicles and those of the clean-fuel vehicles. Low emission vehicles (LEV) are given one credit (i.e. one vehicle equals one credit) and credits for the other categories increase based on their actual emissions. Electric vehicles (EV) are the only vehicles qualifying as a ZEV, and SB 200 allows up to 5.8 credits for utilizing them (Hammett 1996).

However, EVs do create some emissions when the batteries are charged with electricity generated at an electric power plant, but power plant emissions are not considered in the state program. A potential policy problem exists if the amount of credit allotted to the ZEV is excessive. If the credit is excessive, then it is possible that an insufficient number of Tier 1 vehicles will be removed from service. The emission reduction credits are a feasible mechanism to enhance research and development of alternatively fueled vehicles, but it should not be at the expense of the air quality in the nonattainment areas.

Purposes and Research Question

This study expands upon assessment methods presented in the literature in order to illustrate the emission reductions achieved by Senate Bill 200 if EVs are used for compliance. The purposes of this study are: 1) to determine if the credit allotted the electric vehicle is excessive, and 2) if it is excessive, estimate the credit allowance that will achieve the desired emission reductions. The research question is: assuming electric vehicles are used for compliance with Senate Bill 200, will a sufficient number of polluting vehicles be replaced to achieve the emission reductions estimated by Senate Bill 200?

CHAPTER 2

BACKGROUND

The popularity of environmental concerns can be described as a pendulum. When the environment is threatened the pendulum swings up, activists become active, governments regulate, and industry responds. When the threat is less severe the pendulum swings down and the activists are passive, governments deregulate, and industry responds. Such has been the case with the EV.

Although there has been periodic interest in electric vehicles, technological advances and regulatory pressure have sparked a new wave of attention. Auto manufacturers, alternative fuel proponents, environmentalists, and politicians are striving to have their opinions heard in the debate over policies such as created by SB 200.

The requirements of the Texas program are outlined in the Health and Safety Codes. SB 200 requires:

> a local government or private person to have a proportion of the person's newly purchased fleet vehicles and a proportion of the fleet vehicle in the person's total fleet able to operate on an alternative fuel according to the following schedule:
> (1) 30 percent of fleet vehicles purchased after September 1, 1998, *or* at least 10 percent of the fleet vehicles in the total fleet as of September 1, 1998;
> (2) 50 percent of fleet vehicles purchased after September 1, 2000, *and* at least 20 percent of the fleet vehicles in the total fleet as of September 1, 2000;
> (3) 90 percent of fleet vehicles purchased after September 1, 2002, *and* at least 45 percent of the fleet vehicles in the total fleet as of September 1, 2002 (Texas Health and Safety Code 1995).

Literature Review

The primary environmental advantage of electric vehicles is the emission reductions achieved over internal combustion vehicles. Although electric vehicles do not produce any emissions, some are created by power plants that produce electricity to recharge them. Therefore, to analyze the environmental impact of electric vehicles, it is necessary to examine power plant emissions. The benefits of power plant emissions over individual vehicles are as follows:

- the emissions are not mobile, rather a fixed point source that can be more easily controlled and maintained,
- the emissions are usually displaced from the urban nonattainment area to a rural area,
- full time professionals maintain utilities,
- state and federal agencies routinely monitor utilities,
- the new federal mandates will require the utilities to become even cleaner, and
- the emissions are out of phase in time with conventional mobile and industrial sources (electric vehicles are primarily charged overnight). This last benefit is particularly important in the formation of ozone, which is a photochemical (daytime) process (SCEVC 1992, 17).

The emissions of power plants must be considered, and it is difficult to assess the impacts on a large scale, because power plants use different fuels and different emission control technology. The emissions most commonly studied are nitrogen oxides (NOx), carbon monoxide (CO), particulate matter (PM), sulfur oxide (SOx), and volatile organic compounds (VOCs) also referred to as non-methane organic compounds (NMOG), or hydrocarbons (HC).

Many proponents of the EV argue that when power plant emissions are considered the emission reductions achieved by EVs is still considerable (Gribben 2000, California 2000). EVs can have a significant impact on improving air quality in regions such as California that use a substantial amount of hydropower, nuclear energy, and natural gas to fuel the power plants (Gribben 2000, California 2000). However, EV critics are skeptical of such findings because the benefits realized by EV technology are dependent on the fuel used to produce the electricity (Littman 1999, Neufville et al. 1996, Gordon and Richardson 1995).

The Claremont Graduate School analyzed the impact electric vehicles would have on the air quality in the Los Angeles Basin based on various fleet sizes. It was determined that in a fleet of one hundred thousand, carbon monoxide (CO) and hydrocarbons (HC) would be reduced by up to ninety-nine percent, and nitrogen oxides (NOx) would be reduced by up to eighty-one percent (Claremont Graduate School 1989).

The Claremont study also analyzed ozone production. This analysis was based on three market penetration scenarios: low growth, steady growth, and breakthrough technology. The steady growth and breakthrough technology scenarios showed modest improvements. However, the impact of the low growth scenario was omitted because the overall air quality impact attributable to a small fleet of electric vehicles was judged to be negligible. It should be noted that the relationship between concentrations of ozone precursors (NOx and VOC) and ozone air quality is nonlinear. A fifty percent reduction in annual NOx emissions for the Los Angeles Basin may translate into only a ten percent reduction in ozone, depending on the conditions used in the airshed modeling (Claremont Graduate School 1989).

The EPA contracted a private firm to develop a method to evaluate the environmental and economic effects of electric vehicles (EPA 1991). The study discussed the nationwide impact, but clearly stated that accurate estimation of local impacts is not feasible based upon a large-scale study. Potential environmental effects depend on the types of fuels used to generate electricity, the proximity of the power plants, and the extent of emissions controls (EPA 1991). Although the study was never finalized, a draft version of it provides an excellent method for evaluating impacts on a local scale. Based on this study, I chose to analyze impacts in only one of Texas' nonattainment areas.

The Texas Natural Resource Conservation Commission (TNRCC) has compiled a database that contains information on private fleets in Texas nonattainment areas (Brown 1995). The state utilized this database to determine the baseline vehicle population in the technical analysis of SB 200 (TNRCC 1996). This baseline population was used to project the number of clean-fuel vehicles utilized for compliance with the state program in the years 1998-2007. I used this database to determine the potential electric vehicle population.

CHAPTER 3

ASSUMPTIONS AND METHODS

Assumptions

This study makes several assumptions about EV technology, the specific mandates, and public reaction to SB 200. It is important to emphasize that the scenarios presented should not be construed as forecasts. Rather, these cases have been chosen to illustrate a broad range of possible impacts that electric vehicles could have in Texas nonattainment areas (Claremont Graduate School 1989). The assumptions of the methodology are listed below, and further discussed in Appendix A:

- EVs have technological characteristics, such as fuel efficiency, range, and vehicle weight, of the Chrysler electric minivan (the EPIC)
- Range is not a limiting factor
- EVs travel fifty-six miles per day
- Fleets natural turn-over rate is thirty-three percent per year
- Fleet growth rate is 2.2 percent per year
- EVs will travel to eighty percent of battery discharge (fifty-six miles per day)
- Low emission vehicles travel one hundred miles per day
- Fleets will not achieve compliance mandates until the last day required. (To realize a "worst case" scenario)
- Fleets will only purchase vehicles necessary to satisfy the percent-of-total-fleet requirements until September 1, 2002
- Emissions of replaced internal combustion vehicles will be equal to a Tier 1 (conventional) vehicle as defined by the federal program
- Transit fleets are not considered
- Fleet vehicles will operate two hundred and fifty days per year
- Vehicles with a gross vehicle weight rating (gvwr) $\leq$ 6,000 pounds could be replaced with an EV
- No vehicles are garaged at home
- Power plant emissions generated outside of the region are not considered.
- Possible advances in EV technology will not be considered
- Emissions from low emission vehicles (LEV) are equivalent to those defined in the federal program
- EVs will achieve 2.45 miles per kilowatt-hour (m/kWh)

Methods

This study illustrates the emission reductions achievable in Texas if electric vehicles (EV) are utilized for compliance with SB 200. I based this study on the Houston-Galveston area because it is the largest nonattainment area in Texas. A spreadsheet model was created that calculates the emission reductions achieved by SB 200 if electric vehicles are utilized for compliance. The model utilizes three scenarios of electric vehicle credits, and compares these emission reductions to the anticipated emission reductions of the state program.

Each scenario assumes that a different amount of credit is given to the electric vehicle. Credits were set at four, five, and six. The emission reductions achieved in each of these scenarios were compared to those anticipated by the state. At the inception of this study the state was considering credits of up to 5.8 (Hammett 1996).

The goal of SB 200 is to comply with the federal program by removing Tier 1 vehicles from service. In my study the number of Tier 1 vehicles removed from service is solely dependent on the number of credits given the electric vehicle. For example: assume a fleet owner operates one hundred vehicles, and the ZEV is allowed four credits. The mandates state that as of September 1, 1998, the owner is required to have at least twenty percent of the total fleet operating as clean-fuel vehicles. If the owner chooses to purchase LEV vehicles, then they must replace twenty vehicles because each LEV is given one credit. However, if the owner chooses to purchase ZEVs, then they only needs to purchase five electric vehicles because each ZEV is allowed four credits (i.e. one ZEV equals four LEV).

This study assumes that fleet owners will purchase only electric vehicles in order to comply with SB 200. The only exception is that fleet owners will not purchase EVs to replace vehicles that weigh more than six thousand pounds, because the replaceability of an internal combustion vehicle is based on its weight (See Appendix A: Assumptions). For all vehicles in excess of six thousand pounds, it is assumed that fleet owners purchase a low emission vehicle (LEV).

The methods used in my study are based on those used by the Claremont Graduate School (Claremont Graduate School 1989) as well as the method developed by the EPA (EPA 1991). However, this study goes beyond the methods presented in the literature. I calculate the emission reductions realized by using EVs, and compare them to those anticipated by the state program. These findings are then used to estimate the amount of credit that should be granted the zero emission vehicles once power plant emissions are considered (Table 1).

Table 1: Methods

Step 1 Estimate the number of electric vehicles that will replace Tier 1 (conventional vehicles)	Step 8 Estimate the emissions created by the LEV
Step 2 Estimate the number of miles traveled by electric vehicles	Step 9 Estimate the emissions that would have been created by the Tier 1 (conventional) vehicles replaced by LEV
Step 3 Estimate the electric utility emissions generated by charging the electric vehicles	Step 10 Subtract the quantity of emissions generated by Tier 1 vehicles (calculated in Step 9) from the emissions created by LEV (calculated in Step 8) to determine the emission reductions attributed to the LEV
Step 4 Estimate the emissions that would have been created by the Tier 1 vehicles replaced by EVs	Step 11 Add the emission reductions attributed to the EVs (Step 5) to the emission reductions attributed to the LEV (Step 10) to determine the total emission reductions of this study
Step 5 Subtract the quantity of emissions generated by Tier 1 vehicles (calculated in Step 4) from the emissions created by charging electric vehicles (calculated in Step 3) to determine the emission reductions attributed to the EVs	Step 12 Calculate the emission reductions anticipated by the state due to SB 200
Step 6 Estimate the low emission vehicle (LEV) population (LEV were utilized to replace vehicles over six thousand pounds)	Step 13 Compare the emission reductions anticipated by SB 200 (Step 12) to those of this study (Step 11)
Step 7 Estimate the number of LEV miles traveled	Step 14 Estimate an accurate credit allowed zero-emission vehicles based on the findings of this study

A detailed description of each of these steps is provided in Appendix B, however a brief overview is necessary in order to understand the results of the study.

Step 1

First, the number of EVs that would be purchased in each of the study years was determined in order to estimate the number of vehicles purchased for 1) the percent-of-new-purchase mandates and 2) the percent-of-total-fleet mandates of SB 200. The EV population was obtained by making several queries in a database maintained by the TNRCC, which contains detailed information on each registered fleet in the state.

Step 2

I multiplied the annual EV population determined in Step 1 by fifty-six miles driven per day and two hundred fifty business days per year to realize the annual miles traveled by EVs.

Step 3

I determined the amount of electricity required to charge the EV batteries by dividing the annual miles traveled by the EV (determined in Step 2) by the mileage rating assumed by this study (2.45 miles/kilowatt-hour). This mileage rating is very similar to the gas mileage rating used to describe the fuel efficiency of an internal combustion vehicle. Instead of miles-per-*gallon* of gasoline, miles-per-*kilowatt-hour* of electricity is used. After determining the amount of electricity required I determined the power plant emissions of each pollutant based on information provided by Reliant Energy, the predominant energy provider in the Houston-Galveston area (Newman 1999).

Step 4

The amount of pollution generated by the vehicles that would be replaced was determined. The EPA has calculated average emission standards for Tier 1 (conventional) vehicles for each pollutant analyzed in this study. These standards provide the grams of emissions generated for every mile driven. Therefore, I multiplied the Tier 1 emission standards by the annual mileage to determine the amount of emissions that would have been created by the Tier 1 vehicles had an EV not replaced them.

<u>Step 5</u>

The quantity of emissions created by charging EVs is subtracted from the quantity of emissions generated by the Tier 1 vehicles to determine the emissions reductions attributed to the EV.

<u>Steps 6-10</u>

These are very similar to Steps 1 through 5, but they calculate the emission reductions attributed to the low emission vehicles (LEV). It was assumed that LEVs would be used to replace vehicles in excess of six thousand pounds.

<u>Step 11</u>

This step combines emission reductions attributed to the EV with those of the LEV to realize the overall emission reductions attributed to SB 200.

<u>Step 12</u>

A determination of the emission reductions anticipated by the state was required in order to evaluate the impact of the EV. The state program is based on one LEV replacing one Tier 1 vehicle. In the State Implementation Plan for SB 200, the state showed the estimated number of LEV purchased each year. I used these vehicle populations and the emission factors established by the EPA for both LEV and Tier 1 vehicles to determine the state's estimated emission reductions achieved in the Houston-Galveston nonattainment area.

Step 13

The results of the state's program were compared to those of my study to determine if the emission reductions anticipated by the state would be achieved if electric vehicles were utilized for compliance.

Step 14

The previous findings were utilized to determine the credit that should be granted the zero emission vehicles if emissions generated at the power plant are considered. This study provides the data necessary to calculate the amount of emission reductions anticipated by the state. It also provides the data necessary to calculate an emission-reduction factor for the EV. Knowing these factors the following were calculated by working backward through the spreadsheet model:

1. total mileage required by EVs in order to achieve the required emission reductions
2. credit given to achieve this mileage.

CHAPTER 4

ANALYSIS AND RESULTS

I anticipated that electric vehicles would cause a significant emission reduction per vehicle. However, my concern was that Senate Bill 200 might require only a small number of electric vehicles due to the large amount of credit allowed the ZEV. Since only a small number of EVs would be required, only a small number of Tier 1 vehicles would be removed from service. Thus, the overall emission reductions achieved in the Houston-Galveston nonattainment area was unlikely to achieve the results anticipated by the state program.

The results of the study show that contrary to the state's position that the electric vehicle is a "zero" emission vehicle, charging EVs would create several tons of emissions in the years 2000-2007. Although the Texas program is mainly focused on volatile organic compounds (VOCs) and nitrous oxides (NOx), this study also included calculations of particulate matter (PM) and carbon monoxide (CO) emissions. Comparing the emissions generated by charging EVs to the emissions of the vehicles they replaced (Tier 1 vehicles) it is clear that some emission reductions are achieved. Table 2 illustrates mission reductions realized in each scenario of credits allowed the EV. Emissions created by charging EVs are subtracted from the emissions that Tier 1 vehicles would have generated had they been utilized (Table 2). As expected, the amount of emission reductions decrease as the credits increase. This is because fewer EVs are utilized when a larger number of credits is given, and therefore fewer Tier 1 vehicles are removed from service.

TABLE 2: Emissions Created by Charging EVs 2000-2007 (tons)

	Emissions Created by Tier 1 Vehicles			Emissions Created by charging EVs			Emission Reductions Resulting from EV Use		
Credits	4	5	6	4	5	6	4	5	6
VOC	319.6	246.5	199.5	14.8	11.4	9.2	304.8	235.1	190.3
NOx	1278.3	985.9	797.9	608.6	469.4	379.9	669.7	516.5	418.0
PM	255.7	197.2	159.5	20.1	15.5	12.5	235.6	181.67	147.0
CO	4346.3	3352.0	2712.8	130.1	100.4	81.2	4216.2	3251.6	2631.6

In order to evaluate the credit that TNRCC is granting the EV, a comparison of these results to the expectations of the Texas' program is necessary to achieve the goals of the study. First, it must be determined whether the credit allotted the electric vehicle is excessive. Then, if it is the credit allowance that will achieve the desired emission reductions must be estimated.

As stated in the State Implementation Plan (SIP) for SB 200, the state determined equivalency with the federal program by estimating the number of light-duty LEV used per year for all of the non-attainment areas combined (TNRCC 1996). The state's contention is that more LEVs are purchased under the state program than the federal program; therefore the state program should be in compliance.

In the state's evaluation, the LEV population in all three nonattainment areas (Houston-Galveston, Dallas-Ft. Worth, and El Paso) was used to determine the impact statewide. Since my study is only concerned with the impact in the Houston-Galveston nonattainment area, I extrapolated the results as follows. According to the TNRCC fleet database, the Houston-Galveston area accounts for 53.4 percent of the total base population of fleet vehicles. Since the state program is based on LEV population, and the

LEV population was calculated from the base vehicle population, I assume that 53.4 percent of the statewide emission reductions will be realized in the Houston-Galveston area (Table 3).

TABLE 3: Annual LEV Population in the Houston-Galveston Area (State Program)

Year	Population
1998	408
1999	2,594
2000	6,093
2001	11,474
2002	14,785
2003	20,854
2004	25,533
2005	29,278
2006	29,922
2007	30,580

Source: Texas Natural Resource Conservation Commission. 1996. Revisions to the State Implementation Plan (SIP) for the Substitution of the Federal Clean Fuel Fleet Program. Rule Log Number 95153-114-AI

Estimated reductions under the three scenarios fall far below the state's estimated reductions (Table 4). Neither the targeted VOC nor the NOx reductions were achieved by any of the scenarios of this study. The VOC reductions are only 37.5 percent of those anticipated by the state and the NOx reductions are only 18 percent of those anticipated by the state in the best scenario (four credits).

TABLE 4: Comparison of the Emission Reductions Realized by Utilizing EVs to the Emission Reductions of the State Program 2000-2007 (tons)

	VOC Emission Reductions (Tons)	Percent of State Program	NOx Emission Reductions (Tons)	Percent of State Program
State Estimate	812.7	100%	3,715.2	100%
EV Study – 4 Credits	304.8	37.5%	669.7	18.0%
EV Study – 5 Credits	235.1	28.9%	516.5	13.9%
EV Study – 6 Credits	190.3	23.4%	418.0	11.3%

Is the credit allotted the EV excessive? At the inception of SB 200, the TNRCC was considering credits of up to 5.8 for the electric vehicle. It is evident that with this amount of credit the desired emission reductions will not be achieved if EVs are utilized for compliance.

What credit allowance will achieve the desired emission reductions? Comparing the difference in emissions between EVs, LEV and Tier 1 vehicles per mile driven answers this question. The state program is based on LEVs replacing Tier 1 vehicles, and my study replaces Tier 1 vehicles with EVs. The calculations in this study as well as the state's program use an emission factor in grams/mile of each pollutant for the LEV and Tier 1 vehicles (as established by the EPA). My study provides the data necessary to calculate a similar factor in grams/mile of each pollutant for the EV. The EV factor is the amount of pollution generated by charging the EVs (in grams) divided by the annual mileage of EVs. Therefore, I compared the emission reductions realized by replacing a Tier 1 vehicle with either a LEV or an EV (Table 5).

Electric vehicles are much cleaner than the Tier 1 vehicles with respect to VOC and NOx emissions (Table 5). The EVs are more effective at reducing VOC emissions by 0.238 grams per mile, and NOx emissions by 0.524 grams per mile.

TABLE 5: Comparison of the Emissions Generated by LEV and EVs (grams/mile)

	Tier 1 Vehicle Compared to a LEV			Tier 1 Vehicle Compared to an EV		
	Tier 1[a] Factor	LEV [a] Factor	Difference	Tier 1 [a] Factor	EV [b] Factor	Difference
VOC	0.250	0.075	0.175	0.250	0.012	0.238
NOx	1.000	0.200	0.800	1.000	0.476	0.524
Particulate Matter	0.200	0.080	0.120	0.200	0.016	0.184
Carbon Monoxide	3.400	3.400	0.000	3.400	0.102	3.300

[a] Light-duty vehicle emission factors as established by the EPA
[b] EV emission factor as established by this study

The problem is that the number of EVs used is not large enough to meet the required emission reductions. Although the EV is much cleaner than the Tier 1 vehicle on a per-mile basis, not enough Tier 1 vehicles are removed from service to achieve the required emission reductions. Since the miles driven per day and the amount of days driven per year are fixed factors, the only way to obtain the required emission reductions is to get more EVs on the road. This can only be accomplished by decreasing the amount of credit given the EV.

I estimated that the Texas Clean Fuel Fleet Program will reduce VOC emissions by approximately 812.7 tons (Table 4). I also determined that utilizing EVs reduces VOC emissions by 0.238 grams for every mile driven (Table 5). Converting the 812.7 tons to grams and dividing by our emission reduction factor (0.238 grams per mile) reveals that 3,095,100,741 miles must be driven by EVs in order to achieve the anticipated emission reductions. In my study when a credit of five is used only 894,367,265 miles are driven by EVs. Therefore, the actual miles driven divided by the mileage required provides a ratio. This ratio was then multiplied by five credits to determine the credit that should be given the EV if power plant emissions are considered. Based on these factors, the VOC emission reductions estimated by the Texas program would be achieved if ZEVs were given a credit of 1.4 as shown in the following calculation:

812.7 tons = 736,633,976 grams

736,633,976 grams / 0.238 grams per mile = 3,095,100,741 miles

894,367,265 miles / 3,095,100,741 miles = .29 ratio

.29 ratio * 5 credits = 1.4 credits.

The credit given any clean-fuel vehicle is based upon its emissions as compared to a LEV vehicle. Since the electric vehicles actually emit more NOx emissions than the LEV, no credit should be issued on this basis. Following the same methodology used to determine an accurate VOC credit, the NOx emission reductions estimated by the state would be achieved if ZEVs were given a credit of 0.7 (i.e. less credit than allowed the LEV).

When power plant emissions in the Houston-Galveston area are considered, LEVs actually reduce NOx emissions better than an electric vehicle, which is considered to be a zero emission vehicle (Table 5). The LEV will reduce NOx emissions by 0.8 grams for every mile driven, whereas an EV will only reduce NOx emissions by 0.524 grams for every mile driven. This is important because the amount of credit given each clean-fuel vehicle should be based on its ability to reduce pollution. If the ZEV does not reduce NOx emissions as well as the LEV, then the ZEV should not receive as much credit as the LEV for compliance with SB 200.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

It is a common assumption that electric vehicles create less air pollution than gasoline vehicles (Wang and Marr 1994, Sperling 1995). It has also been argued that markets for electric vehicles currently exist if consumers can be persuaded to purchase these vehicles (OECD/IEA 1993, Cohen and Commoner 1994). This study proves that although utilizing electric vehicles can reduce certain air emissions, their use may result in greater NOx emissions than other clean-fuel vehicles on the market. The credits offered by the Texas Clean Fuel Fleet program could be one of the incentives that are needed to spark the electric vehicle market. However, if the number of credits awarded an electric vehicle is too large, then the number of electric vehicles on the road could be too insignificant to improve the levels of VOC emissions, and could actually increase the levels of NOx emissions.

It is now evident that the credit allowed the electric vehicle should be different depending on the emissions considered. The primary goal of the Texas program has been to reduce VOC emissions since they are believed to be the main precursors to ozone (Brown 1996c). Since the primary goal of SB 200 is to reduce VOC emissions it is my recommendation that a credit of 1.4 be utilized for the ZEV.

Several studies indicate that an accurate assessment of electric vehicles needs to be performed on a local level (EPA 1991, OECD/IEA 1993), but few have actually done this. My analysis of the Houston-Galveston nonattainment area quantified the emissions generated by utilizing electric vehicles when power plant emissions are considered. This method can now be used to assess the impact of electric vehicles in all nonattainment areas.

APPENDIX A: ASSUMPTIONS OF THE METHODOLOGY

Vehicle Characteristics

At the time this study was initiated, Chrysler was developing an electric minivan (the EPIC) that could be utilized for fleet use (Morris 1995). The technological characteristics such as fuel efficiency, range, and vehicle weight of the Chrysler EPIC were used in the emission reduction estimations.

Electric Vehicle Range

Electric vehicle range is not considered to be a limiting factor in the study. This is based on a survey conducted by the Electric Vehicle Development Corporation that examined actual daily travel patterns of vans used by fleet operators in the U.S. It was determined that 250,000 vans (thirty-eight percent of all fleet vans) travel less than sixty miles per day (Brunner and Wood 1988). The Chrysler minivan has a maximum range of seventy miles (Morris 1995), and the suggested range to increase battery life is fifty-six miles (Roberts 1996).

It would be beneficial to know the average miles traveled by those vehicles in the survey by the Electric Vehicle Development Corporation. Since this information was not found in the literature, the study assumes that electric vehicles will travel fifty-six miles per day. It is also assumed that they operate two hundred fifty days per year, which is consistent with data used by the Department of Energy (DOE 1995).

The state estimates that petroleum-fueled vehicles travel one hundred miles per day. This study assumes that EVs would only be utilized in situations that are within their limitations. The literature suggests that a significant portion of fleet vehicles travel less than the range achieved by the electric vehicle. Therefore, my study is based on the actual range of the EV.

Fleet Growth Rate

It is assumed that the average fleet growth rate is 2.2 percent per year. This is the growth rate utilized in SB 200 (Brown 1996b).

Electric Utility Emissions

Estimation of electricity demand for battery recharge requires an estimate of efficiencies for both the vehicle and the battery charger. In the Claremont study, the fuel efficiency of the vehicle is a variable that ranged from one to four miles per kilowatt hour (m/kWh), and the battery charger was assumed to be eighty-three percent efficient (Claremont Graduate School 1989). For example, a recharge efficiency of eighty-three percent and a vehicle efficiency of 2 m/kWh results in an overall fuel efficiency rating of 1.66 m/kWh (2m/kWh * .83). My study assumes that electric vehicles have a vehicle efficiency of 2.5 m/kWh (Craven 1996), and the recharger is ninety-eight percent efficient (Sundarababu 1996), which results in an overall efficiency of 2.45 m/kWh. Both of these determinations are based on information supplied by Electrosource, the battery manufacturer for the Chrysler minivan.

The power plant emissions were based on actual emissions within the Houston-Galveston nonattainment area only. Some electricity consumed in the Houston-Galveston area is generated outside the region. Since these emissions generated in other areas are not considered in SB 200, they are not considered in this study.

Low Emission Vehicles

SB 200 assumes that low emission vehicles will travel 25,000 miles per year, and this figure was for the study (Brown 1996c). The emission quantities of each criterion pollutant for low emission vehicles are also the same as that assumed by SB 200.

Vehicle Population

The population consists of local government and privately owned fleets in Houston, Texas that are affected by Senate Bill 200. SB 200 regulates local government fleets with more than fifteen vehicles and private fleets with more than twenty-five vehicles (Texas 1995). SB 200 exempts vehicles that are garaged at home and available for personal use. The study assumes that no vehicles are garaged at home. Although SB 200 also regulates transit fleets, they are not considered in the study.

Weight Limitations of the Electric Vehicle

Electric vehicles are not a feasible option for all fleets since currently produced electric vehicles have limited carrying capacity (i.e. tonnage of cargo that can be transported). The gross vehicle weight rating (gvwr) for the Chrysler minivan is similar to its gasoline counterpart (Roberts 1996), which has a gvwr of 5,350 pounds (Chrysler 1996). Only vehicles with gvwr similar to that of the Chrysler minivan are assumed as replaceable; gvwr is the weight of a vehicle loaded to capacity. The TNRCC has grouped all vehicles with gvwr less than six thousand pounds into one data set. Vehicles in this data set are assumed to operate within the weight limitations of electric vehicles.

For example, if a fleet consists entirely of trucks with a gvwr over fifteen thousand pounds, it is not feasible to replace them with an electric vehicle having a gvwr of six thousand pounds. However, if the same fleet had one vehicle with a gvwr less than six thousand pounds, then it is assumed that it could be replaced with an electric vehicle. It is assumed that fleets will purchase low emission vehicles (LEV) to replace those that do not meet the weight constraints of the electric vehicle.

Compliance Requirements

Although SB 200 mandates compliance in 1998, fleets will not be penalized if twenty percent of their vehicles are low emission as of September 1, 2000. Therefore, it is possible that fleets will delay vehicle replacement until the year 2000. In order to analyze a "worst case" scenario it is assumed that fleets will not be in compliance until September 1, 2000. Likewise, it is assumed that fleets will not achieve the forty-five percent requirement until September 1, 2002 (the last day possible).

The percent-of-new-purchase requirements will most likely have little effect until after September 1, 2002 (Brown 1996a). This is because fleets will presumably purchase more than the percent-of-new-purchases required, in order to achieve the percent-of-total-fleet requirements.

For example, the average annual turnover rate for fleet cars and light trucks assumed by the State Implementation Plan for SB 200 is thirty-three percent (Brown 1996b). In a fleet of three hundred, one hundred vehicles would be replaced each year due to normal turn over (thirty-three percent of three hundred). The percentage-of-new-purchases mandated by SB 200 that must be low emission vehicles after September 1, 2000 is fifty percent. So to meet the percentage-of-new-purchase requirement, the fleet would need to purchase fifty low emission vehicles each year (fifty percent of the one hundred vehicles purchased). In comparison, a fleet of three hundred vehicles will need to have sixty (twenty percent) low emission vehicles by September 1, 2000, and an additional seventy-five (twenty-five percent) by September 1, 2002, to meet the percent-of-total-fleet mandates. For this reason it is assumed that fleets will purchase only the number of low emission vehicles needed to satisfy the percent-of-total-fleet requirements before September 1, 2002.

APPENDIX B: FORMULAS
(Based on a Credit of Five)

Step 1: Estimate the Electric Vehicle Population

Determining the vehicle population involves a complex formula based on the various fleet percentage requirements of SB 200. For illustrative purposes, Appendix B is written assuming a credit of five. Based on EVs receiving five credits, fleets could satisfy the percent-of-total-fleet mandate by ensuring that four percent (twenty percent mandate divided by five credits) of the fleet is electric in the year 2000, and nine percent (forty-five percent mandate divided by five credits) in the year 2002. After the year 2002, fleets need only to satisfy the percent-new-purchase requirement. Fleets could satisfy this mandate by ensuring eighteen percent of their purchases are EVs (ninety percent mandate divided by five credits).

The potential of an internal combustion vehicle to be replaced by an electric one is based on its weight. In order to calculate the number of vehicles needed to satisfy the percent-of-total-fleet requirements, fleets were grouped into three categories based on the percentage of vehicles below six thousand pounds (PEVC).

Assuming a credit of five, fleets in "Group A" have a PEVC of more than nine percent, and would fully satisfy the percent-of-total-fleet mandates by using only electric vehicles in the years 2000 and 2002. Fleets in "Group B" have a PEVC of less than nine percent, but greater than four percent, and would fully satisfy SB 200 using electric vehicles in the year 2000, but would purchase some low emission vehicles in the year 2002. Finally, fleets in "Group C" have a PEVC of less than four percent, and would purchase both electric and low emission vehicles in the year 2000. Fleets in "Group C" would purchase only low emission vehicles in the year 2002. Most of Step 1 was completed at the TNRCC on the fleet database.

A. For each fleet, the percentage of existing vehicles that could be replaced by an electric vehicle was determined.

$FEVC / FT = PEVC$
Where:
$FEVC$ = number of vehicles under 6,000 pounds
FT = total number of vehicles in the fleet
$PEVC$ = percentage of fleet that is below 6,000 pounds

B. Determine the total electric vehicles purchased by all fleets in Group A ($PEVC \geq 9\%$)

The year 2000: $\Sigma(FT * 4\%) = EV_1$
Where:
FT = total number of vehicles in the fleet
4% = mandated requirement (20% mandate divided by 5 credits)
EV_1 = Group A electric vehicles purchased in the year 2000

The year 2002: $\Sigma(FT * 5\%) = EV_2$
Where:
FT = total number of vehicles in the fleet
5% = mandated requirement (25% mandate divided by 5 credits)
EV_2 = Group A electric vehicles purchased in the year 2002

C. Determine the total electric vehicles purchased by all fleets in Group B ($PEVC < 9\%$, but $\geq 4\%$)

The year 2000: $\Sigma(FT * 4\%) = EV_3$
Where:
FT = total number of vehicles in the fleet
4% = mandated requirement (20% mandate divided by 5 credits)
EV_3 = Group B electric vehicles purchased in the year 2000

The year 2002: $\Sigma(FT * \{PEVC - 4\%\}) = EV_4$
Where:
FT = total number of vehicles in the fleet
$PEVC$ = percentage of fleet that is below 6,000 pounds
4% = mandated requirement (20% mandate divided by 5 credits)
EV_4 = Group B electric vehicles purchased in the year 2002

D. Determine the total electric vehicles purchased by all fleets in Group C (PEVC < 4%, but > 0%)

The year 2000: $\Sigma(FT * PEVC) = EV_5$

Where:

FT = total number of vehicles in the fleet

PEVC = percentage of fleet that is below 6,000 pounds

EV_5 = Group C electric vehicles purchased in the year 2000

E. Determine the number of electric vehicles utilized for compliance in the year 2000 (adjusted to account for fleet growth since 1996)

$(EV_1 + EV_3 + EV_5) * 1.022^4 = EV_{2000}$

Where:

EV_1 = Group A electric vehicles purchased in the year 2000

EV_3 = Group B electric vehicles purchased in the year 2000

EV_5 = Group C electric vehicles purchased in the year 2000

1.022^4 = Four years of growth at a rate of 2.2% per year

EV_{2000} = Total number of electric vehicles utilized in the year 2000

F. Determine the total number of electric vehicles utilized for compliance in the year 2002 (adjusted to account for fleet growth since 1996)

$(EV_{2000}) + (EV_2 + EV_4) * 1.022^6 = EV_{2002}$

Where:

EV_{2000} = Total number of electric vehicles utilized in the year 2000

EV_2 = Group A electric vehicles purchased in the year 2002

EV_4 = Group B electric vehicles purchased in the year 2002

1.022^6 = Six years of growth at a rate of 2.2% per year

EV_{2002} = Total number of electric vehicles utilized in the year 2002

G. This step determines the total electric vehicle population September 1, 2003 through September 1, 2007. These are the vehicles required to satisfy the percent-of-new-purchase mandate each year.

Fleets with PEVC $\geq$ 5.94%: $\Sigma\{(FT * 5.94\% * 1.022^Y) + EV_{2002} - OLD\} = EV_{(PEVC \geq 5.94)}$

Fleets with PEVC < 5.94%: $\Sigma\{(FT * PEVC * 1.022^Y) + EV_{2002} - OLD\} = EV_{(PEVC \leq 5.94)}$

$EV_{(PEVC \geq 5.94)} + EV_{(PEVC \leq 5.94)} = EV_X$

Where:

PEVC = percentage of fleet that is below 6,000 pounds

5.94% = percent-new-purchase rate (18% mandate * 33% turnover)

FT = total number of vehicles in the fleet

1.022^Y = 2.2% growth rate per year (where Y is the number of years)

EV_{2002} = total number of electric vehicles utilized in the year 2002
OLD = number of electric vehicles sold due to normal turnover (vehicles 3 years old based on 33% turnover)
EV_X = total number of electric vehicles utilized in the year "x"

Step 2: Estimate the Annual EV Mileage

This step was done for each of the study years, and determined the vehicle miles traveled each year by electric vehicles.

$EV_X * 56 * 250 = VMT_X$

Where:
EV_X = total number of vehicles utilized in the year "x"
56 = daily ~~miles traveled~~
250 = days of operation per year
VMT_X = annual vehicle miles traveled in the year "x"

Step 3: Estimate the Electric Utility Emissions Generated by Charging EVs

A. Determine the total number of kilowatt-hours needed to recharge the electric vehicles each year.

$VMT_X / 2.45 = kWh_T$

Where:
VMT = annual vehicle miles traveled
2.45 = efficiency rating of the electric vehicle in miles per kilowatt hour
kWh_T = annual kilowatt hours needed to recharge the vehicles

B. Determine the power plant emissions of each criterion pollutant.

$(kWh_T * E/kWh_{CO}) = E_{ECO}$ $(kWh_T * E/kWh_{HC}) = E_{EHC}$
$(kWh_T * E/kWh_{PM}) = E_{EPM}$ $(kWh_T * E/kWh_{NO}) = E_{ENO}$

Where:
kWh_T = annual kilowatt hours needed to recharge the vehicles
E/kWh_* = emissions per kilowatt hour
E_{E*} = total annual power plant emissions
Note: asterisks indicate each pollutant

Step 4: Estimate the Emissions of the Tier 1 vehicles (those replaced by the EV)

$(VMT_x * \text{Tier 1 } E/M_{CO}) = E_{ICO}$ $(VMT_x * \text{Tier 1 } E/M_{HC}) = E_{IHC}$

$(VMT_x * \text{Tier 1 } E/M_{PM}) = E_{IPM}$ $(VMT_x * \text{Tier 1 } E/M_{NO}) = E_{INO}$

Where:

VMT_x = annual vehicle miles traveled in the year "x"

Tier 1 E/M_* = emissions per mile

E_{I*} = total annual vehicular emissions

Note: asterisks indicate each pollutant

Step 5: Determine the Emission Reductions Attributed to the EV

$E_{ICO} - E_{ECO} = E_{RCO}$ $E_{IHC} - E_{EHC} = E_{RHC}$

$E_{IPM} - E_{EPM} = E_{RPM}$ $E_{INO} - E_{ENO} = E_{RNO}$

Where:

E_{I*} = total annual Tier 1 vehicular emissions

E_{E*} = total annual power plant emissions

E_{R*} = annual emission reductions realized by utilizing electric vehicles

Note: asterisks indicate each pollutant

Step 6: Estimate the Low Emission Vehicle (LEV) Population

These vehicles are assumed to replace those that do not conform to the weight constraints of the electric vehicle. Fleets in Group A would not purchase any LEV vehicles.

A. Determine the number of low emission vehicles purchased by all fleets in Group B (PEVC < 9%, but ≥ 4%).

The year 2002: $\Sigma\{FT * (45\% - PEVC * 5)\} = LEV_1$

Where:

FT = total number of vehicles in the fleet

45% = mandated low emission vehicle requirement for the year 2002

PEVC = percentage of fleet that is below 6,000 pounds

5 = credit assumed in this scenario

LEV_1 = Group B low emission vehicles purchased in the year 2002

B. Determine the number of low emission vehicles purchased by all fleets in Group C (PEVC < 4%, but > 0%).

The year 2000: $\Sigma\{FT * (20\% - PEVC * 5)\} = LEV_2$

Where:

FT = total number of vehicles in the fleet

20% = mandated low emission vehicle requirement for the year 2000

PEVC = percentage of fleet that is below 6,000 pounds

5 = credit assumed in this scenario

LEV_2 = Group C low emission vehicles purchased in the year 2000

The year 2002: $\Sigma(FT * 25\%) = LEV_3$

Where:

FT = total number of vehicles in the fleet

25% = low emission vehicles required in the year 2002 (45% mandate minus the 20% purchased in the year 2000)

LEV_3 = Group C low emission vehicles purchased in the year 2002

C. Determine the total number of low emission vehicles utilized for compliance in the year 2000 (adjusted to account for fleet growth since 1996).

$LEV_2 * 1.022^4 = LEV_{2000}$

Where:

LEV_2 = Group B low emission vehicles purchased in the year 2000

1.022^4 = Four years of growth at a rate of 2.2% per year

LEV_{2000} = Total number of low emission vehicles utilized in the year 2000

D. Determine the total number of low emission vehicles utilized for compliance in the year 2002 (adjusted to account for fleet growth since 1996).

$LEV_{2000} + (LEV_1 + LEV_3) * 1.022^6 = LEV_{2002}$

Where:

LEV_{2000} = Total number of low emission vehicles utilized in the year 2000

LEV_1 = Group B low emission vehicles purchased in the year 2002

LEV_3 = Group C low emission vehicles purchased in the year 2002

1.022^6 = six years of growth at a rate of 2.2% per year

LEV_{2002} = Total number of low emission vehicles utilized in the year 2002

E. This step determines the total low emission vehicle population September 1, 2003 through September 1, 2007. These are the vehicles required to satisfy the percent-of-new-purchase mandate each year.

$EV_{POP} * 1.022^Y + LEV_{2002} - OLD_{LEV} = LEV_X$

Where:

$EV_{POP} = \Sigma\{FT * (29.7\% - PEVC * 5)$

FT = total number of vehicles in the fleet

29.7% = percent-new-purchase rate (the mandated 90% for low emission vehicles * 33% turnover)

PEVC = percentage of fleet that is below 6,000 pounds

5 = credit

1.022^Y = 2.2% growth rate per year (where Y is the number of years)

LEV_{2002} = number of low emission vehicles utilized in the year 2002

OLD_{LEV} = number of low emission vehicles sold due to normal turnover

(vehicles 3 years old based on 33% turnover)
LEV_X = total number of low emission vehicles utilized in year "x"

Step 7: Estimate the Annual LEV Mileage

$LEV_X * 25{,}000 = VMT_{LEVX}$
Where:
LEV_X = number of low emission vehicles utilized in year "x"
25,000 = annual mileage of low emission vehicles
VMT_{LEVX} = annual miles traveled by low emission vehicles in the year "x"

Step 8: Estimate the Emissions Created by LEV

$(VMT_{LEVx} * E/M_{lCO}) = E_{LCO}$ $(VMT_{LEVx} * E/M_{lHC}) = E_{LHC}$
$(VMT_{LEVx} * E/M_{lPM}) = E_{LPM}$ $(VMT_{LEVx} * E/M_{lNO}) = E_{LNO}$
Where:
VMT_{LEVx} = annual miles traveled by low emission vehicles in the year "x"
E/M_{l*} = emissions per mile
E_{L*} = annual emissions by low emission vehicles
Note: asterisks indicate each pollutant

Step 9: Estimate the emissions of the Tier 1 vehicles (those replaced by the LEV)

$(VMT_{LEVx} * \text{Tier 1 } E/M_{CO}) = E_{tCO}$ $(VMT_{LEVx} * \text{Tier 1 } E/M_{NO}) = E_{tNO}$
$(VMT_{LEVx} * \text{Tier 1 } E/M_{PM}) = E_{tPM}$ $(VMT_{LEVx} * \text{Tier 1 } E/M_{NO}) = E_{tNO}$
Where:
VMT_{LEVx} = annual miles traveled by low emission vehicles in the year "x"
Tier 1 E/M_* = emissions per mile (EPA rating)
E_{t*} = total annual emissions of Tier 1 vehicles
Note: asterisks indicate each pollutant

Step 10: Determine the Emission Reductions attributed to the LEV

Tier 1 $E_{tCO} - E_{LCO} = E_{rCO}$ Tier 1 $E_{tHC} - E_{LHC} = E_{rHC}$
Tier 1 $E_{tPM} - E_{LPM} = E_{rPM}$ Tier 1 $E_{tNO} - E_{LNO} = E_{rNO}$
Where:
Tier 1 E_{t*} = total annual emissions of Tier 1vehicles
E_{L*} = total annual emissions of low emission vehicles
E_{r*} = annual emission reductions realized by utilizing low emission vehicles
Note: asterisks indicate each pollutant

Step 11: Determine the Total Emission Reductions

Combine the emission reductions realized by utilizing EVs, with those realized by using LEV.

$E_{rCO} + E_{RCO} = E_{TCO}$

$E_{rPM} + E_{RPM} = E_{TPM}$

$E_{rHC} + E_{RHC} = E_{THC}$

$E_{rNO} + E_{RNO} = E_{TNO}$

$E_{rSD} + E_{RSD} = E_{TSD}$

Where:
E_{r*} = annual emission reductions realized by utilizing low emission vehicles
E_{R*} = annual emission reductions realized by utilizing electric vehicles
E_{T*} = total emission reductions achieved by SB 200 in a given year.
Note: asterisks indicate each pollutant

Step 12: Calculate the Emissions Reductions anticipated by the State Program

A. Estimate the annual miles traveled.

$LEV_{SX} * 100 * 250 = VMT_X$

Where:
LEV_{SX} = total number of vehicles utilized in the year "x" by the state program
100 = daily miles traveled
250 = days of operation per year
VMT_{LEVSX} = annual vehicle miles traveled in the year "x" by the state program

B. Estimate the emissions of the LEVs utilized in the state program.

$(VMT_{LEVsx} * E/M_{lCO}) = E_{LCO}$

$(VMT_{LEVsx} * E/M_{lPM}) = E_{LPM}$

$(VMT_{LEVsx} * E/M_{lHC}) = E_{LHC}$

$(VMT_{LEVsx} * E/M_{lNO}) = E_{LNO}$

Where:
VMT_{LEVsx} = annual miles traveled by low emission vehicles in the year "x"
E/M_{l*} = emissions per mile
E_{L*} = annual emissions by low emission vehicles
Note: asterisks indicate each pollutant

C. Estimate the emissions of the Tier 1 vehicles. These are the vehicles replaced by LEVs in the state program.

$(VMT_{LEVsx} * \text{Tier 1 } E/M_{CO}) = E_{ICO}$

$(VMT_{LEVsx} * \text{Tier 1 } E/M_{PM}) = E_{IPM}$

$(VMT_{LEVsx} * \text{Tier 1 } E/M_{NO}) = E_{INO}$

$(VMT_{LEVsx} * \text{Tier 1 } E/M_{NO}) = E_{INO}$

Where:
VMT_{LEVsx} = annual miles traveled by low emission vehicles in the year "x"
Tier 1 E/M_* = emissions per mile (EPA rating)
E_{I*} = total annual emissions of Tier 1 vehicles
Note: asterisks indicate each pollutant

D. Determine the total emission reductions realized the state program.

Tier 1 $E_{ICO} - E_{LCO} = E_{rCO}$ Tier 1 $E_{IHC} - E_{LHC} = E_{rHC}$
Tier 1 $E_{IPM} - E_{LPM} = E_{rPM}$ Tier 1 $E_{INO} - E_{LNO} = E_{rNO}$

Where:
Tier 1 E_{I*} = total annual emissions of Tier 1vehicles
E_{L*} = total annual emissions of low emission vehicles
E_{r*} = annual emission reductions realized by utilizing low emission vehicles
Note: asterisks indicate each pollutant

Step 13: Comparison of the Emission Reductions Anticipated by the State Program to the Emission Reductions of this Study

The results of the state's program were compared to those of this study to determine if the emission reductions anticipated by the state would be achieved if electric vehicles were utilized for compliance.

Step 14: Estimation of an Accurate EV Credit Considering Power Plant Emissions

A. This step determined the miles required to be driven in order to achieve the emission reductions anticipated by the state. It is based on the scenario of 5 credits allowed electric vehicles.

$E_{state} * TG / ERF = VMT_{state}$

Where:
E_{state*} = Emission reduction anticipated by the state program (tons)
TG = tons to grams factor (907184.7 grams/ton)
ERF* = emission reduction factor of electric vehicles as calculated by this study
VMT_{state*} = vehicle miles required to achieve emission reductions anticipated by the state
Note: asterisks indicate each pollutant

B. This step calculates the credit allotted the EV.

$VMT_{PCC5} / VMT_{state} * 5 = C$

Where:

VMT_{PCC5} = total vehicle miles traveled by EVs when a credit of 5 is utilized

VMT_{state*} = vehicle miles required to achieve emission reductions anticipated by the state

5 = credit allotted the EV in this scenario

C* = credit required to achieve the state's anticipated emission reductions.

Note: asterisks indicate each pollutant

APPENDIX C: CALCULATION RESULTS

Scenario One: Based on 4 credits

Step 1: Estimate the electric vehicle population
A. Step 1 was performed at the TNRCC on the fleet database.

B. Electric vehicles purchased by all fleets in Group A

EV1 =	3902.95
EV2 =	4917.72

C. Electric vehicles purchased by all fleets in Group B

EV3 =	33.8
EV4 =	17.2

D. Electric vehicles purchased by all fleets in Group C

EV5 =	12

E. Electric vehicles utilized for compliance in the year 2000

EV_{2000}=	4308

F. Electric vehicles utilized for compliance in the year 2002

EV_{2002}=	9931

G: Total EV population 2003 - 2007

Year 2003 =	12416
Year 2004 =	168734
Year 2005 =	11403
Year 2006 =	11777
Year 2007 =	11817

Step 2: Annual EV miles traveled

Year 2000 =	60310268
Year 2001 =	60310268
Year 2002 =	139035423
Year 2003 =	173829772
Year 2004 =	236232341
Year 2005 =	159645518
Year 2006 =	164875577
Year 2007 =	165444061
Total =	1159683227

Step 3: Electric Utility Emissions
A. Kilowatt hours of electricity

Year 2000 =	24616435.9
Year 2001 =	24616435.9
Year 2002 =	56749152.4
Year 2003 =	70950927.2

Year 2004 =	96421363.7
Year 2005 =	65161435.8
Year 2006 =	67296154.0
Year 2007 =	67528188.0
Total =	473340092.8

B. Power plant emissions of each criterion pollutant (tons)

	PM	VOC	NOx	CO
Year 2000	1.04	0.77	31.65	6.77
Year 2001	1.04	0.77	31.65	6.77
Year 2002	2.41	1.77	72.97	15.6
Year 2003	3.01	2.21	91.23	19.51
Year 2004	4.09	3.01	123.98	26.51
Year 2005	2.77	2.03	83.79	17.91
Year 2006	2.86	2.10	86.53	18.50
Year 2007	2.87	2.11	86.83	18.56
Total	20.09	14.77	608.64	130.13

Step 4: Estimate the Emissions from Tier 1 vehicles (tons)

	PM	VOC	NOx	CO
Year 2000	13.30	16.62	66.48	226.03
Year 2001	13.30	16.62	66.48	226.03
Year 2002	30.65	38.32	153.26	521.09
Year 2003	38.32	47.90	191.61	651.49
Year 2004	52.08	65.10	260.40	885.37
Year 2005	35.20	43.99	175.98	598.33
Year 2006	36.35	45.44	181.74	617.93
Year 2007	36.47	45.59	182.37	620.06
Total	255.67	319.58	1278.33	4346.33

Step 5: Determine the emission reductions attributed to the EVs (tons)

	PM	VOC	NOx	CO
Year 2000	12.25	15.85	34.83	219.27
Year 2001	12.25	15.85	34.83	219.27
Year 2002	28.24	36.54	80.29	505.48
Year 2003	35.31	45.69	100.38	631.98
Year 2004	47.99	62.09	136.42	858.86
Year 2005	32.43	41.96	92.19	580.41
Year 2006	33.49	43.34	95.21	599.43
Year 2007	33.61	43.49	95.54	601.50
Total	235.58	304.82	669.69	4216.20

Step 6: Estimate the low emission vehicle population (LEV)

A. Determine the number of low emission vehicles purchased by all fleets in Group B.

LEV1 =	98.72

B. Determine the number of low emission vehicles purchased by all fleets in Group C.

LEV2 =	51.40
LEV3 =	124.25

C. Determine the total number of low emission vehicles utilized for compliance in the year 2000

LEV_{2000} =	56.07

D. Determine the total number of low emission vehicles utilized for compliance in the year 2002

LEV_{2002} =	311.06

E. Determine the total low emission vehicle population (2003 -2007)

Year	EVPOP	1.022Y	EVPOP * 1.022^Y	LEV2002	OLD_{LEV}	Calculation
2003	118.11	1.16	137.54	108.75	56.08	190.22
2004	118.11	1.19	140.57	108.75	0	249.32
2005	118.11	1.22	143.66	108.75	254.98	0
2006	118.11	1.24	146.82	108.75	137.54	118.03
2007	118.11	1.27	150.05	108.75	140.57	118.23

*Calculations in the years 2005 results in a negative number. Since it is not possible to have a have a negative number of vehicles on the road, zero LEVs will be utilized.

Step 7: Estimate of the annual vehicle miles traveled by low emission vehicles

Year	LEVX	Miles Traveled	VMT
2000	56.07	25.000	1401866.67
2001	56.07	25.000	1401866.67
2002	311.06	25.000	7776464.90
2003	190.22	25.000	4755493.54
2004	249.32	25.000	6233009.64
2005	0	25.000	0
2006	118.03	25.000	2950727.75
2007	118.23	25.000	2955831.26

Step 8: Estimation of the emissions from low emission vehicles (tons)

Year	VOC	CO	NOx	PM
2000	0.12	5.25	0.31	0.12
2001	0.12	5.25	0.31	0.12
2002	0.64	29.15	1.71	0.69
2003	0.39	17.82	1.05	0.42
2004	0.52	23.36	1.37	0.55
2005	0.00	0.00	0.00	0.00
2006	0.24	11.06	0.65	0.26
2007	0.24	11.08	0.65	0.26
Total	2.27	102.97	6.06	2.42

Step 9: Estimation of the emissions from Tier 1 vehicles (tons)

	VOC	CO	NOx	PM
Year 2000	0.39	5.25	1.55	0.31
Year 2001	0.39	5.25	1.55	0.31
Year 2002	2.14	29.15	8.57	1.71
Year 2003	1.31	17.82	5.24	1.05
Year 2004	1.72	23.36	6.87	1.37
Year 2005	0.00	0.00	0.00	0.00
Year 2006	0.81	11.06	3.25	0.65
Year 2007	0.81	11.08	3.26	0.65
Total	7.57	102.97	30.29	6.06

Step 10: Determination of the emission reductions realized by using low emission vehicles (tons)

	VOC	CO	NOx	PM
Year 2000	0.27	0.00	1.24	0.19
Year 2001	0.27	0.00	1.24	0.19
Year 2002	1.50	0.00	6.86	1.03
Year 2003	0.92	0.00	4.19	0.63
Year 2004	1.20	0.00	5.50	0.82
Year 2005	0.00	0.00	0.00	0.00
Year 2006	0.57	0.00	2.60	0.39
Year 2007	0.57	0.00	2.61	0.39
Total	5.30	0.00	24.23	3.63

Step 11: Determine the total emission reductions

	VOC	CO	NOx	PM
Year 2000	16.12	219.27	36.06	12.44
Year 2001	16.12	219.27	36.06	12.44
Year 2002	38.04	505.48	87.15	29.27
Year 2003	46.61	631.98	104.58	35.94
Year 2004	63.29	858.86	141.92	48.81
Year 2005	41.96	580.41	92.19	32.43
Year 2006	43.91	599.43	97.81	33.88
Year 2007	44.06	601.50	98.15	34.00
Total	310.12	4216.20	693.92	239.21

Scenario Two: Based on 5 credits

Step 1: Estimate the electric vehicle population
A. Step 1 was performed at the TNRCC on the fleet database

B. Electric vehicles purchased by all fleets in Group A

EV1 =	3127.80
EV2 =	3909.75

C. Electric vehicles purchased by all fleets in Group B

EV3 =	24.08
EV4 =	11.28

D. Electric vehicles purchased by all fleets in Group C

EV5 =	9.00

E. Electric vehicles utilized for compliance in the year 2000

EV_{2000}=	3448.35

F. Electric vehicles utilized for compliance in the year 2002

EV_{2000}=	7916.27

G: Total EV population 2003 - 2007

Year 2003 =	9891
Year 2004 =	13459
Year 2005 =	9113
Year 2006 =	8300
Year 2007 =	8308

Step 2: Annual EV miles traveled

Year 2000 =	48276928
Year 2001 =	48276928
Year 2002 =	110827830
Year 2003 =	138475928
Year 2004 =	188423206
Year 2005 =	127579402
Year 2006 =	116194488
Year 2007 =	116312554
Total =	894367265

Step 3: Electric Utility Emissions

A. Kilowatt hours of electricity

Year 2000 =	19704868.60
Year 2001 =	19704868.60
Year 2002 =	45235848.94
Year 2003 =	56520786.84
Year 2004 =	76907431.17
Year 2005 =	52073225.64
Year 2006 =	47426321.49
Year 2007 =	47474511.88
Total =	365047863.15

B. Power plant emissions of each criterion pollutant (tons)

	PM	VOC	NOx	CO
Year 2000	0.84	0.61	25.34	5.42
Year 2001	0.84	0.61	25.34	5.42
Year 2002	1.92	1.41	58.17	12.44
Year 2003	2.40	1.76	72.68	15.54
Year 2004	3.26	2.40	98.89	21.14
Year 2005	2.21	1.62	66.96	14.32
Year 2006	2.01	1.48	60.98	13.04
Year 2007	2.01	1.48	61.04	13.05
Total	15.49	11.39	469.40	100.36

Step 4: Estimate the Emissions from Tier 1 vehicles (tons)

	PM	VOC	NOx	CO
Year 2000	10.64	13.30	53.22	180.94
Year 2001	10.64	13.30	53.22	180.94
Year 2002	24.43	30.54	122.17	415.37
Year 2003	30.53	38.16	152.64	518.99
Year 2004	41.54	51.93	207.70	706.18
Year 2005	28.13	35.16	140.63	478.15
Year 2006	25.62	32.02	128.08	435.48
Year 2007	25.64	32.05	128.21	435.92
Total	197.17	246.47	985.87	3351.96

Step 5: Determine the emission reductions attributed to the EVs (tons)

	PM	VOC	NOx	CO
Year 2000	9.81	12.69	27.88	175.52
Year 2001	9.81	12.69	27.88	175.52

Year 2002	22.51	29.13	64.00	402.93
Year 2003	28.13	36.40	79.97	503.45
Year 2004	38.28	49.53	108.81	685.04
Year 2005	25.92	33.53	73.67	463.83
Year 2006	23.60	30.54	67.10	422.44
Year 2007	23.63	30.57	67.17	422.87
Total	181.68	235.08	516.48	3251.60

Step 6: Estimate the low emission vehicle population (LEV)

A. Determine the number of low emission vehicles purchased by all fleets in Group B.

LEV1 =	69.40

B. Determine the number of low emission vehicles purchased by all fleets in Group C.

LEV2 =	39.10
LEV3 =	108.75

C. Determine the total number of low emission vehicles utilized for compliance in the year 2000

LEV_{2000} =	42.66

D. Determine the total number of low emission vehicles utilized for compliance in the year 2002

LEV_{2000} =	246.56

E. Determine the total low emission vehicle population (2003 -2007)

Year	EVPOP	1.022Y	EVPOP * 1.022Y	LEV2002	OLDLEV	Calculation
2003	86.93	1.16	101.23	108.75	42.66	167.33
2004	86.93	1.19	103.46	108.75	0.00	212.21
2005	86.93	1.22	105.74	108.75	203.91	10.58
2006	86.93	1.24	108.06	108.75	101.23	115.58
2007	86.93	1.27	110.44	108.75	103.46	115.73

Step 7: Estimate of the annual vehicle miles traveled by low emission vehicles

Year	LEVX	Miles Traveled	VMT
2000	42.66	25000.00	1066400.52
2001	42.66	25000.00	1066400.52
2002	246.56	25000.00	6164092.24
2003	167.33	25000.00	4183196.87
2004	212.21	25000.00	5305276.04

2005	10.58	25000.00	264487.89
2006	115.58	25000.00	2889487.67
2007	115.73	25000.00	2893243.90

Step 8: Estimation of the emissions from low emission vehicles (tons)

Year	VOC	CO	NOx	PM
2000	0.09	4.00	0.24	0.09
2001	0.09	4.00	0.24	0.09
2002	0.51	23.10	1.36	0.54
2003	0.35	15.68	0.92	0.37
2004	0.44	19.88	1.17	0.47
2005	0.02	0.99	0.06	0.02
2006	0.24	10.83	0.64	0.25
2007	0.24	10.84	0.64	0.26
Total	1.97	89.32	5.25	2.10

Step 9: Estimation of the emissions from Tier 1 vehicles (tons)

	VOC	CO	NOx	PM
Year 2000	0.29	4.00	1.18	0.24
Year 2001	0.29	4.00	1.18	0.24
Year 2002	1.70	23.10	6.79	1.36
Year 2003	1.15	15.68	4.61	0.92
Year 2004	1.46	19.88	5.85	1.17
Year 2005	0.07	0.99	0.29	0.06
Year 2006	0.80	10.83	3.19	0.64
Year 2007	0.80	10.84	3.19	0.64
Total	6.57	89.32	26.27	5.25

Step 10: Determination of the emission reductions realized by using low emission vehicles (tons)

	VOC	CO	NOx	PM
Year 2000	0.21	0.00	0.94	0.14
Year 2001	0.21	0.00	0.94	0.14
Year 2002	1.19	0.00	5.44	0.82
Year 2003	0.81	0.00	3.69	0.55
Year 2004	1.02	0.00	4.68	0.70
Year 2005	0.05	0.00	0.23	0.03
Year 2006	0.56	0.00	2.55	0.38
Year 2007	0.56	0.00	2.55	0.38
Total	4.60	0.00	21.02	3.15

Step 11: Determine the total emission reductions

	VOC	CO	NOx	PM
Year 2000	12.90	175.52	28.82	9.95
Year 2001	12.90	175.52	28.82	9.95
Year 2002	30.32	402.93	69.44	23.33
Year 2003	37.20	503.45	83.66	28.68
Year 2004	50.55	685.04	113.49	38.98
Year 2005	33.58	463.83	73.91	25.95
Year 2006	31.10	422.44	69.65	23.99
Year 2007	31.13	422.87	69.72	24.01
Total	239.68	3251.60	537.49	184.83

Scenario Three: Based on 6 credits

Step 1: Estimate the electric vehicle population

A. Step 1 was performed at the TNRCC on the fleet database.

B. Electric vehicles purchased by all fleets in Group A

EV1 =	2585.75
EV2 =	3267.45

C. Electric vehicles purchased by all fleets in Group B

EV3 =	19.60
EV4 =	12.40

D. Electric vehicles purchased by all fleets in Group C

EV5 =	3.00

E. Electric vehicles utilized for compliance in the year 2000

EV_{2000}=	2845.57

F. Electric vehicles utilized for compliance in the year 2002

EV_{2002}=	6582.88

G: Total EV population 2003 - 2007

Year 2003 =	8336
Year 2004 =	11283
Year 2005 =	7649
Year 2006 =	6086
Year 2007 =	6075

Step 2: Annual EV miles traveled

Year 2000 =	39837996
Year 2001 =	39837996
Year 2002 =	92160364
Year 2003 =	116701327
Year 2004 =	157955660
Year 2005 =	107080788
Year 2006 =	85202026
Year 2007 =	85048943
Total =	723825100

Step 3: Electric Utility Emissions

A. Kilowatt hours of electricity

Year 2000 =	16260406.60
Year 2001 =	16260406.60
Year 2002 =	37616475.25
Year 2003 =	47633194.49
Year 2004 =	64471697.85
Year 2005 =	43706444.10
Year 2006 =	34776337.23
Year 2007 =	34713854.19
Total =	295438816.30

B. Power plant emissions of each criterion pollutant (tons)

	PM	VOC	NOx	CO
Year 2000	0.69	0.51	20.91	4.47
Year 2001	0.69	0.51	20.91	4.47
Year 2002	1.60	1.17	48.37	10.34
Year 2003	2.02	1.49	61.25	13.10
Year 2004	2.74	2.01	82.90	17.72
Year 2005	1.85	1.36	56.20	12.02
Year 2006	1.48	1.08	44.72	9.56
Year 2007	1.47	1.08	44.64	9.54
Total	12.54	9.22	379.89	81.22

Step 4: Estimate the Emissions from Tier 1 vehicles (tons)

	PM	VOC	NOx	CO
Year 2000	8.78	10.98	43.91	149.31
Year 2001	8.78	10.98	43.91	149.31
Year 2002	20.32	25.40	101.59	345.40
Year 2003	25.73	32.16	128.64	437.38
Year 2004	34.82	43.53	174.12	592.00
Year 2005	23.61	29.51	118.04	401.32
Year 2006	18.78	23.48	93.92	319.33
Year 2007	18.75	23.44	93.75	318.75
Total	159.58	199.47	797.88	2712.79

Step 5: Determine the emission reductions attributed to the EVs (tons)

	PM	VOC	NOx	CO
Year 2000	8.09	10.47	23.01	144.84
Year 2001	8.09	10.47	23.01	144.84

Year 2002	18.72	24.22	53.22	335.06
Year 2003	23.71	30.67	67.39	424.28
Year 2004	32.09	41.52	91.22	574.27
Year 2005	21.75	28.15	61.84	389.31
Year 2006	17.31	22.39	49.20	309.76
Year 2007	17.28	22.35	49.11	309.21
Total	147.04	190.25	417.99	2631.57

Step 6: Estimate the low emission vehicle population (LEV)

A. Determine the number of low emission vehicles purchased by all fleets in Group B.

LEV1 =	74.39

B. Determine the number of low emission vehicles purchased by all fleets in Group C.

LEV2 =	38.40
LEV3 =	70.50

C. Determine the total number of low emission vehicles utilized for compliance in the year 2000

LEV_{2000} =	41.89

D. Determine the total number of low emission vehicles utilized for compliance in the year 2002

LEV_{2002} =	207.13

E. Determine the total low emission vehicle population (2003 -2007)

Year	EVPOP	1.022Y	EVPOP * 1.022Y	LEV2002	OLDLEV	Calculation
2003	71.66	1.16	83.45	108.75	41.89	150.31
2004	71.66	1.19	85.29	108.75	0.00	194.04
2005	71.66	1.22	87.16	108.75	165.24	30.67
2006	71.66	1.24	89.08	108.75	83.45	114.38
2007	71.66	1.27	91.04	108.75	85.29	114.50

Step 7: Estimate of the annual vehicle miles traveled by low emission vehicles

Year	LEVX	Miles Traveled	VMT
2000	41.89	25000.00	1047308.95
2001	41.89	25000.00	1047308.95
2002	207.13	25000.00	5178273.08
2003	150.31	25000.00	3757723.39
2004	194.04	25000.00	4850930.56

2005	30.67	25000.00	766874.40
2006	114.38	25000.00	2859496.13
2007	114.50	25000.00	2862592.55

Step 8: Estimation of the emissions from low emission vehicles (tons)

Year	VOC	CO	NOx	PM
2000	0.09	3.93	0.23	0.09
2001	0.09	3.93	0.23	0.09
2002	0.43	19.41	1.14	0.46
2003	0.31	14.08	0.83	0.33
2004	0.40	18.18	1.07	0.43
2005	0.06	2.87	0.17	0.07
2006	0.24	10.72	0.63	0.25
2007	0.24	10.73	0.63	0.25
Total	1.85	83.84	4.93	1.97

Step 9: Estimation of the emissions from Tier 1 vehicles (tons)

	VOC	CO	NOx	PM
Year 2000	0.29	3.93	1.15	0.23
Year 2001	0.29	3.93	1.15	0.23
Year 2002	1.43	19.41	5.71	1.14
Year 2003	1.04	14.08	4.14	0.83
Year 2004	1.34	18.18	5.35	1.07
Year 2005	0.21	2.87	0.85	0.17
Year 2006	0.79	10.72	3.15	0.63
Year 2007	0.79	10.73	3.16	0.63
Total	6.16	83.84	24.66	4.93

Step 10: Determination of the emission reductions realized by using low emission vehicles (tons)

	VOC	CO	NOx	PM
Year 2000	0.20	0.00	0.92	0.14
Year 2001	0.20	0.00	0.92	0.14
Year 2002	1.00	0.00	4.57	0.68
Year 2003	0.72	0.00	3.31	0.50
Year 2004	0.94	0.00	4.28	0.64
Year 2005	0.15	0.00	0.68	0.10
Year 2006	0.55	0.00	2.52	0.38
Year 2007	0.55	0.00	2.52	0.38
Total	4.32	0.00	19.73	2.96

Step 11: Determine the total emission reductions

	VOC	CO	NOx	PM
Year 2000	10.47	144.84	23.01	8.09
Year 2001	10.47	144.84	23.01	8.09
Year 2002	24.22	335.06	53.22	18.72
Year 2003	30.67	424.28	67.39	23.71
Year 2004	41.52	574.27	91.22	32.09
Year 2005	28.15	389.31	61.84	21.75
Year 2006	22.39	309.76	49.20	17.31
Year 2007	22.35	309.21	49.11	17.28
Total	190.25	2631.57	417.99	147.04

State Program Calculations

A. Estimate the annual miles traveled.

Years	Vehicle Miles Traveled
2000	152336850
2001	286851450
2002	369621450
2003	521357550
2004	638330250
2005	731940450
2006	748040550
2007	764501100
Total	4212979650

B. Estimate the emissions from low emission vehicles (tons)

Year	VOC	CO	NOx	PM
2000	12.59	570.94	33.58	13.43
2001	23.71	1075.08	63.24	25.30
2002	30.56	1385.29	81.49	32.60
2003	43.10	1953.97	114.94	45.98
2004	52.77	2392.37	140.73	56.29
2005	60.51	2743.21	161.37	64.55
2006	61.84	2803.55	164.91	65.97
2007	63.20	2865.24	168.54	67.42

C. Estimate the emissions from Tier 1 vehicles (tons)

Year	VOC	CO	NOx	PM
2000	41.98	570.94	167.92	33.58
2001	79.05	1075.08	316.20	63.24
2002	101.86	1385.29	407.44	81.49
2003	143.67	1953.97	574.70	114.94
2004	175.91	2392.37	703.64	140.73
2005	201.71	2743.21	806.83	161.37
2006	206.14	2803.55	824.57	164.91
2007	210.68	2865.24	842.72	168.54

D. Estimate the total emission reductions achieved by the state program (tons)

Year	VOC	CO	NOx	PM
2000	29.39	0.00	134.34	20.15
2001	55.33	0.00	252.96	37.94

2002	71.30	0.00	325.95	48.89
2003	100.57	0.00	459.76	68.96
2004	123.14	0.00	562.91	84.44
2005	141.19	0.00	645.46	96.82
2006	144.30	0.00	659.66	98.95
2007	147.48	0.00	674.17	101.13
Total	812.70	0.00	3715.21	557.28

<u>Determination of Credit Allowed the Electric Vehicle (Based on this study)</u>

VOC Emission Reductions Anticipated by the State (tons)

812.00

VOC Emission Reductions Anticipated by the State (grams)

736633976.40

Miles Driven to Achieve the Anticipated Reductions

3095100741.18

Credit Calculation

1.4

NOx Emission Reductions Anticipated by the State (tons)

3715.00

NOx Emission Reductions Anticipated by the State (grams)

3370191160.50

Miles Driven to Achieve the Anticipated Reductions

6431662520.04

Credit Calculation

0.70

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VITA

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