ELECTRIC VEHICLES AS AN OZONE REDUCTION STRATEGY FOR NEW ENGLAND

by

Scott D. Wright

B.S., Mechanical Engineering, Purdue University, 1991

Submitted to the Department of Mechanical Engineering on May 15, 1995,
in Partial Fulfillment of the Requirements for the Degree of

MASTER OF SCIENCE
in Technology and Policy
at the

Massachusetts Institute of Technology

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ABSTRACT

There has been and continues to be debate about the feasibility of Electric Vehicles (EVs) in New England and the other Northeast states. The primary motivation for EVs is anticipated reductions in ground-level ozone concentrations, which persistently far exceed the health-based standards of the Clean Air Act. The purpose of this study is to evaluate EVs as a strategy to address this problem, and to suggest subsequent implications for environmental policy.

A bottom-up, engineering-based model was developed to simulate the future impacts of adopting EVs in New England. Cost and emissions impacts to the transportation and electric power sectors were calculated separately, and then combined to give "net" impacts. The focus was on the precursor emissions of ozone, but impacts for other emissions were also included. Numerous EV options, including permutations on penetration levels, time frame, and end-use applications were compared.

The results showed that even accounting for the emissions produced by the electric power sector, the adoption of EVs in New England will substantially reduce ozone precursor emissions (at a cost), though there is a time lag of many years for any NO_x reductions. End-use applications of EVs affect changes in the impacts and even reversals of trends, with domestic commuter end-uses performing superiorly compared to commercial fleet end-uses. Tradeoffs must be considered, as EVs reduce emissions of ozone precursors, but increase other emissions.

Implications for EV-related policies were inferred from the results, as well as generalized implications applicable to the evaluation of other environmental strategies. These implications, combined with the study's supporting research, provide direction for a number of areas where further research will be most useful for influencing informed policy.

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Background and Motivation

The thesis of this study is that evaluations of environmental strategies often employ simplistic, even superficial, methods and that an approach which incorporates the question of interest into the structure of the analysis, builds on fundamental engineering and economic precepts from the bottom-up, and accounts for potential effects on multiple polluting mediums, is much more elucidating for understanding the dynamics of a strategy, especially in regards to tradeoffs, uncertainties, and effects over time.

As a case in point, the focus of this study is on the evaluation of the electric vehicle strategy, a highly debated option in New England for reducing emissions of nitrogen oxides and reactive organic gases, both precursor emissions of ground-level ozone. Conclusions for this specific strategy are developed, as well as more general guidelines applicable to future evaluations of other environmental strategies.

INTRODUCTION

Preliminary reports on 1994's ground-level ozone concentrations indicate that New England continues to be in gross violation of National Ambient Air Quality Standards (NAAQS), perhaps even worse than in previous years. In 1993, a total of 27 full days of exceedance beyond the national standards were recorded in the Northeast, and mid-way through the 1994 ozone season it appears that this count will be surpassed. In addition, the data reveals that New England's 1993 peak concentration of 170 parts per billion (ppb) was surpassed by a 187 ppb concentration (50% over the 120 ppb set forth in the NAAQS), with over two months of the ozone season remaining.[1]

However, such exceedances are routine in New England and across the United States. It was estimated by the EPA in 1989 that 67 million people in

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[1]Northeast States for Coordinated Air Use Management, "Northeast AIReport," Issue 14, Summer, 1994.

the U.S. live in areas which exceed the national standard at least once per year.[2] Most of these areas are in the Northeast and California. Of the 98 areas of the U.S. deemed as "nonattainment" areas by the Environmental Protection Agency (EPA), 10 are within New England. To be designated as "nonattainment," there must be at least three maximum daily one-hour average ozone concentrations above 120 ppb over a three year period. With the exception of Vermont, all of the New England states are partially or entirely exceeding the ozone NAAQS on this basis.

The purpose of this study is to assess the emissions and cost impacts of a strategy aimed at mitigating the ozone problem in New England – the mandated proliferation of electric vehicles (EVs). Though EVs are just one component of a broad mobile source policy directive instigated in California, this single component has generated substantial controversy as two states in New England have opted to adopt the California program. Several other states are considering it, and there has been a well-publicized initiative for the entire Northeast region to adopt EVs. Litigation is still pending in many states between contentious parties. Though the litigation hinges on many aspects, one certain determinant is the long-term emission and cost impacts associated with the region-wide adoption of EVs. This study characterizes these impacts using a detailed bottom-up engineering simulation of emission and cost impacts. Various EV options and uncertainties are explored, and relevant policy implications are enumerated.

This chapter provides a background on the characteristics of ground-level ozone in New England, the emissions most relevant to ozone formation, the current regulatory tactics for controlling ozone levels, the context of electric vehicles, the previous electric vehicle studies for New England, and the goals and general approach employed in this study.

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[2]EPA, "National Air Quality and Emissions Trends Report," Office of Air Quality Standards and Planning, Research Triangle Park, N.C., February, 1989.

CHARACTERISTICS OF GROUND-LEVEL OZONE IN NEW ENGLAND

Concern for the routine and widespread exposure to ground-level ozone is well-founded, as ozone has been proven to cause adverse effects to human health and vegetation. Ozone is a threshold pollutant, with the NAAQS set at a level sufficient to protect human health with an "adequate margin of safety"[3]– this language intentionally is left ambiguous to provide flexibility as improved information on health effects evolves. High, but brief, concentrations of ozone can impair the respiratory system – causing shortness of breath, chest pain, coughing, and wheezing. A noticeable effect of ozone-induced smog is eye irritation. Long-term exposure can induce chronic effects – causing reduced pulmonary response and premature aging of the lungs. Children, asthmatics, and the elderly are especially susceptible.[4] Effects on vegetation can include bleaching on green leaves, browning on conifer needles, and suppression of growth.[5] Ozone has been identified as the air pollutant with the most adverse effects on agricultural crop yields in the U.S., including decreased yields, reduced crop quality, and increased susceptibility to biotic and abiotic stresses. It is estimated that loss of crop production due to elevated ambient ozone levels translates to annual losses of billions of dollars in the U.S..[6]

With such costs imposed upon society, ground-level ozone is the classic case of an economic "externality," where the decision making framework of the producers of emissions is external to the environmental costs. Who are the producers of the emissions? If they can be identified, then corrective actions can be taken to internalize the costs of ozone damage in their decision making. This is much easier said than done. The difficulty lies in the fact that the producers of emissions are ubiquitous, present at every level of

[3]Clean Air Act, as amended in 1971, Section 109.
[4]As paraphrased by E.H. Pechan and Associates in a study for the Northeast States for Coordinated Air Use Management. "Adopting the California Low Emission Vehicle Program in the Northeast States - An Evaluation," E.H. Pechan and Associates, Inc. and Energy and Environmental Analysis, Inc., July, 1991, p. 6. The original source is the EPA - "Air Quality Criteria for Ozone and Other Photochemical Oxidants," Volume I, Environmental Criteria and Assessment Office, 1984.
[5]John H. Seinfeld, Atmospheric Chemistry and Physics of Air Pollution, John Wiley and Sons, Inc., New York, New York, 1986, p.52.
[6]Pechan, p. 7.

society and associated with multiple, diverse human activities. Transportation, electricity generation, and industrial production account for the majority of the emissions created by humans. Such activities permeate all sectors of society (residential, commercial, and industrial) in a complex web of interactions and interdependencies.

At one end is consumption, the satisfaction of human wants and needs, and at the other end is production, the creation of goods and services to meet those needs. The intervening agents are institutions and infrastructures, which ultimately dictate the allocation of both goods/services and emissions. The latter can be quite removed from the consumer (e.g., emissions created eight states away by a producer) or immediate (e.g., emissions created by the personal automobile). Though inadvertently implied, there is no distinct chain of events. A dynamic process of feedback exists between all stages, each shaping one another – all within the framework of the natural environment.

At each interface where emissions are created, whether related to consumption or production activities, the common thread is energy. It is in energy conversions where emissions are created. Matter can be neither created nor destroyed, only converted to more and less usable forms. Emissions are one of those less usable outputs of energy conversion. Emissions are not only less usable, but also can be clearly undesirable, as the case with toxic emissions. What dictates the breakdown between what is usable versus unusable (and the characteristics of these outputs) is the specific process of energy conversion employed, with technology playing an integral role. Outputs can be changed, managed, and redirected with different technologies and processes, but not eliminated.

This is the crux of the EV alternative, as emissions for energy conversions in transportation activity are shifted and modified to other mediums, namely electricity generation. Emissions are no longer the simple product of internal combustion and personal driving patterns, but of large-scale boilers and combustion turbines and the complex dispatch algorithms used coordinate a system of generation plants (in the case of New England, hundreds of plants). Personal driving patterns still play a role, but not as directly because the infrastructures and institutions of electricity supply are significant intervenors.

It is important to make the distinction that the ozone levels referenced here are for tropospheric ozone (ground-level ozone), as opposed to stratospheric ozone. Tropospheric ozone, occurring between the earth's surface and about 10 kilometers altitude, is responsible for "smog," while stratospheric ozone, occurring between 10 and 50 kilometers, assists in warming the planet by absorbing ultraviolet rays emitted by the sun. Stratospheric ozone is referred to in the global climate change dialogue. High stability of the region which separates the troposphere and the stratosphere prevents mixing or exchange between tropospheric and stratospheric ozone.[7]

Ozone (O_3) is a colorless, reactive gas produced naturally in trace amounts in the earth's atmosphere. Background concentrations are typically about 10 ppb. There is general consensus within the scientific community that ground-level ozone concentrations are steadily increasing over time. During the 1980's, an increase of about 10% occurred over Europe. The most critical aspect of the ground-level ozone problem is its formation in and downwind of large urban areas, where ozone concentrations can be as high as 200-400 ppb.[8]

Unlike the other pollutants regulated by National Ambient Air Quality Standards, ozone itself is not emitted by human activities. Rather, the ozone formation process is described by a complex set of chemical reactions, with two "precursor" emissions playing critical roles. Most simply put, reactive organic gases (ROG) and nitrogen oxides (NO_x) react in the presence of sunlight to produce ozone. Important secondary species already present in the atmosphere include hydroxyl radicals (OH), molecular oxygen (O_2), and carbon monoxide (CO). Ozone formation is very sensitive to prevailing weather conditions, with formation favored by high temperatures (which induce higher rates of chemical reactions) and slow-moving, high pressure systems (which allow increased mixing). A typical high ozone day occurs

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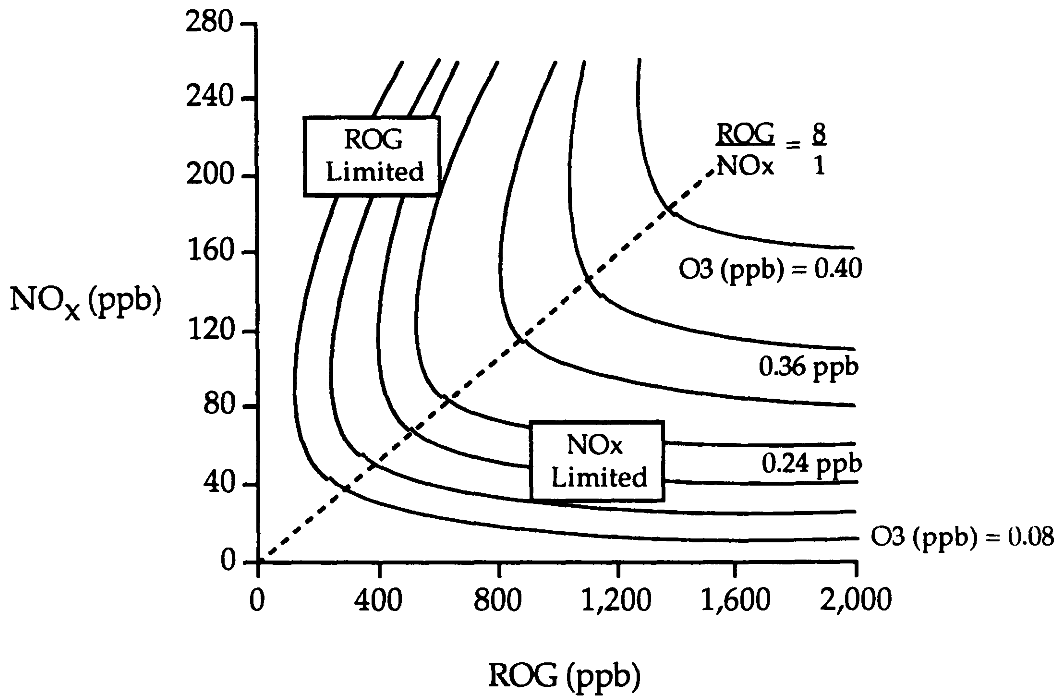
[7]National Research Council (NRC), <u>Rethinking the Ozone Problem in Urban and Regional Air Pollution</u>, National Academy Press, Washington, D.C., 1991, p. 19.
[8]NRC, p. 21, 22, 23.

with warm temperatures, clear skies, and light winds – occurring in the summer months. Consequently, the summer months between May and September are referred to as the "ozone season." In the Northeast, ozone "blankets" lasting several days have been recorded to span regions as large as 100,000 square kilometers. Such multi-day/multi-state occurrences are common, typically lasting three to seven days. On one of these days, the highest concentrations last several hours during mid-day.[9]

The complex chain of reactions does not result in ozone levels directly proportional to ROG or NO_x concentrations, making effective policy design an even more difficult task. The key issue is determining the maximum amount of ozone which can be created, given an initial mixture of ROG and NO_x. Monitoring of concentrations in laboratory ozone formation studies has revealed that the ROG/NO_x ratio is a useful parameter for predicting ozone formation. This ratio can be superimposed on a descriptive mapping of concentrations, called ozone "isopleths," to determine the sensitivity of ozone levels to ROG and NOx concentrations. Figure 1.1 shows typical ozone isopleths. The ultimate goal of isopleth mappings is to determine if ozone reduction policies are appropriately focused on NO_x reductions, ROG reductions, or both. As can be seen, it all depends on the starting point on the map. If the starting point is left of the diagonal line, reducing ROG concentrations is more effective. If starting on the right, reducing NO_x concentrations is more effective. The isopleth mappings vary from region to region and from city to country, so it is necessary to fully characterize them during the peak ozone season to design effective an ozone reduction policy.

[9]Ozone Transport Commission, "The Long-Range Transport of Ozone in the Ozone Transport Region," Technical Support Document, January, 1994, p. 16.

Figure 1.1: Representative Ozone Isopleths[10]



Due to the fact that the New England states have relatively high background concentrations of ROG and that the states are downwind of other major polluting regions (the Midwest and the remainder of the Northeast), it is believed that New England ozone is generally NO_x limited. Thus, NO_x-only control strategies are generally preferred over ROG-only controls. However, ROG-only controls are more effective in reducing ozone levels in densely populated cities, such as Boston, but may also increase ozone levels downwind. Combined control strategies, for both NO_x and ROG, achieve greater reductions than either NO_x or ROG controls alone, except in densely populated cities.[11] Nitrogen oxide controls must play a significant role in ozone reductions in New England, whether or not they are combined with ROG controls. This counters significantly to southern California, where biogenic sources are not as widespread. This difference has implications when evaluating the effectiveness of a given ozone reduction measure conceived for use in one location and considered for adoption in another.

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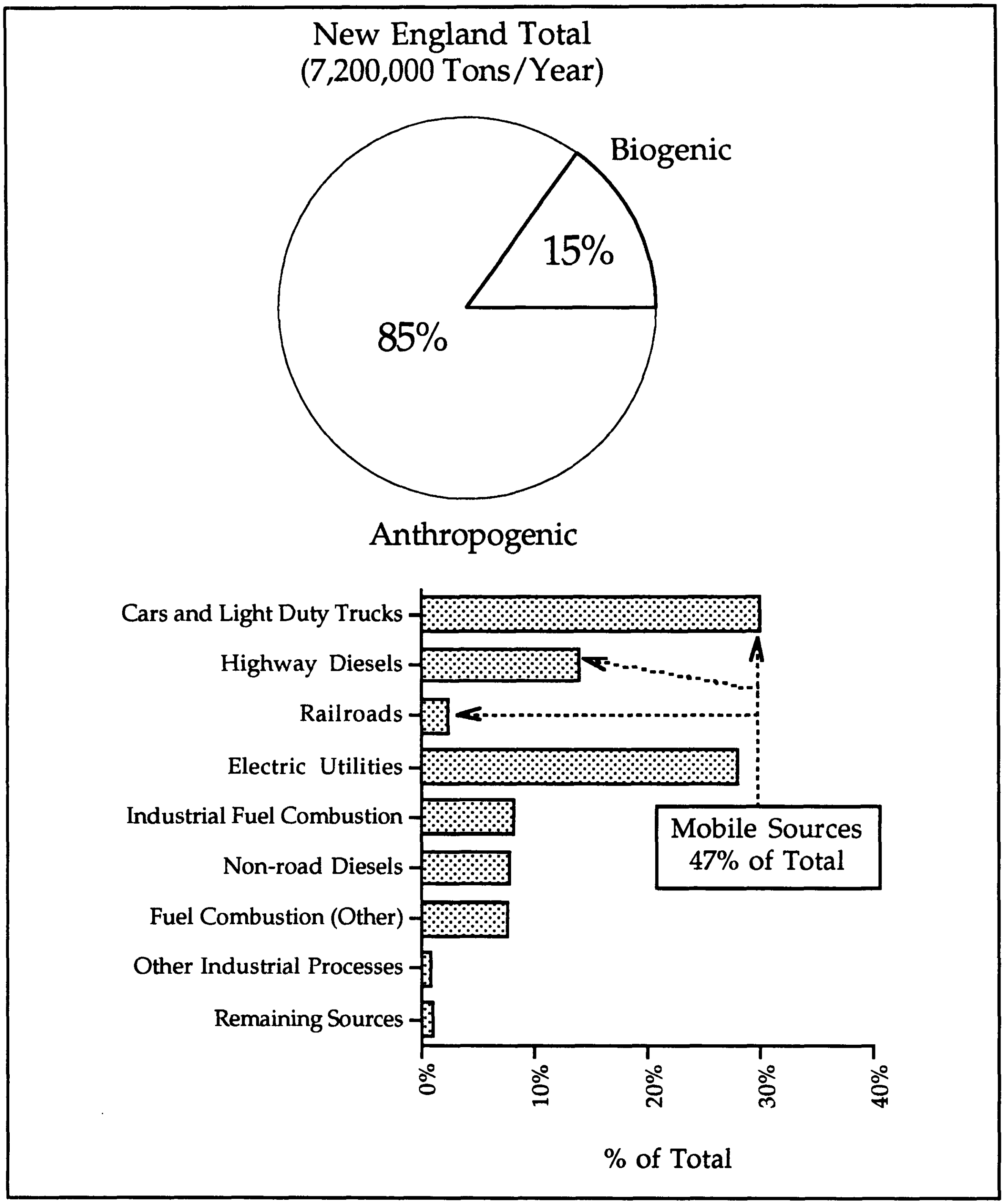
[10] A simplified generic isopleth graph – conceptual. NRC, p. 165.
[11] NRC, p. 362.

Human activities are the chief source of NO_x emissions, with only 15% of total emissions from natural sources, as depicted in Figure 1.2. Of the natural sources, roughly half come from lightning, half from soil processes, and a vary small amount from wildfires. Of the anthropogenic emissions, approximately half are from mobile sources (see footnote below figure). Electric utilities comprise the next largest source, with nearly 30% of total emissions. Within the mobile source category, approximately 65% of the emissions are from passenger cars and light duty trucks.

In contrast, natural sources are the primary emitter of ROG, with human activities comprising less than half of the emissions. The primary biogenic source in the U.S. is forested land, with agricultural cropland accounting for only a few percent of total emissions. Figure 1.3 shows that biogenic sources, on average in the U.S., contribute half of the total emissions. Due to New England's forest-dominated landscape, it is suspected that as much as 65-75% of total emissions are biogenically sourced. Of the anthropogenic emissions, approximately one-third (31%) are from mobile sources. Various industrial applications comprise the majority of ROG emissions, and electric utilities account for negligible amounts. Within the mobile source category, approximately 65% of the emissions are from passenger cars and light duty trucks.

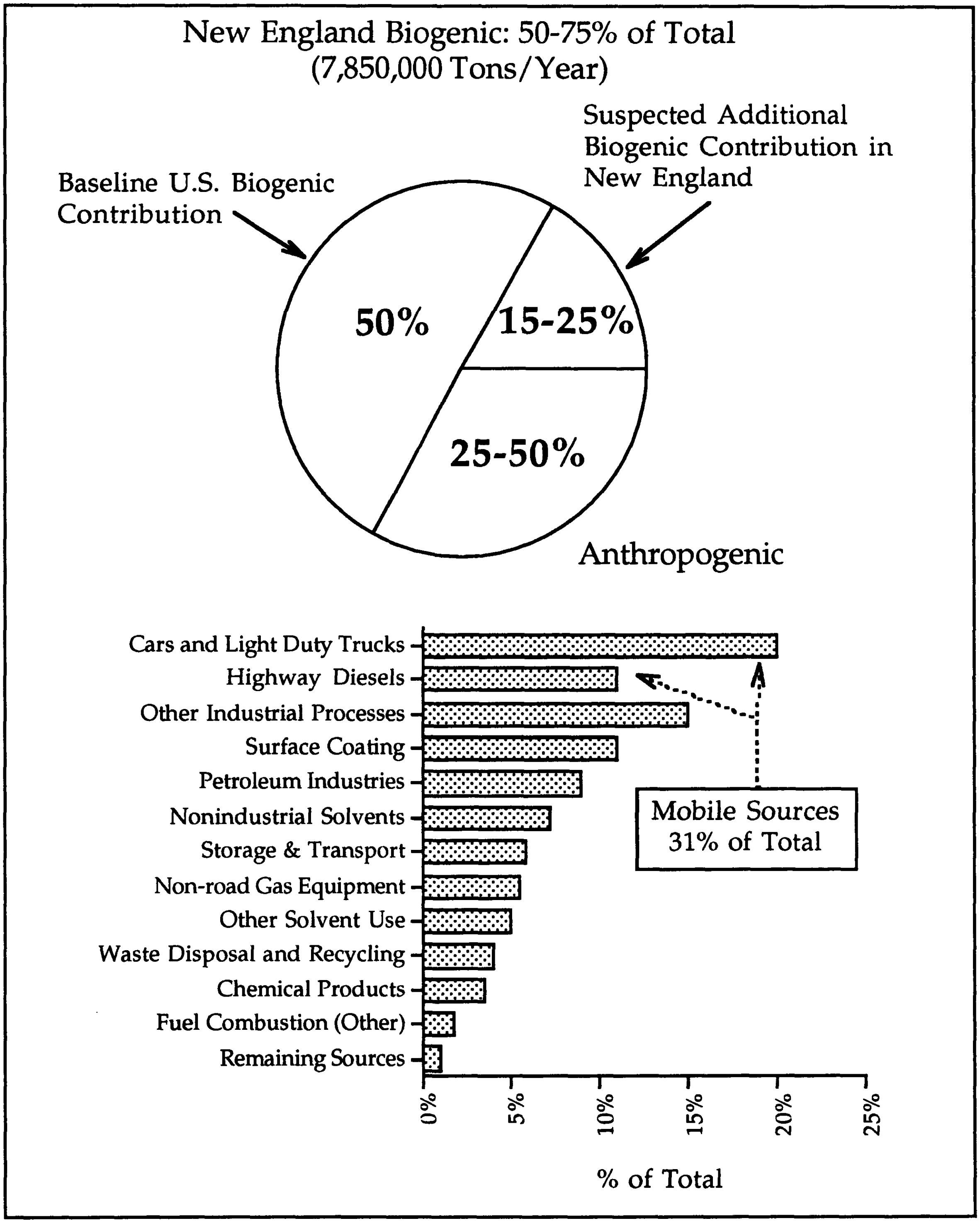
From these inventories, mobile sources are clearly the greatest single category of ozone precursor emissions, suggesting that these sources should merit primary consideration in the formulation of ozone reduction strategies. Furthermore, within the mobile source category, it is evident that passenger cars and light duty trucks dominate over heavy duty trucks, motorcycles, trains, buses, etc. and should, accordingly, be considered as a "target" group in focused strategies.

Figure 1.2: NO_x Inventory[12]



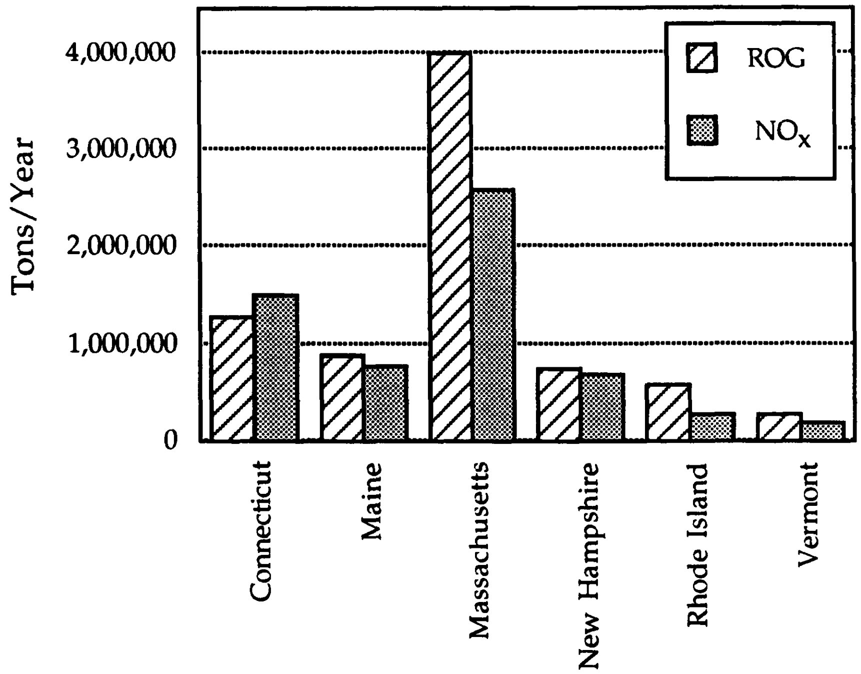
[12]The pie chart breakdown is constructed from a number of independent studies referenced by the National Research Council, NRC, p. 258, 274, 280. It is based on a U.S. national average and sufficiently represents New England. The bar chart is re-created from a compilation of an EPA Interim Inventory (November, 1993) by the Ozone Transport Commission. The source category percentages are averages for the entire Northeast region; great variance may exist from state to state. In New England, mobile sources play a more dominant role and account for 50-55% of total NO_x emissions.

Figure 1.3: ROG Inventory[13]



[13]Same sources as previous footnote. Pie chart - NRC, p.270. Bar chart - OTC compilation of EPA Interim Inventory. The mobile source percentage for New England is approximately equal to the Northeast average shown in the figure – 31%.

Figure 1.4: State Inventories of NO_X and ROG[14]



Emission inventories can continue with many layers of specificity. Figure 1.4 is the final level of detail presented in this study and provides an appreciation for state-by-state variance in emission levels. In general, states have comparable ratios for total NO_X and ROG emission levels, with Massachusetts being the single exception, most likely due to the state's increased industrial activity and, thus, increased ROG emissions. Massachusetts emissions are also at least two to three times as high as those in other New England states.

Because of the complexities previously described, it is difficult to accurately gauge the impacts that NO_X and ROG reductions have on actual air quality. The isopleth context provides a rough compass for assessing the value of NO_X versus ROG emission reductions. In New England, NO_X-only strategies or dual NO_X-ROG strategies are favored. Yet, it is difficult to assess how much a given reduction in NO_X/ROG emissions will influence resulting NO_X/ROG concentrations, and, subsequently, ozone concentrations in the peak ozone season. This study assumes that NO_X and ROG emission reductions are

[14]Based on the EPA Interim Inventory, as compiled by the Ozone Transport Commission.

proportional to NO_x and ROG concentration reductions. Based on the previous discussion, it is further predicated that these reductions will generally lead to ozone concentration reductions, though the proportionality is not well defined at this time. Thus, this study will assess ozone reduction strategies on the basis of NO_x and ROG emission reductions.

REGULATORY MEASURES TO ADDRESS GROUND-LEVEL OZONE: THE CONTEXT OF ELECTRIC VEHICLES

The Clean Air Act (CAA) requires states with nonattainment areas to create State Implementation Plans (SIP) for achieving compliance. The act authorizes the EPA to approve SIPs or to replace rejected ones with federal versions. Convinced of the regional nature of ozone pollution, resulting from demonstrated long-range transport and large multi-state ozone blankets, Congress also enabled the creation of the Ozone Transport Commission (OTC) under the 1990 Clean Air Act Amendments (CAAA) to address the ozone problem in the Ozone Transport Region (OTR) along the northeast corridor. The OTC has representatives from twelve states, from Maine to Virginia. It is empowered to develop recommendations for additional control measures, beyond those set forth in the CAAA, whenever a majority of OTC states determine that such measures are necessary to achieve NAAQS anywhere. Individual states or the OTC (as a whole) may then decide to more stringently control NO_x and ROG emissions from a menu of options.

With the exception of one state, Vermont, all of the New England states are partially or entirely designated as having "nonattainment" status in meeting the ozone standards. Depending on the severity of nonattainment in each area, the 1990 Amendments specify varying provisions and deadlines for states to come into compliance. The worst ozone nonattainment areas in New England (designated as "serious" in the 1990 Amendments), must come into compliance with NAAQS by November of 1999. The Amendments require all nonattainment areas to pursue a number of compliance strategies. For stationary sources, the first phase, termed "Phase I," is focused on NO_x controls to be installed by May of 1995. "Reasonably Available Control Technology" (RACT) is to be used. If the region is still not in compliance after that date, additional stationary source strategies, termed "Phase II" controls, will be necessary. On the mobile source side, states with "serious" nonattainment areas must adopt enhanced inspection and maintenance programs in cities, implement a clean fuels program in cities, adopt refueling regulations, and achieve ROG reductions of three percent per year for six years by 1999.

One of the most critical, and currently controversial, provisions of the 1990 CAAA (Section 177) is the option for nonattainment states to choose to adopt California's emission standards in lieu of the federal standards set forth in the amendments. California historically has been granted the authority to set more stringent standards because California's pollution problems were viewed as more severe. With other regions now being recognized as having serious problems, this option is provided to encourage further reductions from mobile sources.

California's program for the next ten years is the Low Emission Vehicle (LEV) program, which features a fixed schedule of introduction for incrementally cleaner cars and light duty trucks through the year 2004. The incrementally cleaner cars, specified by emission rates (gram/mile) for NO_x, ROG, and CO, are referred to as the Transitional Low Emission Vehicle (TLEV), Low Emission Vehicle (LEV), Ultra Low Emission Vehicle (ULEV), and the Zero Emission Vehicle (ZEV). Compared to the federal program, the LEV program is distinctly technology-forcing, with ZEVs required for sale in 1998. All emission references are on a tailpipe basis. The first vehicle, the TLEV, has standards that manufacturers currently can meet with certain vehicles models, and slight calibrations and hardware modifications will allow many models to compete as TLEVs. The LEV and ULEV standards are currently achievable by only a few models; significant modifications to conventional technology will be needed to meet the California sales levels. The California Air Resources Board (CARB) has projected that alternative fuel vehicles (compressed natural gas, methanol, and ethanol) will achieve the LEV and ULEV standards with less additional technologies and less complex emission controls than gasoline vehicles. Currently, the only promising technology likely to meet the 1998 start date for the ZEVs is the electric vehicle (CARB has stated that only battery-powered vehicles are expected to qualify).[15] Fuel cells and other technologies may eventually be strong competitors. The ZEV component of the LEV program has drawn considerable attention. The various vehicle types are introduced as a mandated percentage of new vehicle sales in each year, with the cleaner vehicles gradually increasing market share over the years 1994-2004.

The default federal program of the CAA, as amended in 1990, similarly requires specified percentages of new vehicle sales to achieve specified emission standards for NO_x, ROG, and CO. Phase I standards, referred to as "Tier I," are to be phased-in through the years 1994-1998. More stringent Phase II standards, referred to as "Tier II," are to be introduced beginning in the year 2004 at the discretion of the EPA administrator. The 1990 Clean Air Act Amendments require the EPA to conduct a study on the needs and costs for Phase II standards. Phase I standards may be retained, or entirely different standards may be set forth. Tier I standards are more relaxed than those of the California program, with the TLEV standards coming very close. Tier II standards, if eventually adopted, will be comparable to ULEV standards. Generally stated in terms of emission standards, it is likely that the California program will provide greater emission reductions than the federal program, especially on a state-wide basis. Recently, however, there has been research which has indicated that the federal standards (in combination with Tier II standards and other mobile source provisions in the 1990 CAAA for cities) may provide comparable results in the long run.[16] Notwithstanding this, it is widely accepted that the California program will provide greater emission reductions.

Because mobile sources contribute a large majority of the human-created ozone precursor emissions in the Northeast, and because the California program is generally believed to be more stringent than the federal program,

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[15]Pechan, p. 32.
[16]A comprehensive study using EPA's aggregate emissions model, MOBILE5a, has indicated that there is little difference in the two programs, especially in the long-run. However, this finding is qualified by the observation that the model assigns less emission reductions from inspection and maintenance programs for California cars, a potential bias in modeling assumptions. Jonathan Fox, John Heywood, and Gregory McRae, "Aggregate Vehicle Emission Estimates for Evaluating Control Strategies," Sloan Automotive Laboratory, Massachusetts Institute of Technology, 1994, p. 7.

several nonattainment states have enacted formal legislation to adopt the California's LEV program.[17] Also, recent research by the OTC has stated that regional strategies, transcending those pursued by any single state, are necessary to achieve NAAQS for the entire OTR. The OTC has also asserted that light duty motor vehicles are the single largest category of ozone precursor emissions and that they must be targeted by regional strategies.[18] With such momentum increasing over time, the OTC considered in 1994 the adoption of the California LEV program, or at least its stringent goals, for the entire Northeast.

One key component of the widespread adoption of the LEV program - the mandated sales of ZEVs - has created substantial controversy. Automobile manufacturers have solid ground for resisting mandated sales in 1998 of a product that is still in the research stages – a product known to have serious performance deficiencies compared to conventional gasoline vehicles. However, proponents for forcing ZEV sales also stand on solid ground, citing large potential environmental benefits not attainable through other means and the need to do so now.

As previously mentioned, only electric powered vehicles (EVs) have the potential of meeting the ZEV mandate as scheduled. Electric vehicles are interesting from a policy perspective for many reasons. From the perspective of regulatory mechanisms, EVs are a classic case of the technology-forcing approach to solving problems. Though couched in flexible language as "ZEVs," EVs are also a classic case of what has come to be known as the command and control approach (mandated sales quantities on a fixed time frame with no options) – an especially stringent example in the eyes of some, as the stakes are high and the deadlines are soon. From another perspective, the adoption of EVs is a classic case of cost shifting, with gasoline producers losing sales to electric utilities and the automobile industry taking on the costs of mass-producing and marketing a new product. From the chief policy

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[17] As of January of 1995, Massachusetts and New York have opted for the LEV program, complete with ZEVs, in the State Implementation Plans. Maine and New Jersey have conditional plans to adopt the LEV program with ZEVs, based on the decisions of other states in the Northeast. Connecticut has opted to conditionally opt for the LEV program, with the exclusion of the ZEV component.

[18] Ozone Transport Commission, p. 52.

perspective taken in this study, that of environmental cost-effectiveness, EVs are a most compelling policy case for their quality of emissions shifting across energy sectors. Batteries have to be recharged with electricity and electricity is generated from a system of power plants which, in turn, has emissions. Thus, the impression of zero-emissions is entirely fallacious, and the popularity of the term "ZEV" may do more damage than good.

This quality of EVs has not eluded policymakers for long. Indeed, the current debate over the widespread adoption of EVs in the Northeast has been particularly fueled by this aspect of EVs and the uncertainty it renders. Because the composition of the electric power sector varies substantially from one region of the country to another, it only stands to reason that the emission impacts of EVs will also vary – but by how much? Does a program conceived for application in California lose its appeal in a region that is NO_x-limited and has, on average, a much dirtier electric power generation system than California?

PREVIOUS ELECTRIC VEHICLE STUDIES FOR NEW ENGLAND

Numerous studies have been completed to evaluate the adoption of EVs in the Northeast. The principle organization for designing region-wide strategies for air pollution, the Northeast States for Coordinated Air Use Management (NESCAUM), completed a study in 1991 which showed that New England and the Northeast would benefit from the adoption of the California LEV program on a pure emission basis .[19] This study considered emission impacts for NO_x, ROG, and CO, as well as three toxics, but did not address emission changes in CO_2 and SO_2 or emissions from the electric power sector. In 1992, NESCAUM completed another study which also addressed the power plant emissions for NO_x, ROG, CO, CO_2 and SO_2, based on many assumptions of New York's electric power sector characteristics.[20]

[19]Pechan, "Adopting the California Low Emission Vehicle Program in the Northeast States - An Evaluation," E.H. Pechan and Associates, Inc. and Energy and Environmental Analysis, Inc., July, 1991.
[20]Michael Tennis, "Impact of Battery-Powered Electric Vehicles on Air Quality in the Northeast States," prepared for the Northeast States for Coordinated Air Use Management, July, 1992.

With the exception of SO_2, the study indicated that EVs would provide significant emission benefits with only minimal electric capacity additions. No costs were assessed for either the mobile or electric power sectors. Another study for the Northeast sponsored by the New Jersey legislature in 1993 addressed ROG and NO_x emissions.[21] This study concluded that the California program would only provide slim benefits and much uncertainty. Though the study makes mention of EVs, no emissions or cost for the electric power sector presented as results.

Some of the previous studies have included information on CO_2, SO_2, CO, and air toxics. Though not direct ozone precursors, these emissions are paramount in other environmental problems[22] and are emitted primarily by mobile sources and electric power plants. Thus, any policy-oriented evaluation of EVs (a strategy which has impacts to both of these sectors) is remiss not to address these emissions. It is important to appreciate the extent to which a strategy for one environmental problem may negate or supplement strategies for other problems.

None of the studies thus far provide an in-depth analysis of potential EV impacts on the electric power sector. The second NESCAUM study takes the electric power sector into account with a top-down approach, making many simplifying assumptions and documenting them well. Such an approach can provide entirely valid results. However, electric utilities are accustomed to more detailed analysis when completing internal Integrated Resource Plans, which are used to determine the cost and emissions impact of various electric load modifiers, such as EVs or demand-side management programs. This form of analysis includes hour-by-hour load impact projections over many years, with a production-cost model simulating the economic dispatch function performed by the utilities (or power pools in the case of New England). While such analysis is possible for an individual utility, it is much

[21]New Jersey Institute of Technology, "Adoption of the California Low Emission Vehicle: An Analysis of the Environmental Impact and Cost," prepared for the New Jersey Legislature, December, 1993.

[22]CO_2 – global climate change, SO_2 – a source of acid rain and a threat to the bronchial system, CO – poisonous to the respiratory system and a critical determinant in atmospheric chemistry, air toxics – a threat to human health as many are carcinogenic. SO_2 and CO are regulated under the Clean Air Act with National Ambient Air Quality Standards.

more difficult on a regional basis because of the large information requirements for these simulations. Also, as utilities are increasingly acting in accordance with competitive market forces, the incentive for sharing proprietary information necessary for the simulations is diminished.

The motivation for this study stems from the following points:

- A detailed simulation of the EV impacts to New England's electric power sector has not been completed on a regional basis.
- The ozone problem, as previously described, is regional in nature and region-wide planning is necessary to address it.
- Each of the previous studies do not address at least one of the crucial elements required for policy evaluations of EVs (e.g., cost impacts, changes in other air pollution emissions, impacts to the electric power sector).
- There is momentum in New England to adopt the California LEV program and electric vehicles in many states (two states have done so already) and eventually throughout the entire Ozone Transport Region, under the auspices of the Ozone Transport Commission.
- There has been, and continues to be, costly litigation between automobile manufacturers, states, the OTC, and the EPA over the region-wide adoption of the California LEV program, specifically, the mandated sales of EVs. The more fully the EV cost/emission impacts are understood and appreciated, the more likely it is that informed negotiations will take place.

GOALS AND APPROACH

The goals of this study include the following:

- to appraise the hypothesis of the thesis statement at the beginning of this chapter, namely that the approach used in this study is more effective for understanding the dynamics of an environmental strategy
- to determine the net emissions and cost impacts resulting from the region-wide adoption of EVs in New England, taking into account emissions and cost components from both the transportation sector and the electric power sector,

- to compare the differences in regional net impacts resulting from varying assumptions about EV penetration levels, including permutations on the number of EVs introduced, the time frame over which EVs are introduced, and the end-uses for which EVs are applied,
- to assess the sensitivity of the EV impacts to some of the uncertainties inherent in forward-looking studies, including future EV costs, future fuel costs, and estimates of offset mobile source emissions,
- to identify the implications and key issues of widespread EV adoption which may be relevant to the ozone mitigation policy in New England,
- to develop generalizations, if possible, from the experience gained in this study which are applicable and useful in the evaluation of other environmental strategies.

Chapter 1 sets the stage by characterizing New England's ozone problem and basic context of the electric vehicle strategy. Chapter 2 sets forth the methodology and assumptions used in the analysis and evaluation. Chapter 3 presents the results. Chapter 4 describes implications for policy and guidelines for future evaluations of environmental strategies, as supported by the results. Chapter 5 briefly discusses research initiatives for future studies. In final, Chapter 6 summarizes the basic conclusions of the study regarding EVs in New England.

The study has been completed by the MIT Energy Laboratory's Analysis Group for Regional Electricity Alternatives (AGREA), a research team which has facilitated discussion between industry, government, consumers, academia, and special interest groups on long-term energy strategies for New England since 1988. The major focus of AGREA in the past has been the detailed modeling of New England's electric power sector – employing multi-attribute scenario-based tradeoff analysis to compare alternative environmental mitigation options, taking into account future uncertainties. The central simulation tool used by AGREA is the industry standard production-cost model, called the Electric Generation Expansion Analysis System (EGEAS). The inputs to EGEAS are the actual data on all of New England's power plants, coordinated through confidentiality agreements with New England utilities and the New England Power Planning arm of the New England Power Pool (NEPOOL). Auxiliary tools created through the years have enabled the AGREA team to evaluate hundreds of attributes for many electric power sector strategies.

This study marks AGREA's first rigorous analysis effort in the mobile source sector. Thus, numerous tools and databases necessary for modeling mobile source inventories (for passenger cars and light duty trucks), growth rates, usage patterns, and emission rates have been developed. These tools are described in great detail herein, in contrast to the electric power sector model, which has been updated (re-hauled) in 1994 but remains fundamentally the same as in past years.

This study complements previous studies by addressing the "net" emissions levels resulting from the adoption of EVs – taking into account both the mobile source elimination of emissions and the electric power sector increases in emissions resulting from the recharging of EV batteries. This study quantifies the changes in net emissions for the ozone precursors, NO_x and ROG, as well as CO, CO_2, and SO_2. Cost-effectiveness is also assessed and various permutations, reflecting options and uncertainties associated with EVs, are analyzed. A detailed bottom-up engineering simulation for a twenty-year study period, 1995-2014, is used to generate all emissions and cost impacts.

Criteria used in this study for evaluation primarily include NO_x and ROG emissions, and secondarily, CO, CO_2, and SO_2 emissions. Emissions are reported on a total 20-year cumulative basis, as well as along year-by-year trajectories to evince dynamics throughout the study period. Another primary criteria is cost, evaluated using similar cumulative and year-by-year criteria. Robustness is measured by selected sensitivity studies on uncertain parameters and by emissions/cost performance across options. The extensive tradeoff analysis traditionally presented by AGREA is not employed here, as this is a detailed scoping study of EV impacts, not a cost-effectiveness comparison to alternative stationary source strategies.

It is important to qualify that no attempt is made to evaluate impacts of adopting EVs with the use of preference or objective functions which assign weights (typically monetary values) to attributes or criteria. As the audience for AGREA represents a cross-section of society, this approach is inappropriate due to differences between individuals and groups and the disparate "values" they attach to various attributes or criteria. In general, this approach requires many assumptions about the probabilities of future conditions (fuel costs, EV costs, electric load growth), the societal valuation of environmental and health impacts, the value of money through time, etc. Though there may be a place and time where such methods are appropriate, the prevalent and unqualified use of them in current policy discussions likely causes more harm than good. In this study the cost and emission impacts are simply presented; decisions about priority and value are left to the individual stakeholders.

∞ Chapter 2 ∞

Research Methodology

INTRODUCTION

The overall approach used for evaluating the impacts of EVs is based on a simulation of energy, emission, and cost impacts. These impacts are evaluated on a regional basis over a 20-year study period (1995 to 2014) for the mobile source and the electric power sectors. These impacts from both sectors are "netted" to allow evaluation of overall impacts. The simulation is executed by a number of models, those previously developed by AGREA and those designed for this study – specifically for EV analyses.

The models are designed using a bottom-up approach, beginning with fundamental engineering relationships for a single EV. This contrasts to a top-down approach which simply assumes EV electrical load impacts as "a percent of connected load" or offset mobile source emissions as a simple function the number of gasoline vehicles removed from service. Though more time-intensive, the bottom-up approach is compelling for its potential to provide to increased accuracy and its noticeable absence in previous studies and current policy dialogue.

A New England EV task force was assembled to review and build consensus on the study inputs, as well as the overall analysis approach. This group consisted of 12 people, representing regulators, industry, utilities, and special interest groups.[1] In addition, all model inputs, including assumptions and references, were distributed for review to 80 advisory group members of MIT's New England project. Industry-standard models are used which are

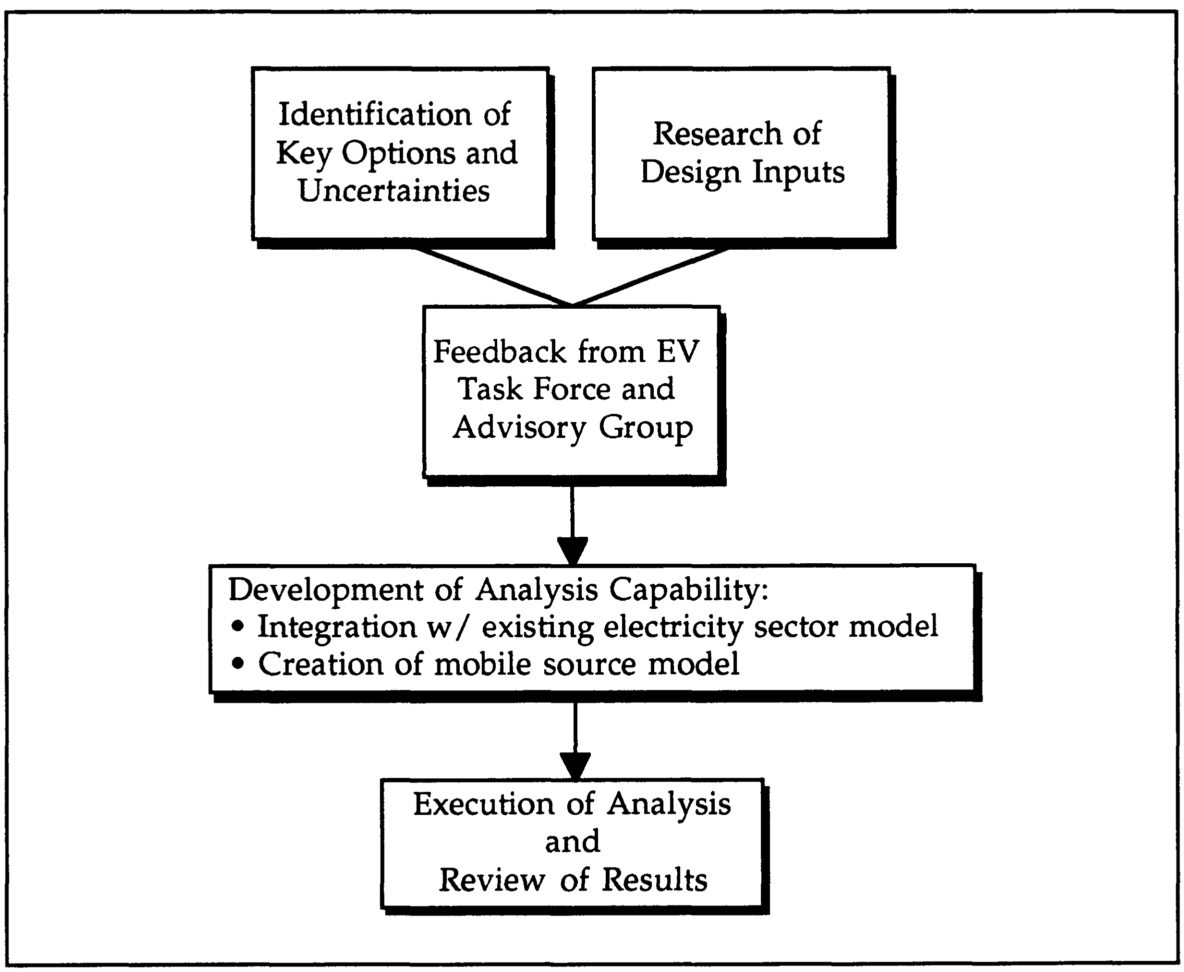
[1]The EV Task Force Meeting took place on June 24, 1994. Attendees included representatives from the Northeast States for Coordinated Air Use Management, New England Power Pool, New England Electric System, Maine Department of Public Utilities, U.S. Environmental Protection Agency, Boston Edison Co., New England Power Planning, Northeast Utilities, Raytheon Engineers and Constructors, Union of Concerned Scientists, and MIT AGREA.

routinely updated and benchmarked, such as EGEAS for the electric power sector and MOBILE5a for mobile sources. Other sub-models use fundamental engineering algorithms which are verifiable by hand-calculations.

The methodology includes the steps as shown in Figure 2.1. Five key categories of inputs are incorporated into these steps:

- EV Penetration Levels
- EV Usage Patterns
- EV Energy Requirements
- Emissions from the Electric Power Sector
- Offset Emissions from Gasoline Vehicles
- EV Cost Impacts.

Figure 2.1: Methodology for EV Analysis



ELECTRIC VEHICLE PENETRATION LEVELS

The final penetration levels of EVs will depend on both the quantities mandated and the success of EV marketing efforts. One desired outcome of the study was to demonstrate the change in impacts over a range of assumed EV penetration levels. This is an example of one such option deemed "interesting" by the EV Task Force and the New England Project Advisory Group. Such an inquiry assists in answering such policy questions as "Are EV impacts directly proportional to penetration levels? Is there a threshold level below which the impacts are mute? Are there significant changes in the trends across varying penetration levels? How long does it take before there is a sufficient saturation of EVs to produce a specified change in emission levels?"

Four penetration levels are modeled. The design of the penetration levels consists of two components. The first is the percentage of new vehicles in each year expected to be EVs, and the second is the breakdown between EVs used for domestic and commercial fleet purposes. The former specification is similar to the approach used in the California LEV mandate (2% in 1998, 5% in 2001, ...), and the latter is based on reasonable expectations of EV applications. The penetration levels are as follows:

Penetration Level	
Small Fleet	EVs pursued only on a demonstration basis (modeled as if only the government sector adopts EVs)
Moderate Fleet	Same penetration level as California LEV program
Moderate Commuter Accent	Same penetration level as California LEV program, Accent on domestic commuters
Large Fleet	Twice the penetration level of the California LEV program

With the exception of the third option, Moderate Commuter Accent, all options are designed with a largest fraction of EVs being used for commercial fleet purposes. This fraction is assumed to change over time, as expected EV range limitations and infrastructure develop over time. The detail for the second option, Moderate Fleet, is shown below and the other options are shown in the Appendix A, along with assumptions and references.

Table 2.1: Design of the "Moderate Fleet" EV Penetration Level

Year	Total New Veh. Sales	% EV's*	Percent EV Sales Dom- estic	Percent EV Sales Fleet	New PC's Domestic	New PC's Fleet	New LDT's Fleet	Total EVs in Service # EVs	Total EVs in Service % All Veh.
1995	782,694	0.0	0.0	0.0	0	0	0	0	0.0
1996	786,607	0.0	0.0	0.0	0	0	0	0	0.0
1997	790,540	0.0	0.0	0.0	0	0	0	0	0.0
1998	794,493	2.0	10.0	90.0	1,589	4,290	10,011	15,890	0.2
1999	798,465	2.0	10.0	90.0	1,597	4,312	10,061	31,859	0.3
2000	802,458	2.0	10.0	90.0	1,605	4,333	10,111	47,908	0.5
2001	806,470	5.0	10.0	90.0	4,032	10,887	25,404	88,232	0.9
2002	810,502	5.0	10.0	90.0	4,053	10,942	25,531	128,757	1.3
2003	814,555	10.0	10.0	90.0	8,146	21,993	51,317	210,212	2.2
2004	818,628	10.0	10.0	90.0	8,186	22,103	51,574	277,774	2.8
2005	822,721	10.0	10.0	90.0	8,227	22,213	51,831	345,674	3.5
2006	826,834	10.0	10.0	90.0	8,268	22,325	52,091	413,913	4.2
2007	830,969	10.0	10.0	90.0	8,310	22,436	52,351	460,719	4.6
2008	835,123	10.0	10.0	90.0	8,351	22,548	52,613	506,170	5.1
2009	839,299	10.0	10.0	90.0	8,393	22,661	52,876	515,193	5.1
2010	843,496	10.0	10.0	90.0	8,435	22,774	53,140	524,261	5.2
2011	847,713	10.0	10.0	90.0	8,477	22,888	53,406	530,955	5.2
2012	851,952	10.0	10.0	90.0	8,520	23,003	53,673	537,683	5.3
2013	856,211	10.0	10.0	90.0	8,562	23,118	53,941	540,371	5.3
2014	860,492	10.0	10.0	90.0	8,605	23,233	54,211	543,073	5.3

* Based on California LEV Program in this case

As this table indicates, it is assumed that the push for EVs in the domestic market will be for passenger cars, not trucks. This is a reasonable assumption for modeling commuter use patterns in New England. Also, the last two columns are the end effect of the population design – the cumulative number of EVs on the road in any given year and the percentage of all vehicles (passenger cars and light duty trucks) which are EVs. Using the assumptions of the CA program, this number exceeds half a million New England vehicles by the year 2008, accounting for 5% of all cars on the road.

Figure 2.2 shows an illustrative comparison of the four penetration levels used in this study. Steady-state values for EV populations are eventually reached because phase-in percentages are held constant in later years (after year 2002) and EVs purchased in early years meet the end of their useful lifetimes and are phased out. Though there is speculation that EVs lifetimes may exceed those of their gasoline vehicle counterparts, it is conservatively assumed that they are the same in this study. It is assumed that domestic vehicles are on the road for 10 years and that fleet vehicles are on the road for 6 years (more rapid mileage accumulation). The effect of differing vehicle lifetimes is demonstrated by the trajectories in Figure 2.2 for Moderate Fleet and Moderate Commuter Accent. The penetration levels are the same, but the longer lifetimes for domestic use vehicles give a noticeably higher steady-state population in later years. On the other extreme, the Small Fleet reaches a steady-state population much sooner because no domestic vehicles are used, only government fleet vehicles (lifetime of 6 years).

Figure 2.3 shows a snap-shot in year 2010 (a year by which the EV penetrations have stabilized – a quasi steady-state) of the "mix" of EVs for each penetration level. The Moderate Fleet and Moderate Commuter Accent have the same EV sales levels, but the height of the bars in the figure differ because of the lifetime effect. The difference in the compositional makeup is clearly shown. As expected, the Large Fleet has exactly twice as many EVs as the Moderate Fleet (with similar composition) and the Small Fleet appears nearly negligible in comparison.

Figure 2.2: Trajectory of Cumulative EVs in Service

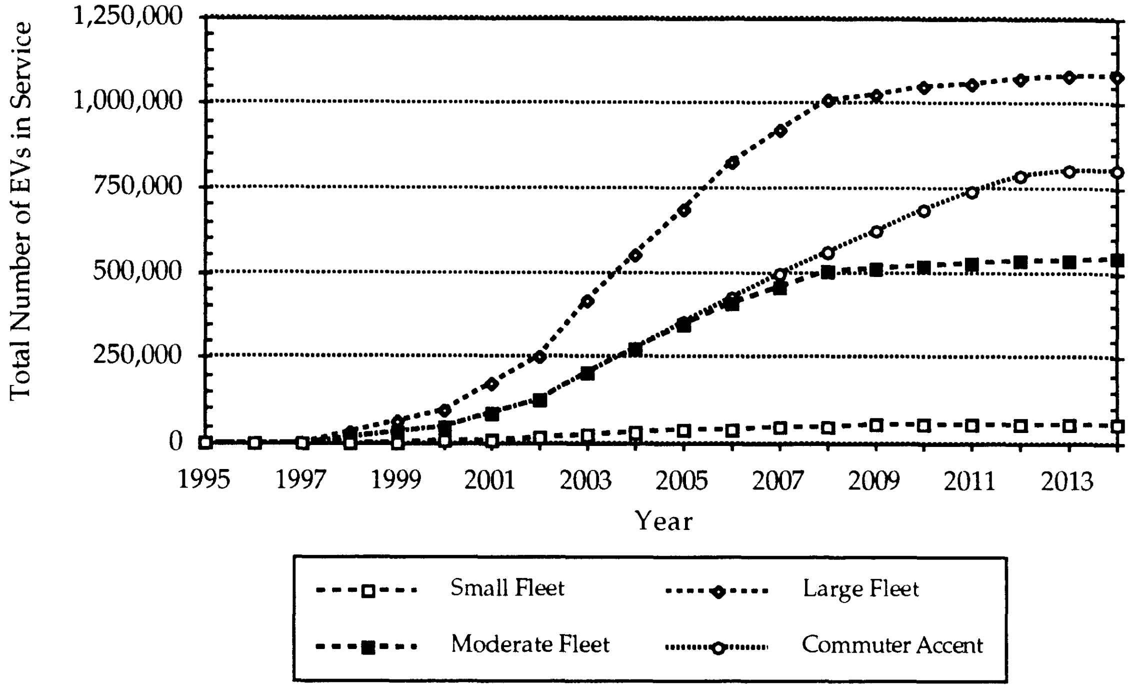
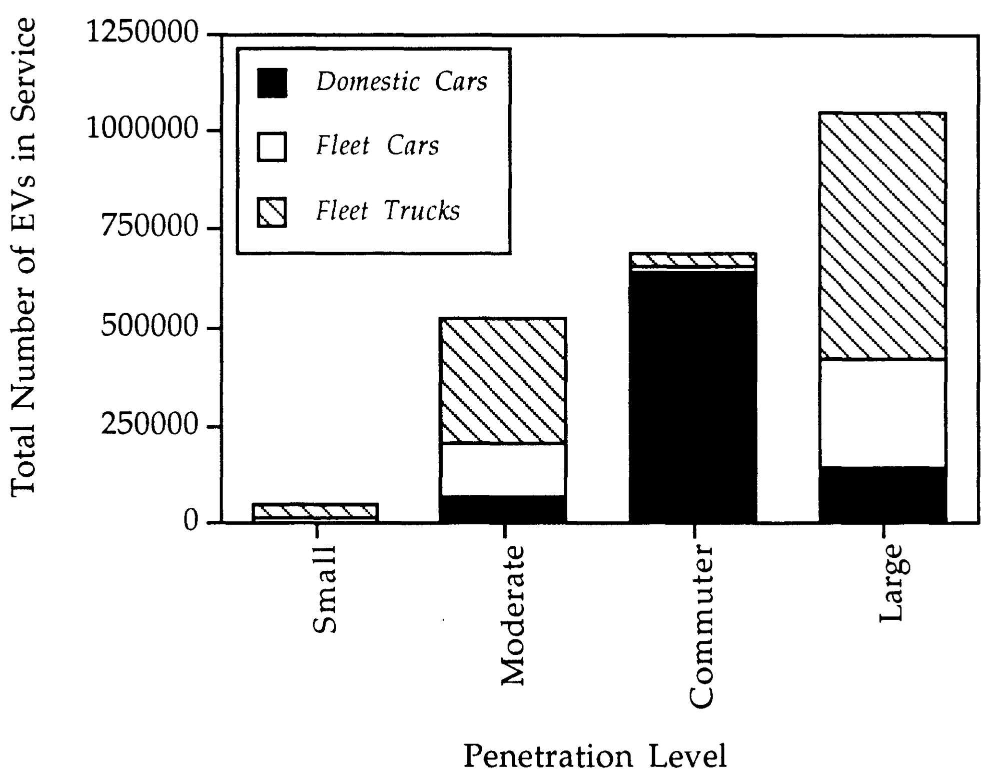


Figure 2.3: Snap-shot of EV Mix in Year 2010



VEHICLE USAGE PATTERNS

Usage patterns are a critical input to the determination of charging requirements, offset gasoline vehicle emissions, and maintenance costs. There are two aspects: annual miles and daily miles. For EVs, it is assumed that the *target* miles are equivalent to those desired with gasoline vehicles. Range limitations for EVs in the early years (due mainly to battery performance) prohibit them from reaching these *target* miles , so only *actual* miles are achieved. Annual target and actual miles are shown in Table B.1 of Appendix B, along with clarifying explanation. For domestic use vehicles in year 1995, it is assumed that the actual annual usage is 10,620 mile per year. For fleet use vehicles (both passenger cars and light duty trucks), the actual annual usages are 20,250 and 14,200 mile per year for passenger cars for light duty trucks, respectively. These values escalate through time as described in Appendix B.

Daily miles driven are required as an input to the EV load impacts model to determine the daily drain on EV batteries and the subsequent daily charging requirements. It is assumed that all fleet vehicles operate on Monday through Friday, and that fifteen percent also operate on Saturday. Vehicles for domestic use are assumed to operate on all days of the week, with the proportions shown in Appendix B. It is assumed that there are no seasonal variations in daily miles driven and that these daily breakdowns apply, on average, throughout the 20 year study period.

ENERGY REQUIREMENTS

To determine EV emissions from stationary sources, the electrical energy requirements must be known. Both demand (kW) and "energy"[2] (kWh) are relevant because an hour-by-hour load specificity is used in the stationary source model. This section will describe how 8,736 hourly load impacts[3] for

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[2]Though the term "energy" is typically used as a catch-all expression for both kW and kWh components, it is used in this section in strict reference to kWh only.
[3]The production-cost model for the electric power generation uses 364 days per year, rather than 365 days, resulting in 8,736 hours per year rather than 8,760 hours per year.

EVs are determined, from beginning to end (one EV and its usage patterns to the aggregate load of an entire population of EVs). Figure 2.4 shows the building blocks which are used. On an hour-by-hour basis, the EV load impacts in any given year are a function of the following parameters:

EV Load Impacts = f (electric vehicle type, usage patterns, vehicle efficiencies, recharging power curves, charging efficiencies, recharging initiation distributions, T&D losses, populations of each vehicle type)

For any given EV type, the energy (kWh) requirements on a per day basis are a function of the miles driven per day (previous section) and the assumed vehicle efficiencies shown in Table 2.2. In a forthcoming AGREA study, three efficiency improvement trajectories are used, but only one is used here. It is assumed that both passenger car and light duty truck efficiencies improve 45% by the year 2014, with the assumed starting efficiencies for year 1998 as shown in the table. The shape of the trajectory is assumed to exhibit diminishing marginal improvements, a hypothesis that larger improvements will be made in the early years (1998 - 2004) when the first mass-produced EVs will be introduced in sequentially larger numbers. This trajectory roughly corresponds to the performance (range) goals of the United States Advanced Battery Consortium, though the schedule of improvements is not as aggressive.[4] This percentage improvement over 20 years is similar to the historical efficiency improvements for gasoline vehicles in the last 20 years.[5]

[4]Electric Power Research Institute, "USABC Update: Meeting the ZEV Challenge," Technical Brief, Palo Alto, CA, May, 1994. The mid-term goal is to effectively double the current 1994 range of EVs by 1998. Current EVs are assessed to have a range of, on average, 60 miles. The long-term goal is to have EVs by the 2001-2003 timeframe with ranges comparable to gasoline vehicles, i.e., 250-300 miles per charge cycle.

[5]There is no basis for any expected correlation in the efficiency improvements in EVs and internal combustion engines; the technologies are obviously vastly dissimilar and at different stages of their development. The correlation is merely offered to indicate that a 45% improvement over 20 years in not unreasonable. Any trajectory of technology improvements must be regarded as highly speculative, thus the rationale for multiple trajectories in the next stage of the ongoing study at MIT.

Figure 2.4: Flowchart for Analysis of EV Energy Impacts

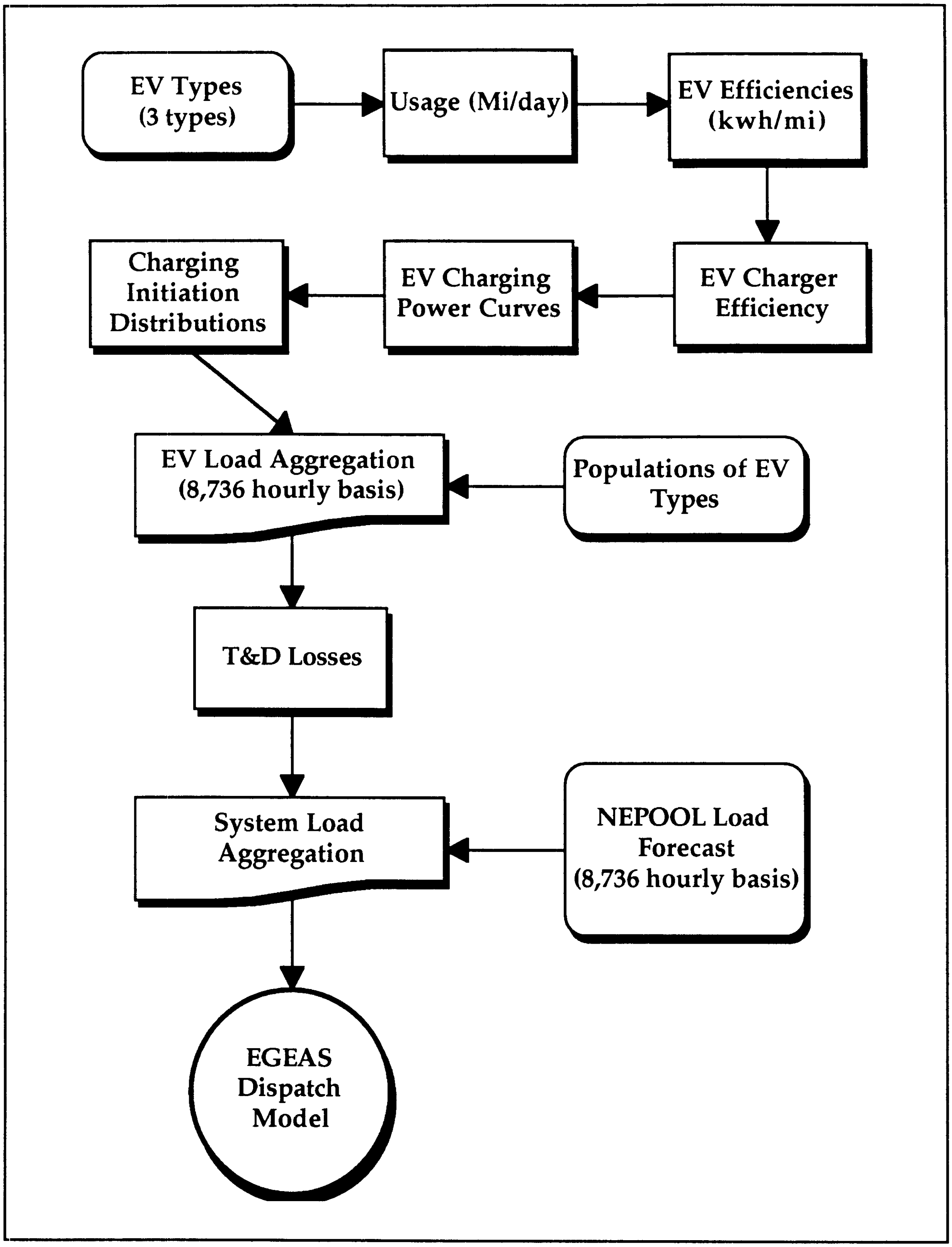

Table 2.2: Assumed EV Motive Efficiencies[6]

Vehicle Type	Battery Type	Avg. Efficiency (kWh/mi)
Passenger Cars		
• GM Impact	Lead Acid	0.14
• Solectria -Force	Lead Acid	0.25
AGREA Generic Passenger Car		0.20
Commercial Fleet Vehicle		
• GM G-Van	Lead Acid	1.00
• Chrysler TEVan	Nickel Iron	0.50
• Ford Ecostar	Sodium Sulfur	0.35
AGREA Generic Light Duty Truck		0.60

The energy (kWh) requirements determined by efficiencies (kWh/mile) and usage patterns (mile/day) correspond to the required depth of discharge of the EV batteries. This energy must be replenished by recharging the batteries. Figure 2.5 shows the assumed charging power profiles for passenger cars and light duty trucks. For a 100% depth of discharge, the charging cycle would require these curves to be duplicated exactly as shown. In reality, the charging cycle will be a fraction of this upper limit and will vary with daily usage patterns. For any given EV, it is assumed, depending on the depth of discharge, that the starting points in the charging cycle (a point on the x-axis) correspond to the depth of discharge and that the curve is then "filled" from left to right. The area under the curve corresponds to the energy (kWh) requirements, as previously determined. The power curves are the transfer mechanism between EV energy consumption and power system load (kW) impacts. An assumed charger efficiency of 85%[7] is applied the power curve demand (kW) impacts, which further increases the power system load impacts of EVs.

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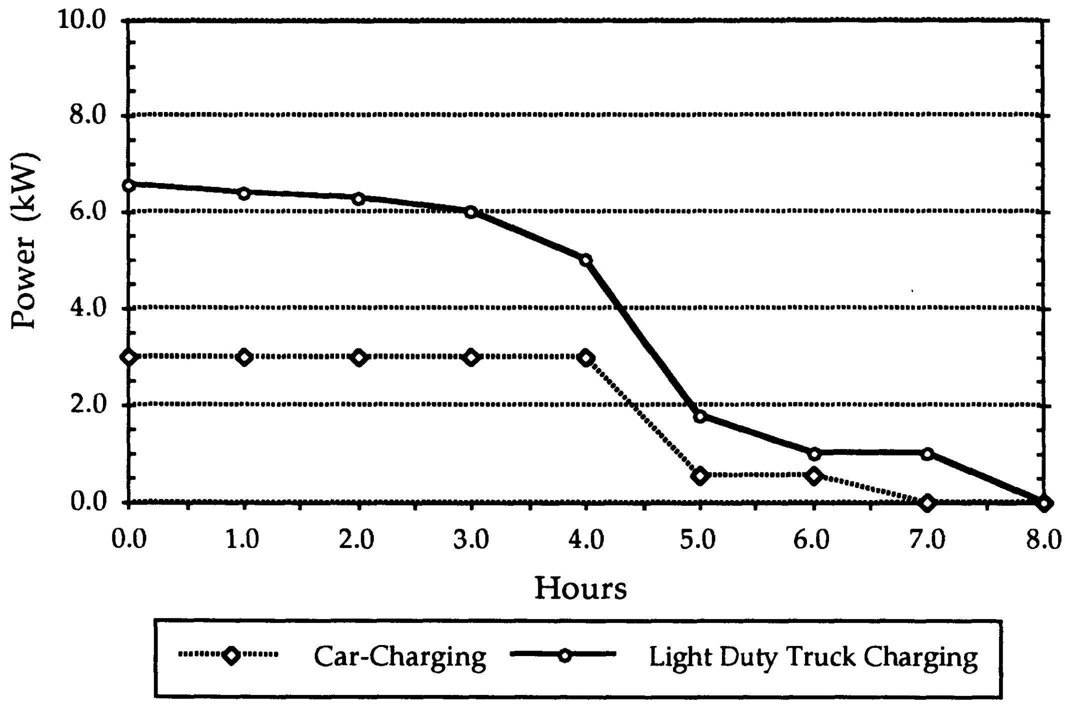
[6]Efficiencies for the GM G-Van and the Chrysler TEVan are from Electric Power Research Institute Inc. (EPRI). EPRI, "Electric Van and Gasoline Van Emissions: A Comparison," Technical Brief, Palo Alto, CA, 1989.
Efficiencies for the GM Impact, Ford Ecostar, and Solectria -Force are verified from multiple sources, with a recent NESCAUM study providing a consolidated summary – Tennis, p. 20.

[7]EPRI, "Status and Trend Assessment of Advanced Battery Charging Technologies," EPRI TR-101322, Palo Alto, CA, November, 1992.

Power curves are assumed constant throughout the study period, i.e., the storage capacity of the batteries is assumed not to change. Improvements in EV range do occur, but are modeled by vehicle efficiency improvements (kWh/mile), rather than battery capacity improvements. This is a simplifying assumption for this first attempt at a bottom-up analysis. Not only will capacity likely increase, but also the duration of full-cycle charging cycle will surely decrease from the present 7 and 8 hour durations. Both of these dynamics are captured in forthcoming AGREA studies. It is difficult to project whether the demand impacts in later years will be over or under-stated by this assumption. because vehicle efficiencies will also improve and reduce the energy charging requirements. Obviously, the power curves are not suitable for modeling the effects of quick charging.

Figure 2.5: Assumed Power Curves for EV Charging[8]



[8]These power curves are based on reviews of monitoring data for the a number of makes and models of EVs. Reliable monitoring data is difficult to find and often displays great variation. These curves capture the basic dynamics involved and were approved, with some deliberation and modifications, by the EV Task Force (which included individuals from utilities equipped with their own monitoring data).

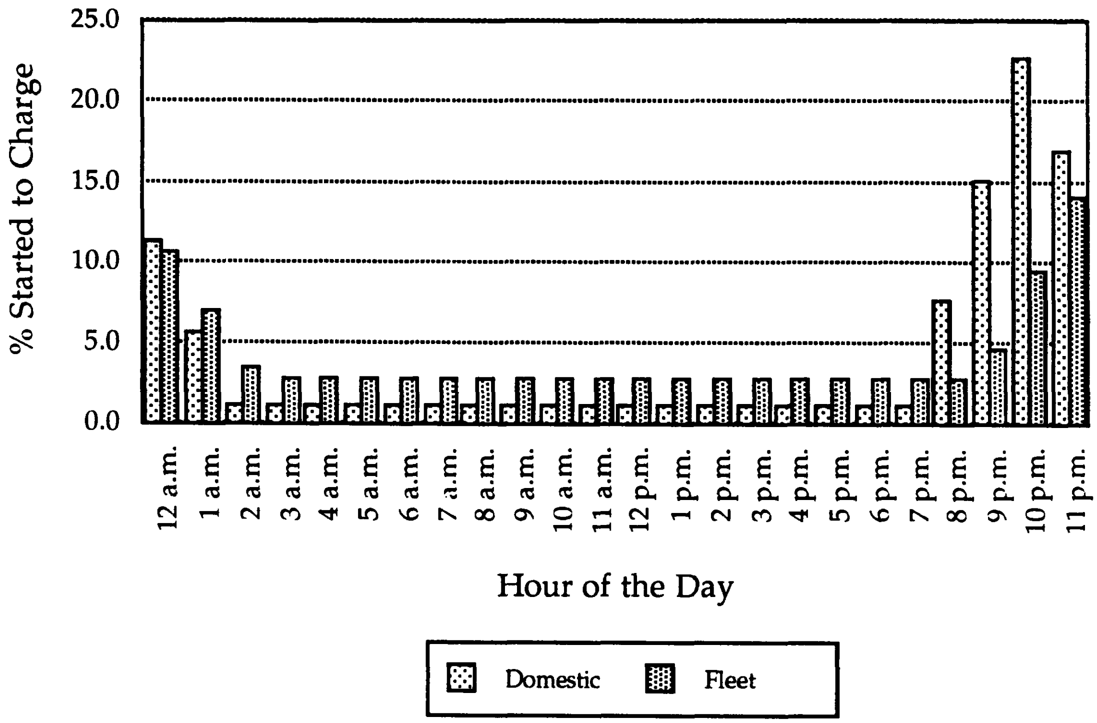
With the efficiencies and power curves defined for each vehicle type, the remaining step is the aggregation of the EV load impacts for the entire population of EVs. A number of assumptions are often made in this regard. It is commonly assumed that consumers will exclusively choose to recharge their EVs at night, when commercial fleets are finished with the business day and when commuters have returned home. This is a convenient assumption for those who anticipate "load filling" benefits for the local utility. It is often assumed that clear rate signals or direct utility controls will obviously enforce the desired EV load impacts.

Such optimism about expected consumer behavior and anticipated control methods might define a best case scenario for someone banking on off-peak load-filling potential. The use of less aggressive assumptions, or a range of scenarios, provides a more conservative approach to this important aspect.

An approach based on a perceived middle ground is used for specifying the distribution of diurnal EV load impacts. A majority of the charging is assumed to begin in the off-peak hours with a flat fraction of on-peak charging. The actual load impacts are determined from these assumed distributions of the hour of the day in which charging begins and the superposition of the power curves previously discussed.[9] For fleet uses, 70% of the EVs are assumed to begin charging exclusively in the off-peak hours with the peak hour at 11 p.m. For domestic uses, 90% of the EVs are assumed to begin charging exclusively in the off-peak hours with the peak hour at 10 p.m. This assumes some minimum level of controls for off-peak charging, e.g. simple time clocks. Even with controls, a *distribution*, as shown in Figure 2.6 is required to describe the anticipated behavior.

[9]As designed with the assumed power curves, charging initiation only marks the beginning of a potential one to seven hour charge cycle for each vehicle, depending on the replenishment requirements. Recharging cycles are thus superimposed upon one another for every hour of the day.

Figure 2.6: Normalized Distribution of Hour of Day in Which Charging Begins



All calculations, up to this point, are performed by a separate program specifically tailored for EV analyses. For any given mix of options (penetration level, vehicle efficiency improvement trajectory, etc.), the program retrieves the necessary inputs from various databases and uses them to calculate the aggregate hour-by-hour load impacts over 20 years.

These aggregate load impacts are then added to the New England Power Planning load forecast, on an hour by hour basis.[10] Because NEPOOL load forecasts are busbar load, rather than distribution level load, the EV load impacts are adjusted by a fixed T&D loss factor assumed to be 8%. This results in the final load forecast which is then fed to the production-cost model, EGEAS. From this, the effect of EV loads on the electric power sector (costs,

[10]New England Power Planning, an arm of the New England Power Pool (NEPOOL) is now including anticipated EV loads in all forecasts, so these impacts must be removed to prevent double counting.

emissions, and a number of other attributes) are provided. The entire procedure is then repeated for any desired mix of EV modeling options.

EMISSIONS FROM THE ELECTRIC POWER SECTOR

As explained in Chapter 1, all AGREA simulations of the electric power sector are performed with EGEAS, using as inputs actual power plant data (heat rates, fixed and variable operations and maintenance costs, maintenance cycles, emission rates, etc.) on all of New England's power plants (over 350 plants, including generic units for future capacity additions). Using the 20-year hour-by-hour EV load impacts developed as described in the previous section, superimposed on an hourly load forecast developed by New England Power Planning, EGEAS then simulates a least cost dispatch of capacity to meet load requirements. To capture dynamics of the electric power sector through time, EGEAS simulates the building of new capacity, the retiring of existing power plants, and the compliance of any specified future emission constraints. Input and output data for the model are benchmarked by New England Power Planning; in addition, data is subject to frequent peer review provided by AGREA's Advisory Group members.

Emission rates for existing power plants are input into EGEAS for every power plant in New England. Emission rates for CO_2 and SO_2 are simply based on the carbon and sulfur content of the fuels used in each plant. The results are tallied by EGEAS on a year-to-year basis, based on the quantity of each fuel type used in each plant. For NO_x, plant specific emission rates provided by New England Power Planning are entered as inputs. To account for Phase I RACT and hypothetical Phase II controls, the emission rates are systematically adjusted using methodologies developed by AGREA. For a complete description of assumptions and methodologies used in EGEAS by the AGREA team, see the project's most recent background information document.[11]

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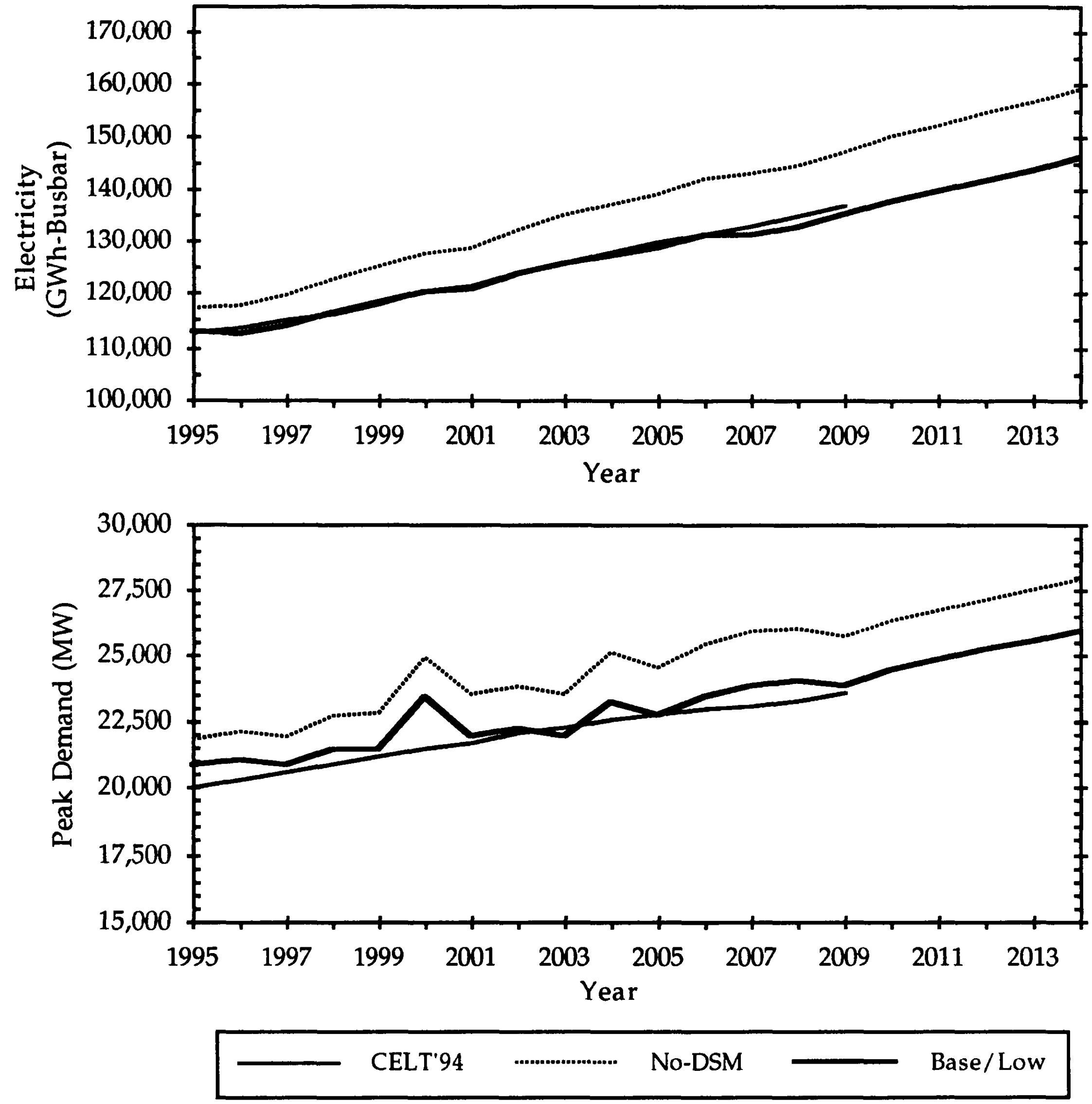
[11]Massachusetts Institute of Technology, Energy Laboratory, Analysis Group for Regional Electricity Alternatives, Background Information for the 1992/1993 Scenario Set - Second Tier/Summer 1993, MIT Energy Lab Working Document, September, 1993.

Each EGEAS simulation provides extensive output data for one scenario. A scenario consists of a strategy and a set of future uncertainties. A strategy consists of a combination of planning options. For this study, the typical AGREA menu of options and uncertainties was greatly simplified, adequate to examine the most relevant aspects of the EVs. See Appendix C for a comprehensive listing of the options and uncertainties used in this study.

The year-by-year New England electricity (GWh) and demand (MW) load trajectories provided by New England Power Planning are shown in Figure 2.7. These trajectories contain no EV loads. The figure shows three load trajectories. The "CELT '94" trajectory is from the annual report issued by New England Power Planning.[12] The "No-DSM" trajectory shows New England loads in the absence of any demand-side management programs. The "Base/Low" trajectory is the load trajectory with New England's "as planned" demand-side management programs; this trajectory is used as the reference trajectory in this study. The last two trajectories are consolidated from hour-by-hour load data to generate the annual figures shown. The hour-by-hour trajectories are specially compiled by New England Power Planning for AGREA purposes. Without any EVs, New England load will increase 33,310 GWh and 5,080 MW by the year 2014 beyond 1994 levels.

[12]New England Power Planning, "Forecast of Capacity, Energy, Loads, and Transmission – 1994-2009," April, 1994. This forecast only extends to the year 2009, 5 years short of the study period.

Figure 2.7: Load Trajectories for New England



To meet these increasing loads, additional capacity will needed in New England. In past studies by AGREA, the impacts of varying new supply mixes (e.g., those with wind, biomass, photovoltaics, clean coal, etc.) have been analyzed and compared. For this analysis, only new natural gas generation technologies are assumed. This is a reasonable assumption, as natural gas units have dominated new supply in U.S. in recent years and are expected to continue to do so in future years. This trend is due to decreased natural gas fuel prices, improved natural gas combustion technologies, low capital costs, availability in small sizes as peaking units, and the cleanliness of natural gas compared to other fossil fuel systems (oil, coal). Table 2.3 lists some of the attributes for the combustion turbine and combined cycle units assumed in this study, which are referenced from New England Power Planning specifications.[13] The combustion turbine and combined cycle units are assumed to have 3 year and 5 year lead times, respectively. An entirely separate algorithm is used for scheduling these capacity additions to determine how many of each unit type are built future years.

Table 2.3: Characteristics of Natural Gas Capacity Additions

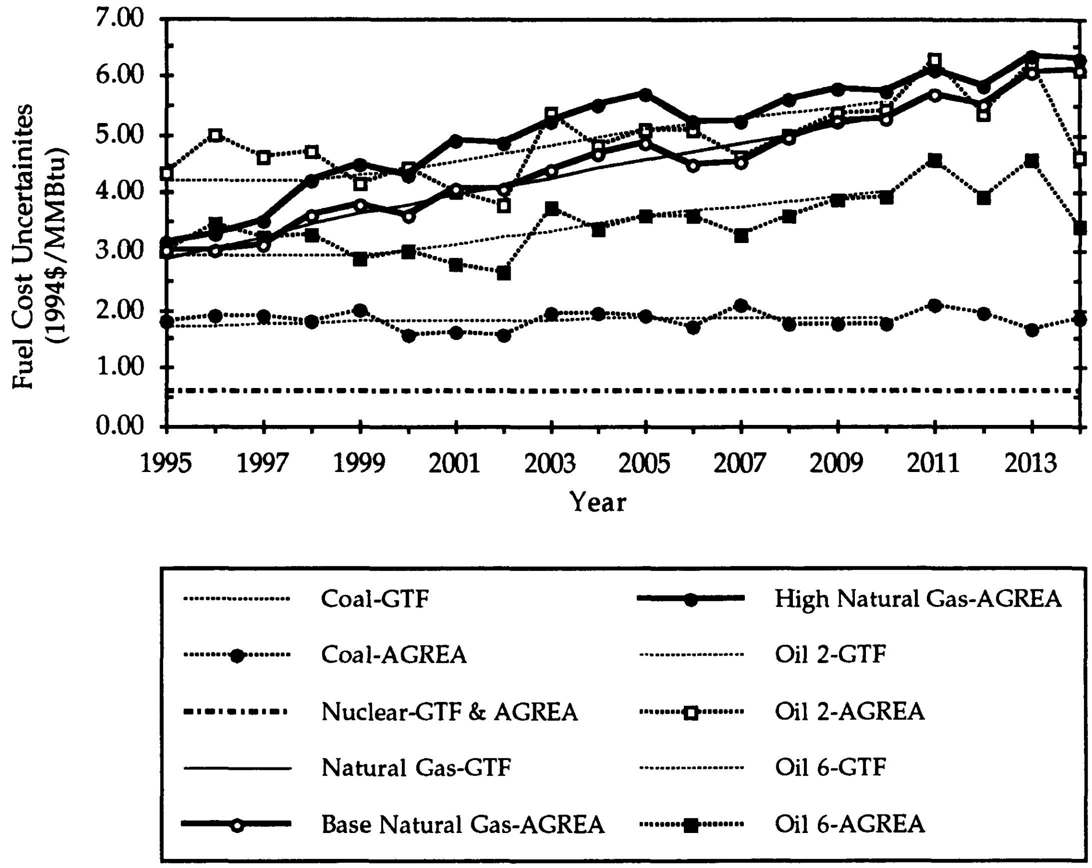
Natural Gas Technology Type	Nameplate Capacity (MW)	Full Load Heat Rate (BTU/ kWh)	Installed Cost ('94$/kW)	Fixed O&M ('94$/kW)	Variable O&M ('94$/ MMBTU)
Combustion Turbine	155	10,550	660	0.08	0.33
Combined Cycle	250	7,520	740	12.35	0.09

A final and essential determinant to the emissions of the electric power sector is the fuel cost trajectory used for future years. Fuel costs are a major constituent of total operating costs and, thus, figure predominantly in the least cost economic dispatch of the system of power plants. The fuel cost trajectory is modeled as an uncertainty, and two trajectories are employed in this study: base fuel costs and high natural gas costs. The latter speaks to concerns about New England's growing dependence on natural gas and the potential vulnerabilities should prices rise substantially in the near and long-term. Natural gas costs are the only values that vary between the fuel cost trajectories in this study. The fuel cost trajectories for natural gas are shown in Figure 2.8, along with the fuel cost trajectories of the other fuel types. The variability in the trajectories reflect the historical trends observed in the highly volatile fuel markets. The straight line segments are the price forecasts

[13]New England Power Planning, "1994 Summary of the Generation Task Force Long-Range Study Assumptions," June, 1994.

made by New England Power Planning.[14] The lines with variability are the noised AGREA versions.

Figure 2.8: Fuel Cost Uncertainties for New England's Electric Power Sector[15]



Emission Offsets from Gasoline Vehicles

Even though emissions are displaced to the electric power sector, the main attraction of EVs is that they produce no tailpipe or evaporative emissions. These offset emissions must be calculated to enable a "net" emissions analysis, as depicted in Figure 2.9. The modeling of offset emissions is an

[14]New England Power Planning, 1994. These forecasts only extend to the year 2010, 4 years short of the study period. The remaining years are estimates, based on extrapolation.
[15]Oil 6 is assumed to be 0.5% weight sulfur. The natural gas price corresponds with the AGREA's interruptible gas, as opposed to firm gas. Coal is assumed to be 0.7% weight sulfur.

involved task, as emission rates vary with vehicle type, age, and fuel economy.

These dynamics over the course of 20 years are captured with an emissions model which subsumes EPA's MOBILE5a program. The EPA program provides emission rates (gram/mile) for NO_x, CO, and ROG and captures the complex dynamics involved in predicting these rates. Unlike NO_x, CO, and ROG emissions, CO_2 and SO_2 emissions are approximately and consistently proportional to the carbon and sulfur content of gasoline. Emission rates for CO_2 and SO_2 are calculated by using a starting value (based on the carbon and sulfur content of gasoline) and adjusting it proportionally to fuel economy for both improving new vehicles and aging used vehicles.

Throughout the study period it is assumed that EVs are an alternative to purchasing new gasoline vehicles and that for every EV purchased there is one less gasoline vehicle on the road. With this approach, the emission rates (gram/mile) for any single offset gasoline vehicle must be known. Note, the use of "composite" rates or fleet-wide "average" rates are often used for simplification purposes. Consistent with the bottom-up analytical approach of this study, this simplification was *not* made. The emission rates (gram/mile) for each vehicle type (and of all ages) in any given year is specified, as depicted in Table 2.4 for NO_x. A condensed version of the rates (those for every 3rd model year and selected vehicle ages) for all emission types is shown in Appendix C.

Figure 2.9: Flow Chart for Analysis of Net Emission Impacts

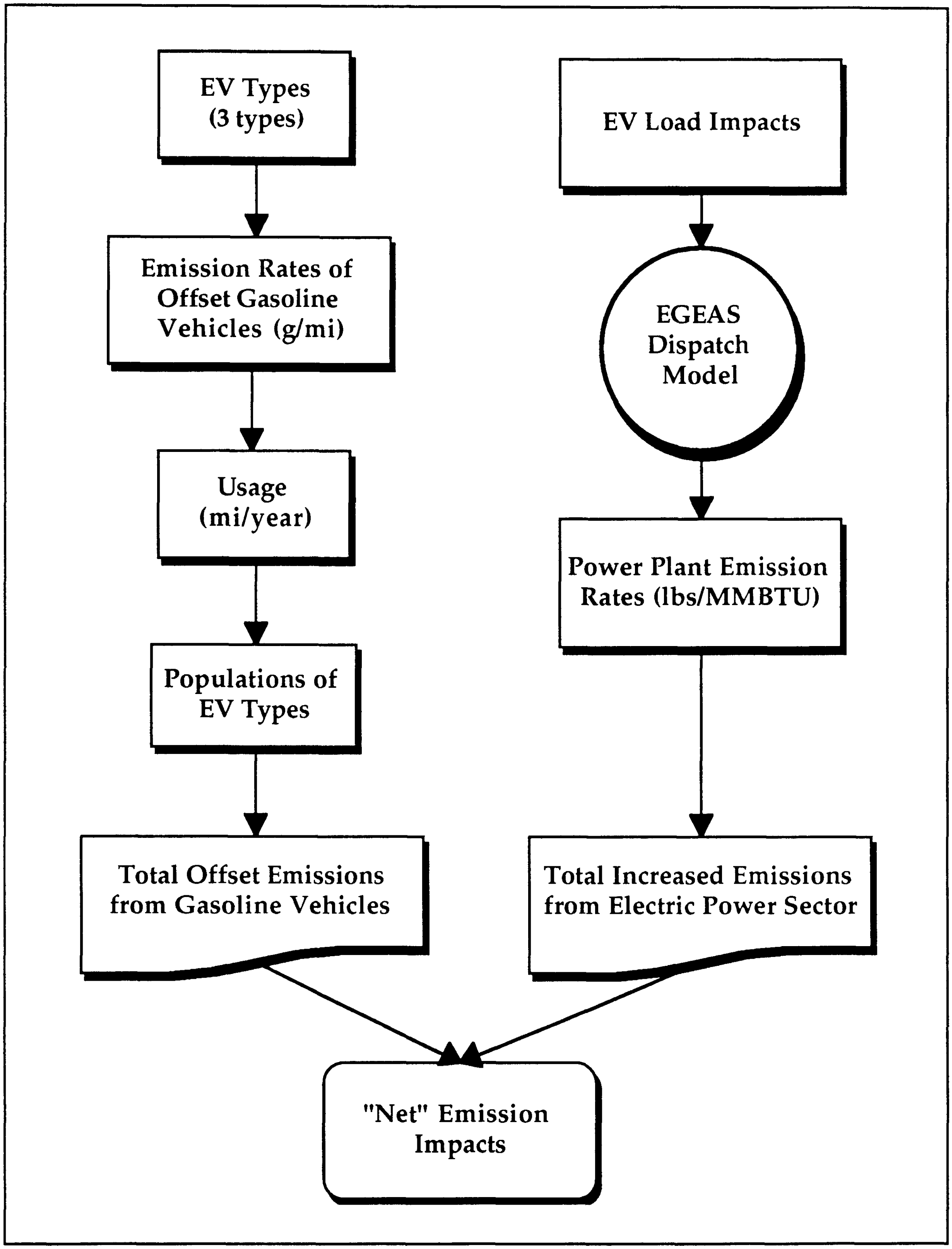


Table 2.4: NO_x Mobile Source Emission Rates (gram/mile)

Purchase Year	1995		1996		1997		----->>	2014	
Vehicle Type	LDT	PC	LDT	PC	LDT	PC		LDT	PC
							----->>		
Year of 1	0.29	0.16	0.25	0.14	0.24	0.14		0.22	0.14
Operation 2	0.53	0.30	0.44	0.21	0.39	0.18		0.36	0.18
3	0.98	0.54	0.81	0.41	0.69	0.29		0.60	0.25
4	1.81	0.73	1.55	0.68	1.21	0.52		0.95	0.32
5	2.54	0.92	2.53	0.92	2.11	0.85	----->>	1.31	0.39
6	3.25	1.24	3.23	1.24	3.22	1.24		1.55	0.48
7	3.96	1.57	3.90	1.56	3.88	1.55		1.74	0.55
8	4.74	1.93	4.61	1.89	4.55	1.87		1.92	0.63
9	5.67	2.28	5.42	2.26	5.27	2.22		2.09	0.61
10	5.62	2.62	6.37	2.62	6.10	2.60		2.25	0.58

Generating emission rates in this form for NO_x, CO, and ROG with the MOBILE5a program requires a number of adjustments to the typical input records, combined with batch-mode execution. This procedure, as well as the input assumptions, are included in Appendix C. Generating rates of this form for CO_2 and SO_2 is simpler because all rates are scaled on the basis of fuel economy to assumed starting values. Appendix C contains the assumptions used for fuel economy projections and starting values.

The Federal Tier I and Tier II programs are used as the reference case for calculating emission rates. These standards are listed in Appendix C. It is common to misinterpret emission *standards* with actual emissions *rates*. Standards only correspond roughly to the actual rates of vehicles. Standards are based on specified test conditions which often bear little resemblance to actual operating conditions and are stated as rates which must be met through a driving cycle of 50,000 miles. Thus, standards are only an input to the determination of actual rates, not the actual rates themselves.

One concern with the use of emission models is the extent to which they overpredict or underpredict emission rates. Because the models are based on the federal test procedure driving cycles (used for setting emission standards for new vehicles, the IM240 in the case of MOBILE5a), the key concern has to do with off-cycle emissions. Recent research by the EPA has confirmed that off-cycle emissions are indeed significant.[16] This very concern was echoed by the EV Task Force in regards to the MOBILE5a model. Among mobile source emission modelers, this issue has been the subject of conferences and studies, but there remains no consensus about the degree of the problem or how to adjust for the inaccuracies. It was found that the model used by the California Air Resources Board, called "EMFAC," has been reviewed more thoroughly than EPA's MOBILE5a program, and that some analysts have made reasonable attempts at adjusting emission rates provided by EMFAC.[17] However, no such conclusive evidence has been gathered for MOBILE5a. It is known that this program (the 5a version) has been significantly improved with calibrations of thousands of actual automobile emission test results. Inaccuracies due to off-cycle emissions remain unknown, but speculations by mobile source emission modelers suggest that the range of under prediction is likely between 3% to 15%, with the greatest under prediction for ROG (due to the compounded complexity of evaporative emissions). Such tenuous information cannot be used to responsibly correct the model's output. To address the concern, a sensitivity study is used to see how the end results might be affected by such uncertainty. This query assumes an across the board 20% underprediction of NO_x and CO and 30% underprediction of ROG emission rates. The findings are presented in the Results Section.

For the most thorough assessment of "net" emission impacts, upstream emissions should be taken into account. These are the emissions associated with the full fuel cycle, including emissions from the production, processing, and transportation of fuels. This should be done for both the mobile source sector and the stationary source sector. As might be suspected, the information requirements for this endeavor are quire large, even though

[16]John German, et. al, "EPA's Survey of In-Use Driving Patterns: Implications for Mobile Source Emission Inventories," Environmental Protection Agency, Office of Mobile Sources, Ann Arbor, MI, November, 1993, provides measurements of off-cycle emissions (hard accelerations, road grade, air conditioning, start/soak effects, for various car models.

[17]A number of studies have attempted such adjustments. Roland Hwang, et. al, "Driving Out Pollution: The Benefits of Electric Vehicles," Union of Concerned Scientists, May, 1994.
Francis Chapman, et. al, "What's the Charge? Estimating Emission Benefits of Electric Vehicles in Southern California," Environmental Defense Fund and Natural Resources Defense Council, 1994.
Simon Washington, "A Cursory Analysis of EMFAC: Reconciling Observed and Predicted Emissions," prepared for the Union of Concerned Scientists and the University of California at Davis, May, 1994.

some definitive work has taken place.[18] There is also the question of how far one should extend the boundaries of the analysis. The scope of this study extends to the entire New England region, but no gasoline and very little natural gas is produced or processed here. Should all emissions, no matter where they are produced, be included? How dependent are upstream emission rates on location? Also, it would seem that life-cycle emissions (associated with the production of automobiles, power plants, transmission networks, batteries, etc.) are really the important and most holistic basis for comparison, rather than just fuel-related emissions. Although incorporating these dimensions is beyond the scope of this study, it is highly recommended that they be included in the continual development of tools for "net" emission analyses and in policy discussions of environmental strategies.

EV COST IMPACTS

For comparisons of EVs on the basis of cost-effectiveness to other ozone mitigation strategies, it is necessary to quantify anticipated cost impacts. This task is fraught with difficulty because there is no historical track record for EVs (at least applicable records). Thus, any attempts are bound to be largely speculative. To address the range of possible outcomes, three uncertainties for cost impacts are analyzed (high, medium, low). The main components of the cost analysis are shown in Figure 2.10.

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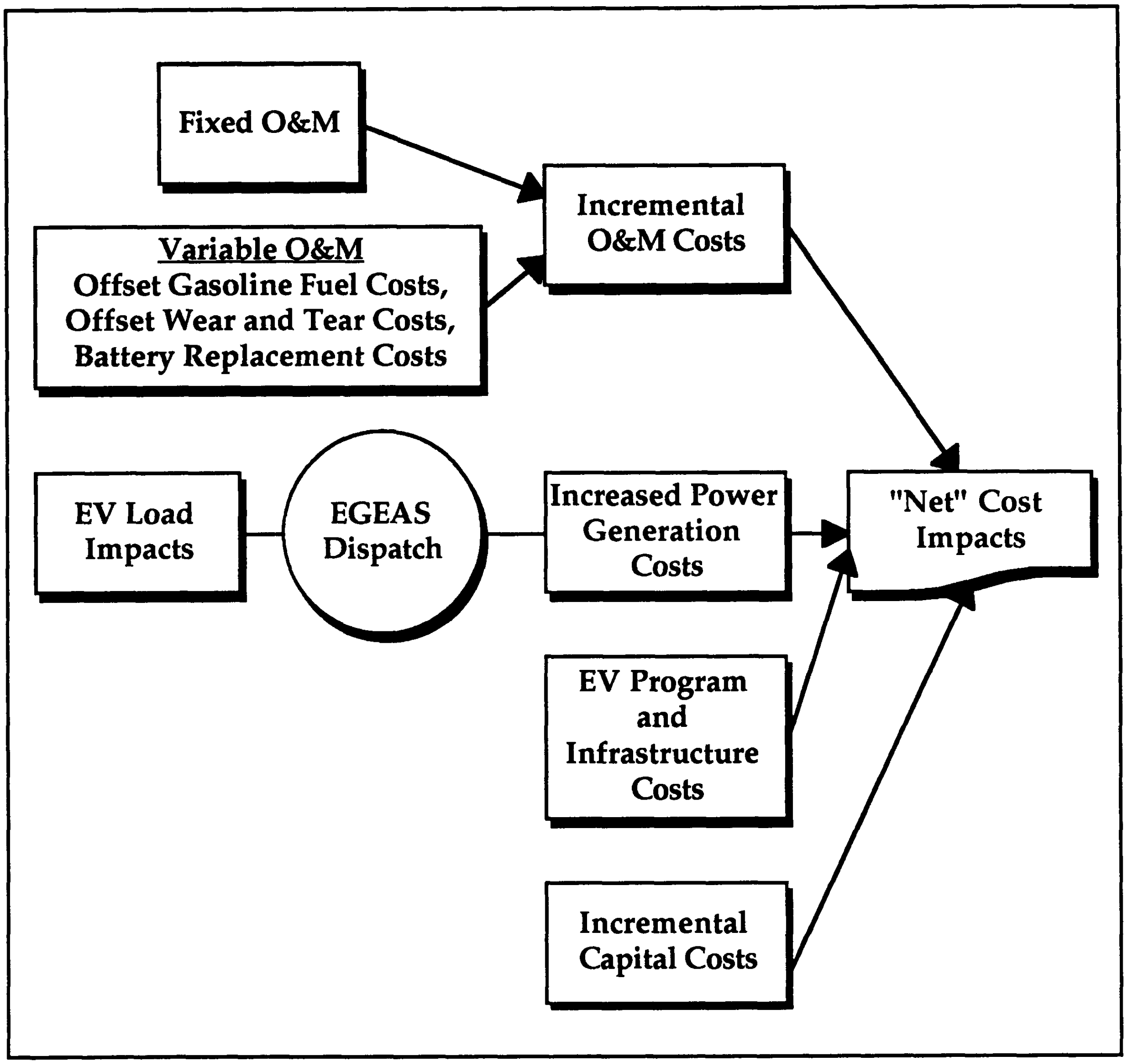
[18]K. G. Darrow, "Light Duty Vehicle Full Fuel Cycle Emission Analysis," for the Gas Research Institute, Chicago, Il, April, 1994.
M. Deluchi, Q. Wang, and D. Greene, "Emissions of Greenhouse Gases from the Use of Transportation Fuels and Electricity," Argonne National Laboratory, ANL/ESD/TM-22, Argonne, Il, 1991.
Shaine Tyson, et. al, "Fuel Cycle Evaluations of Biomass-Ethanol and Reformulated Gasoline," National Renewable Energy Laboratory, NREL/TP-463-4950, Golden, CO, November, 1993.

Figure 2.10 Flowchart for EV Cost Impact Analysis



The incremental capital cost of an EV is the retail price above and beyond that of the offset gasoline vehicle. Because this is the cost to the region, any regional or state tax credits and subsidies are subsumed by these figures. Put another way, this is simply the incremental cost charged by Detroit to EV consumers in New England. Based on recent debates and the deliberations of the EV Task Force, the following incremental costs are assumed (1998$):

Assumed Incremental EV Purchase Costs

Low:	$1,000	per vehicle
Medium:	$5,000	
High:	$15,000	

Note that these incremental costs apply to both passenger cars and light duty trucks. These costs are not inflation adjusted; the 1998 dollar amounts extend throughout the study period. The rationale for this is that economies scale and learning effects will occur as more EVs are phased-in over time, reducing the average cost per vehicle. Charger costs are assumed to be, on average, $300 per electric vehicle (1998$).

Operations and maintenance costs (O&M) have two components; fixed and variable. Fixed O&M includes costs such as insurance, registration, etc. These costs are assumed equivalent for EVs and gasoline vehicles – no cost impacts. Variable O&M includes costs for fuel, general maintenance, and, in the case of EVs, battery replacements.

Fuel costs are calculated using the offset gallons of gasoline that would have been consumed if the EVs had not been purchased. Usage patterns (miles/year), fuel economies (MPG), and populations of each vehicle type are used to calculate the offset gallons. The price of gasoline in New England is assumed to be, on average, $1.25 (1994$) and the year-by year variation is assumed to be the same as Oil 2 (a truly randomized variation as assumed in this study).

General maintenance costs include wear and tear on vehicles – tires, oil changes, mufflers, etc. These costs increase significantly as vehicles age. Because of the characteristics of internal combustion engines (extreme temperatures and combustion effluents), there is a general expectation that these costs will decrease with electric powered vehicles. The extent of the decrease is pure speculation. The EV Task Force resolved to assume that such costs will decrease by 50%. The reference costs for gasoline vehicles are based on historical figures for passenger cars and light duty trucks, as described in

Appendix D. Twenty year trajectories are made for new vehicles, and aging vehicles are assumed to acquire increased maintenance costs of 15% per year.

Battery replacements for all electric vehicles are assumed to be required every 40,000 miles[19]. Costs are assumed to differ for passenger cars and light duty trucks, because light duty trucks will require higher capacity batteries. Battery costs for passenger cars were developed by the EV Task Force, and those for light duty trucks are assumed to be one and a half times those for passenger cars. Trajectories for battery costs are assumed to move with inflation. The assumed battery replacement costs are as follows:

Assumed Battery Replacement Costs

	Passenger Cars	Trucks
Low:	$2,500 per vehicle	$3,750
Medium:	$5,000	$7,500
High:	$7,500	$11,250

Program costs for EVs include all marketing, customer service, and administrative costs incurred by local electric utilities. These cost impacts were not modeled in this study, because it is expected that they will be relatively small in magnitude and that utilities will reallocate, rather than expand, such resources to accommodate EVs.

Infrastructure costs for EVs include all costs incurred by the region required to have a functional population of EVs on the road. Costs will be associated with public charging stations, EV service industries, and expanded distribution systems of electric utilities. Once again, the basis for such costs are the incremental investments over those that would have been incurred for the offset population of gasoline vehicles. Projections of such cost are not impossible to make, but are very time consuming in and of themselves. This difficult, but important, component of regional costs are not incorporated in this stage of the analysis for that reason.

[19]This value was revised upon feedback at a September, 1994 , presentation of preliminary results.

The assumptions and methods used herein make a first attempt at addressing costs on a component basis. As previously qualified, any estimates of costs are speculative. The use of three cost uncertainties enable a possible range of cost impacts to be identified. As developed, it is expected that all these cost estimates are likely to understate regional cost impacts, because no infrastructure costs have been included.

∞ Chapter 3 ∞

Results

The results of the methodology described in Chapter 2 are enumerated here. First, EV energy impacts are described, which are an intermediate result leading the way to the EV emission impacts, which are described second. Third, EV cost impacts are discussed, with a concluding summary of the cost and emission impacts together.

EV ENERGY IMPACTS

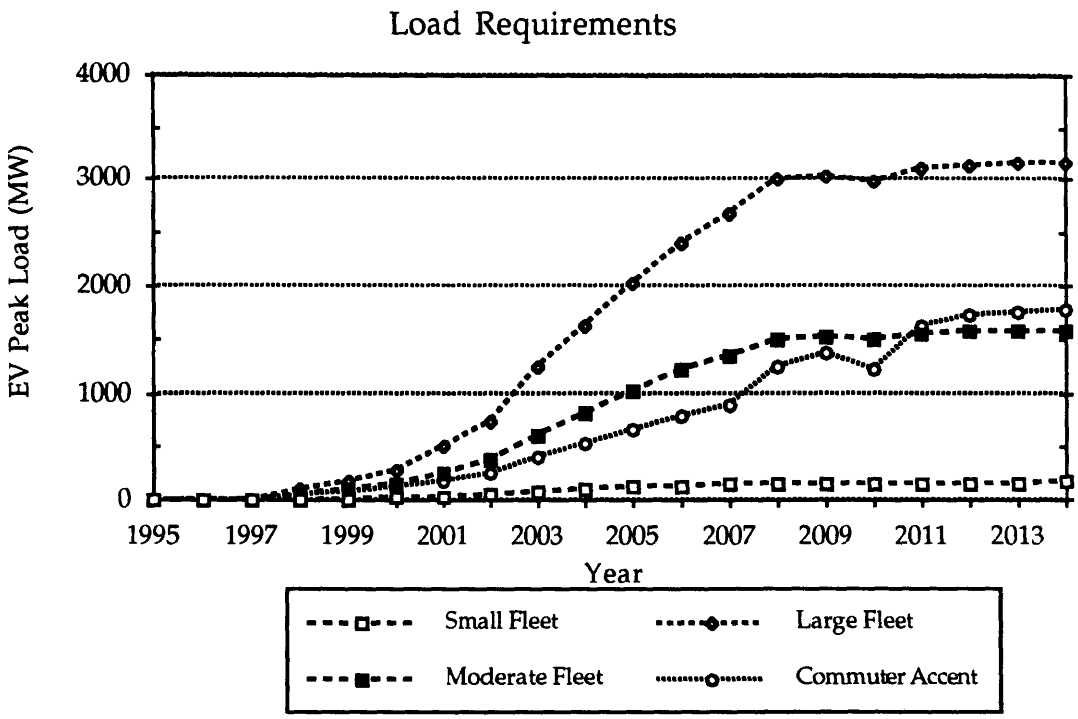
The energy impacts of EVs on New England's power sector are described in this section. These impacts are, in a sense, only intermediate results; policy makers are ultimately interested in emission and cost impacts. Notwithstanding, an understanding of the energy impacts helps explain these pertinent results. Energy impacts influence power system dispatch, and power system dispatch determines emission levels and operational costs. The EV energy impacts of interest include:

- EV Energy Requirements
- Diurnal Load Filling
- Impacts on Peak Load (MW)
- Impacts on Electricity Consumption (GWh)
- Requirements for New Capacity
- Effects on Fuel Mix.

The energy requirements for EVs are shown in Figure 3.1. The top of the figure shows the maximum demand (MW) requirements in every year of the study period. The shape of the curves track those of the Figures 2.2, where EV populations are shown. Maximum demand requirements range from 200 MW for the Small Fleet to 3,100 MW for the Large Fleet. The demand (MW) requirements for the Moderate Fleet is surpassed by that of the Commuter Fleet around year 2011, because commuter cars are assumed to have longer service lives than fleet vehicles, i.e., more commuter cars are on the road. In comparison, the lower portion of Figure 3.1 shows that the electricity (GWh) requirements vary more substantially between the Moderate and Commuter Fleets, indicating that the use of commercial fleet vehicles offer increased capacity factor over commuter vehicles. The average capacity factor for commercial fleet EV populations is 45%, compared to 25% for commuter passenger car EV populations.

Electric utilities anticipate that EVs will provide load filling benefits. There are typically large load fluctuations between days and nights on any power system. Peak load power plants, which are expensive to operate, have to be added to the generation mix to meet the additional daytime loads. From a power planning perspective, it is simpler and more efficient to have loads which do not fluctuate significantly. Inexpensive baseload plants can be used more often and perhaps even preclude the need for building peak-load plants. It was found in this study that EVs are indeed effective for load filling. This is shown in Figure 3.2 for the Moderate Fleet in year 2010. Two representative days have been selected, one for the summer load season and one for the winter load season. Load filling does occur, but the extent of it does not significantly "flatten" the curve. This is because EVs add to peak load (8 a.m. to 6 p.m.) too, even though charging is assumed to take place mostly at night. This dynamic is also present with the Large Fleet, where exceptional load filling might be expected to occur due to the large numbers of EVs, because the additions to peak loads are directly proportionally larger. It is not reasonable to assume that consumer behavior (charging patterns in this case) can be relegated exclusively to evening hours, so the probabilistic distribution assumed in this study (see Figure 2.6) provides these results. Neglecting this realism can overstate load filling benefits by as much as 50%.

Figure 3.1: Electric Vehicle Load Requirements and Electricity Consumption



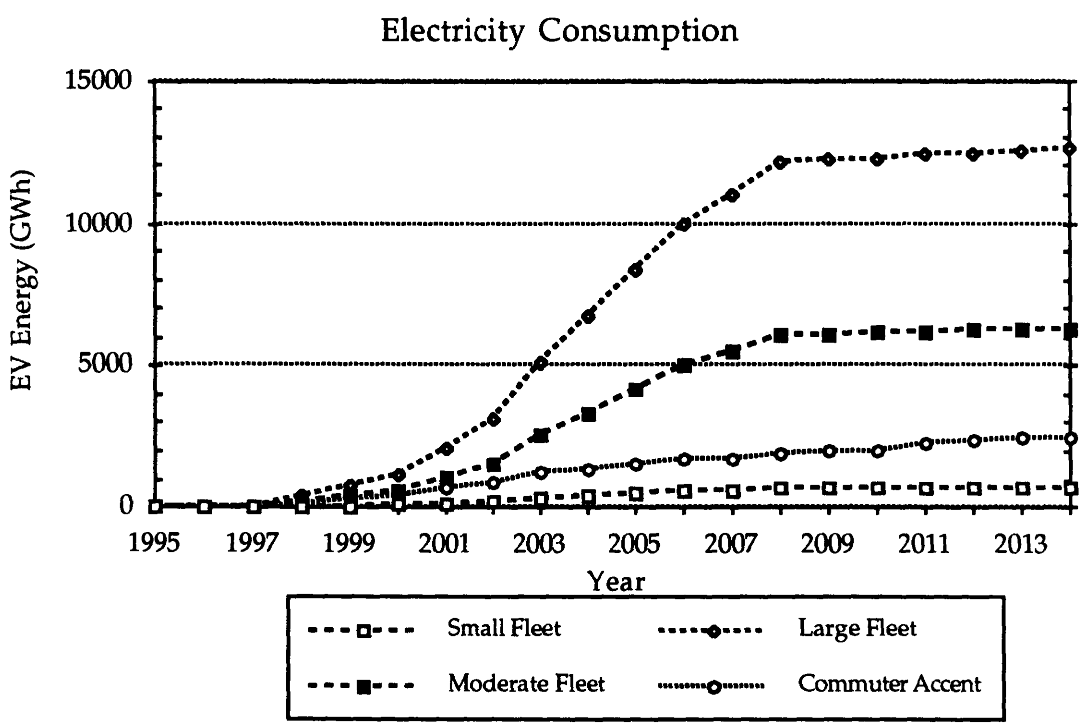
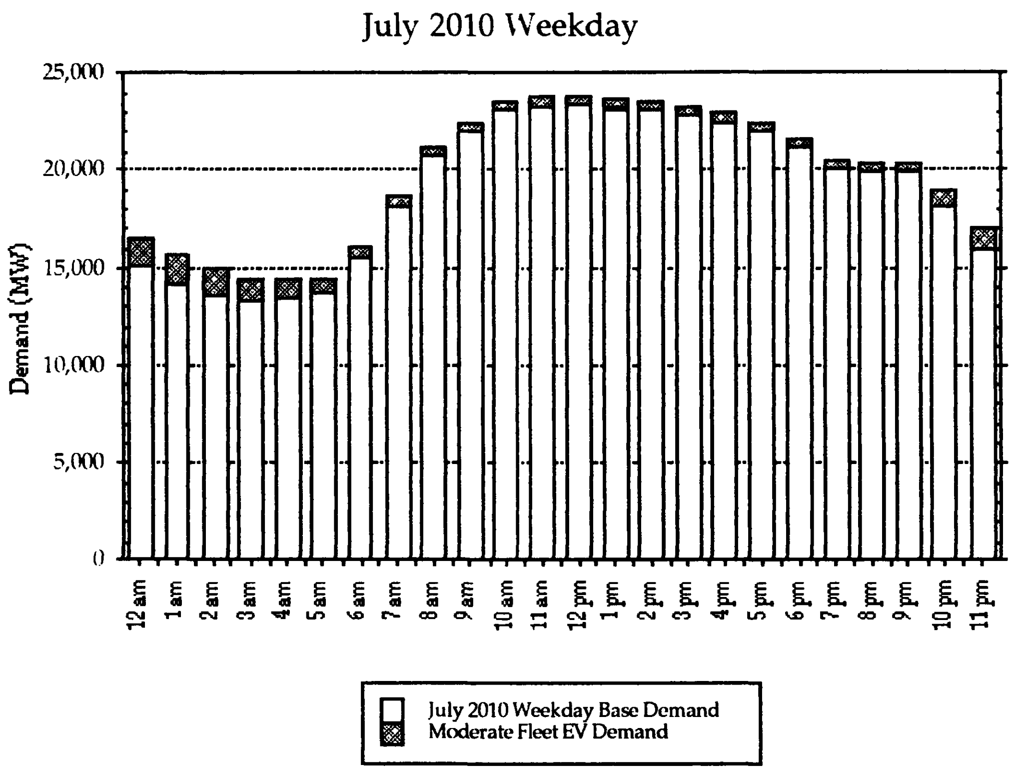
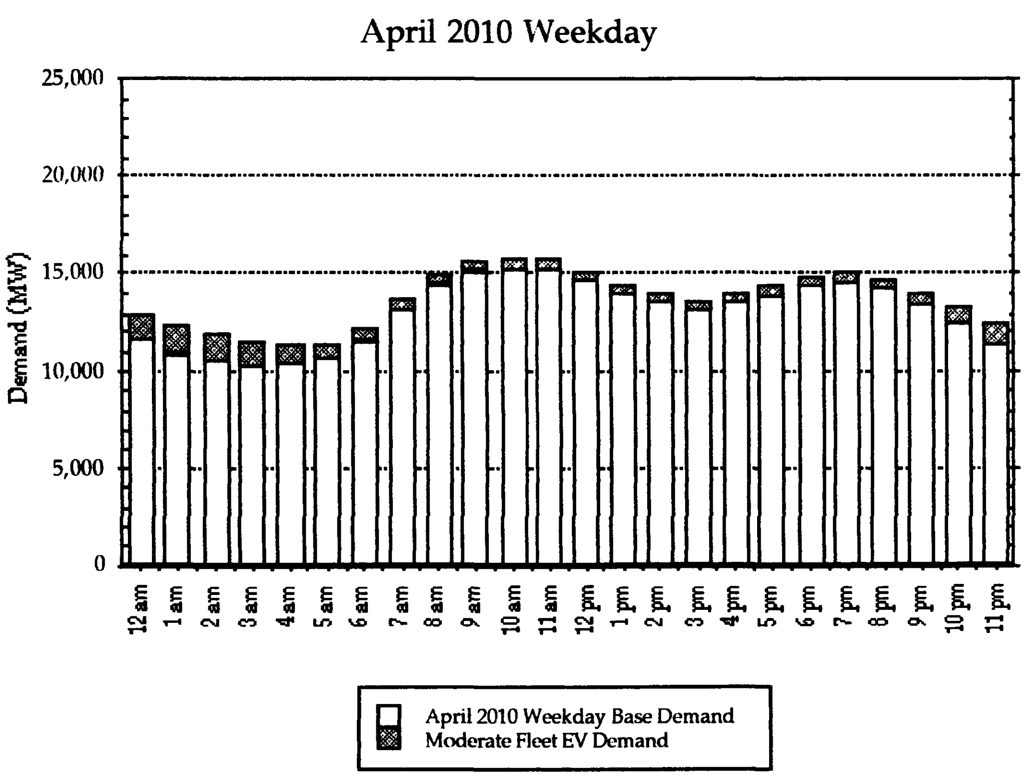


Figure 3.2: Electric Vehicle Hourly Demand Impacts (Moderate Fleet)





The imposition of EV energy requirements on the power sector definitely modifies New England's power system dispatch, resulting in increased fuel consumption and changes in the "mix" of fuel consumption. The annual fuel mix for the entire electric power sector with the Moderate Fleet is shown in Figure 3.3. Alone this figure is not descriptive for observing changes. Figure 3.4 displays the annual changes for each fuel type. These changes in fuel mix result from the dispatch stacking order of plants at each hour. In a rough sense, these changes indicate the extent to which plants of certain fuels are "on the margin." Such "marginality" is sensitive to fuel cost assumptions and the unique diurnal load impacts of EVs, so generalized statements about marginality should not be extracted.

Figure 3.3: New England Fuel Mix with EVs (Moderate Fleet)

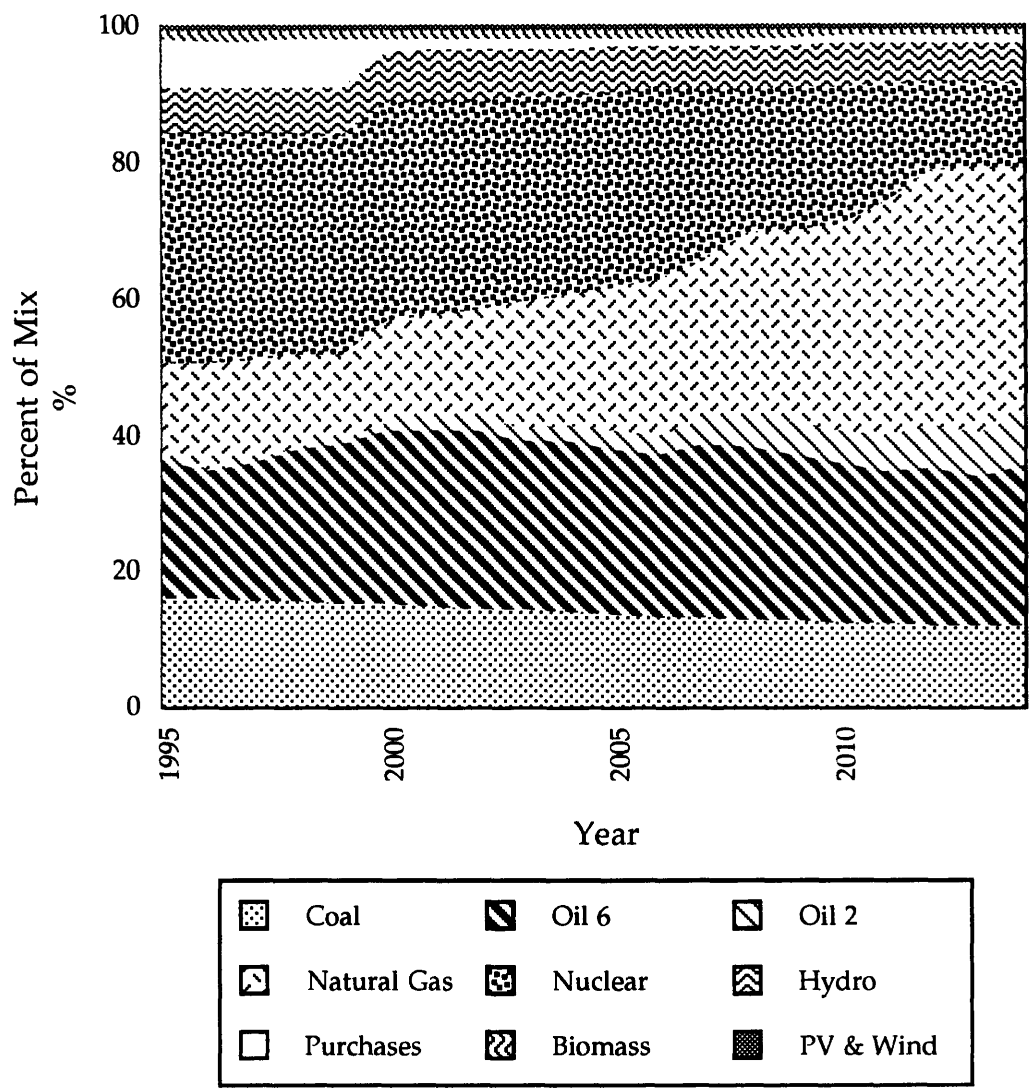


Figure 3.4 shows the impacts to the generation mix due to EV loads. The upper portion of the figure shows the absolute impacts in GWh. In the early years (1998-2003), Oil 6 dominates the incremental generation. After this point, natural gas dominates for the remainder of the study period. The lower portion of the figure reveals that the greatest relative shifts in fuel use are for the fossil fuels (Oil 2, Natural Gas, Oil 6) and power purchases. In the latter years, only Oil 2 and Natural Gas exhibit significant increases (about 10-15%). The use of renewables (Biomass, PV and Wind), nuclear, and coal-fired

generation are approximately unchanged. These generation sources are largely insensitive to load patterns. Renewable are non-dispatchable and are entirely independent from load patterns. Nuclear and coal-fired generation are sufficiently inexpensive (low enough in the loading order) and sized only to meet baseload; any load variation due to EVs do not influence their operation. The use of hydro power is decreased with EV loads in latter years, signifying that all other units outperform hydro power in the dispatch order.

Figures 3.5 and 3.6 show the results on a twenty year cumulative basis for each fuel type. Natural gas is impacted the greatest on absolute contribution to GWh production (Figure 3.5), four times the next closest fuel, Oil 2, but has only the second largest percent increase from the "No EV" case (Figure 3.6). It is clear from Figure 3.5 that Natural Gas dominates the electricity production for EV load, with a 67% share of the GWh required for EVs. Oil 2 and Oil 6 follow with a combined 30% of the GWh required for EVs. Together, these fossil fuels account for 97% of all EV electricity requirements. This result counters the common expectation that the electricity production for EVs will be from clean baseload fuels (hydro and nuclear).

Figure 3.4: Changes in Power System Dispatch Due to EV Load
(Moderate Fleet)

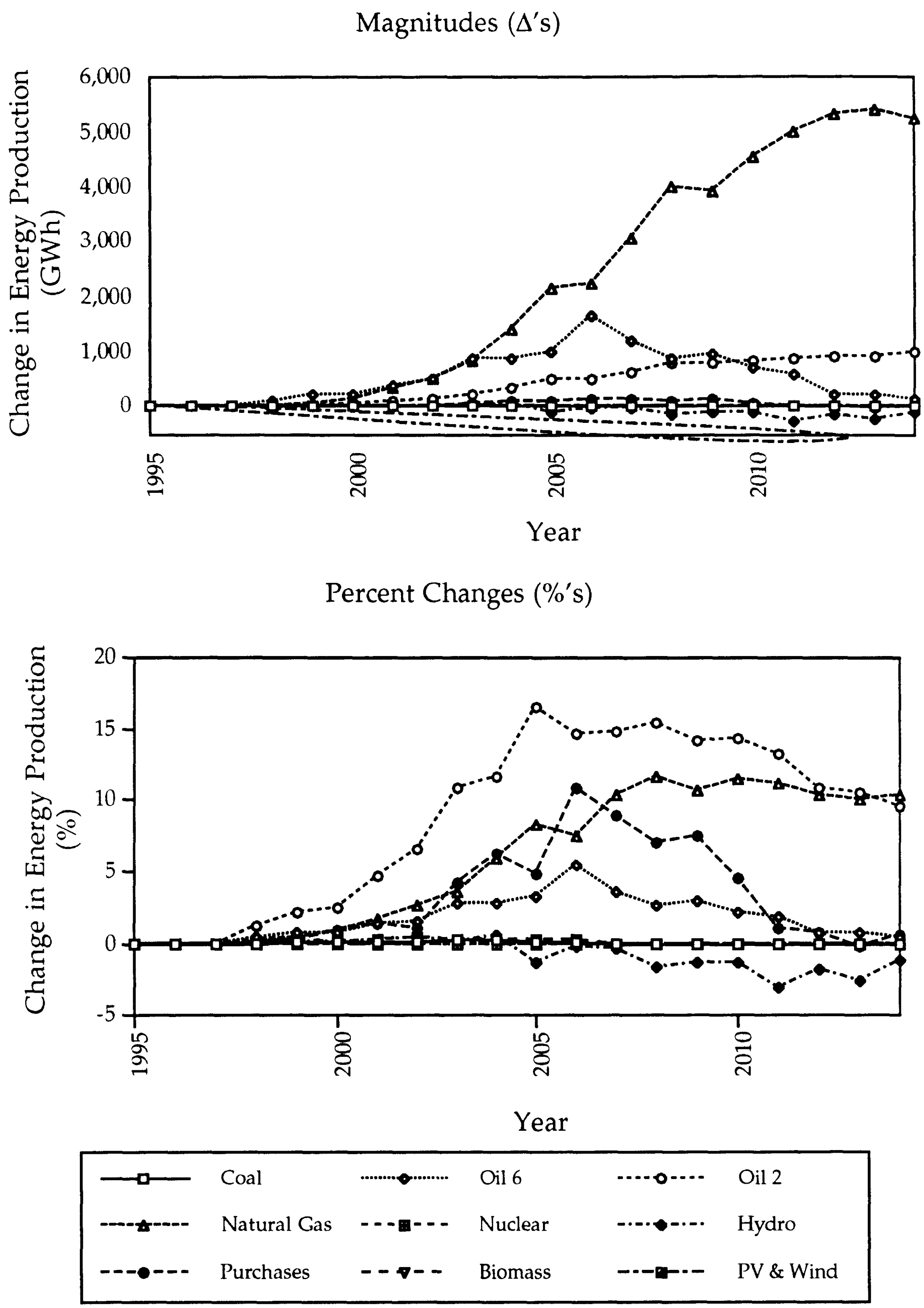


Figure 3.5: Fuels Used for Meeting EV Electric Demand – Moderate Fleet (20 Year Cumulative)

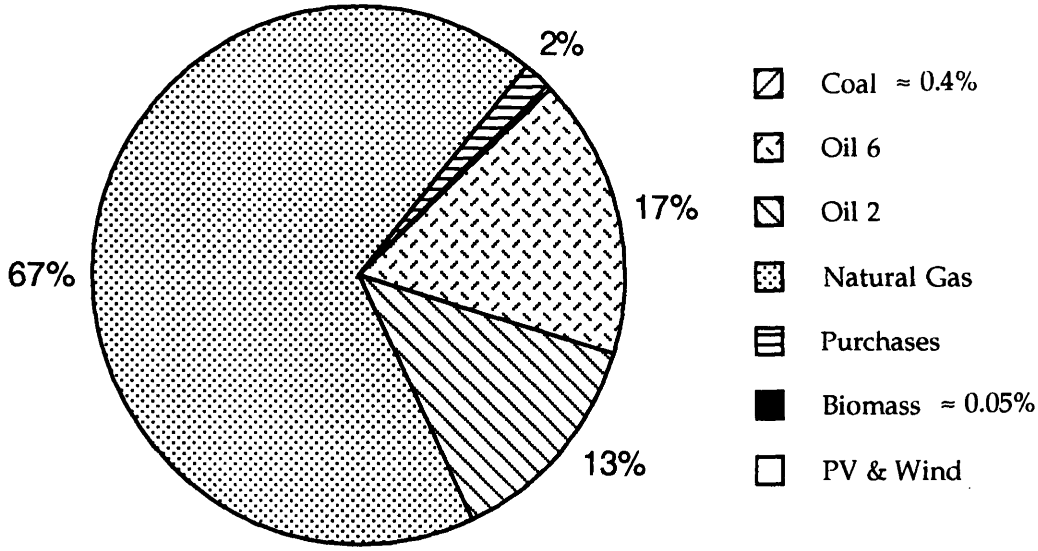
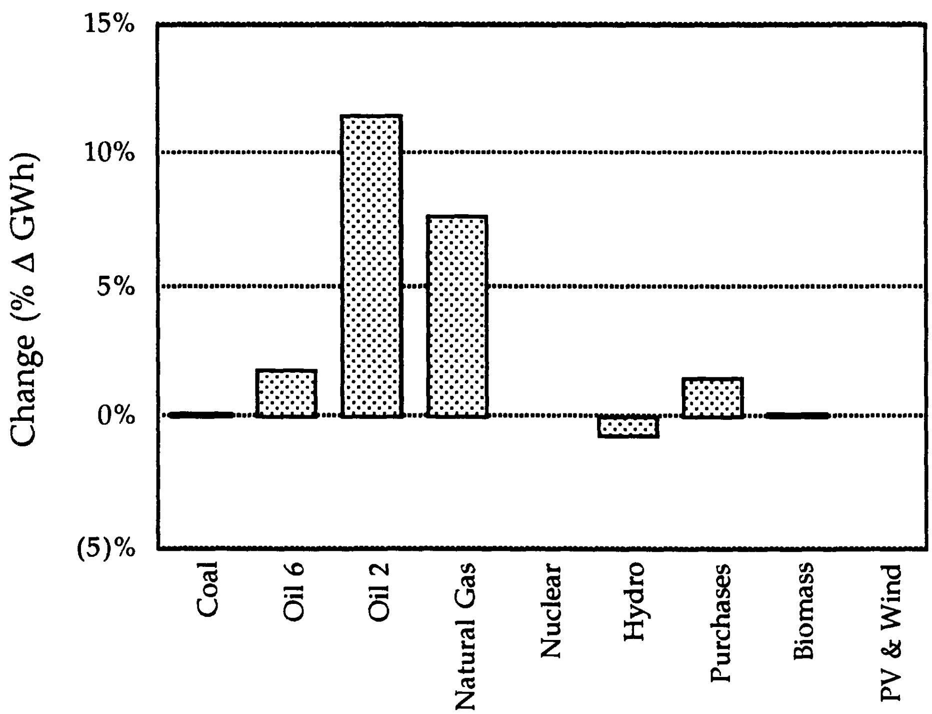


Figure 3.6: Fuels Used to Meet EV Demand – Moderate Fleet (20 Year Cumulative)



From a capacity planning perspective, it is essential to know the peak load impacts from adopting EVs. The peak load impacts are the EV load contributions occurring at the hour of maximum load on the system. Maximum (peak) loads define the amount of generation capacity required. This assists in asking the questions, "Will new power plants have to be built to meet EV loads? If so, how many?" The peak load impacts from adopting EVs are shown in Figure 3.7. The load impacts appear to be little more than "noise" on total system load. The lower portion of the figure shows the percentage increases in each year. The load impacts attain maximum steady state values around the year 2010, and they range from 45 MW to 950 MW for the Small Fleet and Large Fleet, respectively. These correspond to 0.2% to 4% increases over the system load with no EVs. Table 3.1 shows these figures, as well as the power plant capacity additions required to meet these load increases. No new generation is required for the Small Fleet option. The Moderate Fleet requires 655 MW of new generation capacity, and the Moderate Commuter Accent requires 250 MW. The only difference between these two options is the vehicle type emphasis (Fleet trucks and passenger cars versus commuter passenger cars). The Large Fleet requires 1560 MW of new capacity, over twice the amount of the Moderate Fleet. Recall that the only difference between these two options is that the Large Fleet has twice as many EVs.

Figure 3.7: Electric Vehicle Peak Load Impacts

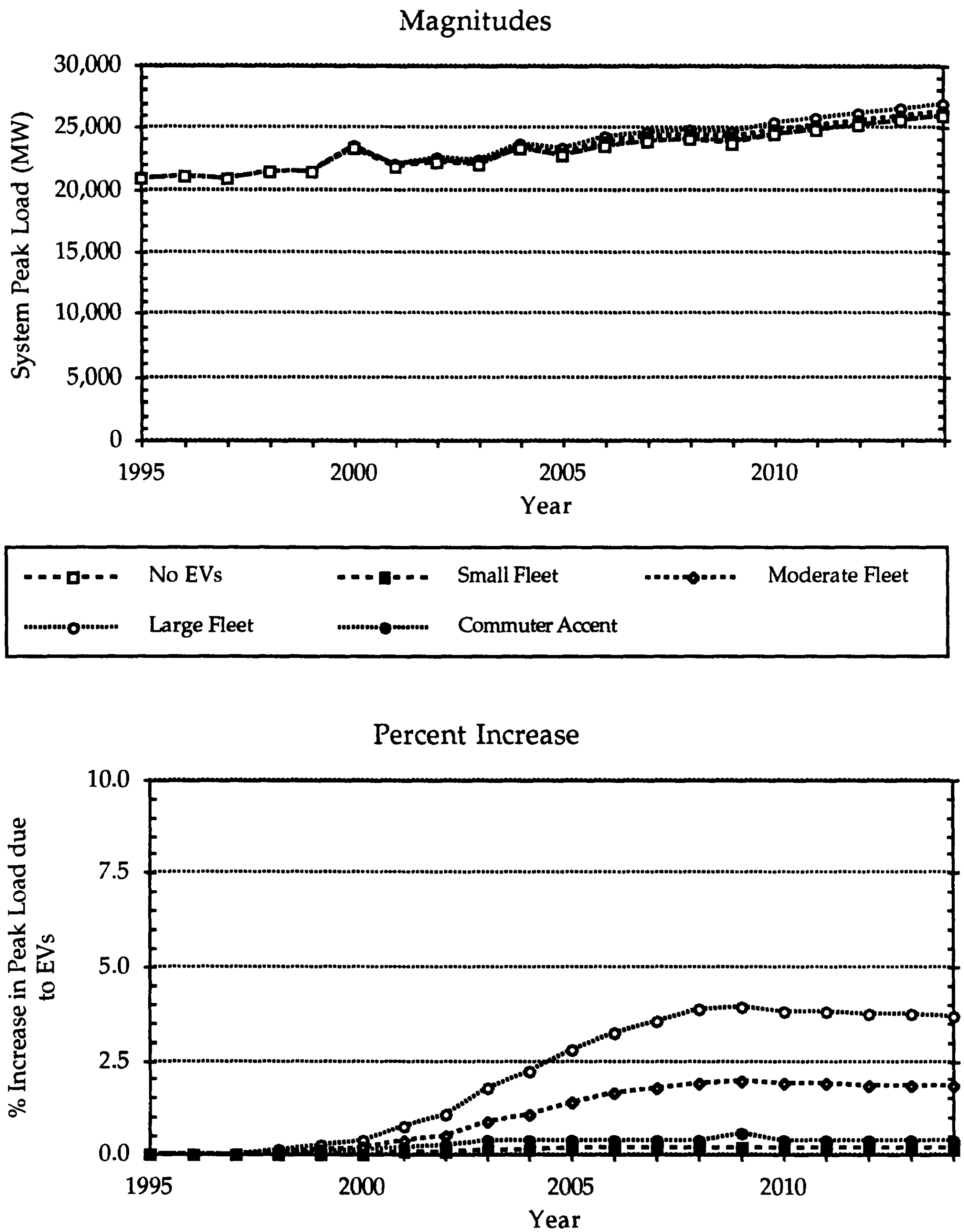
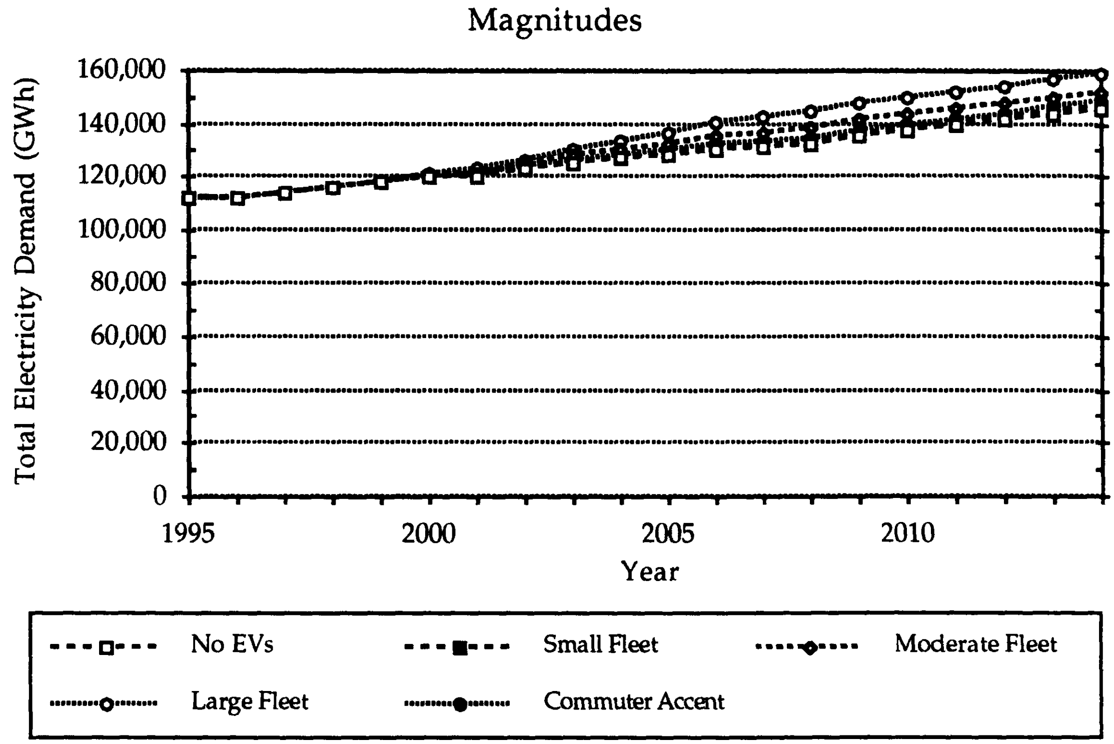


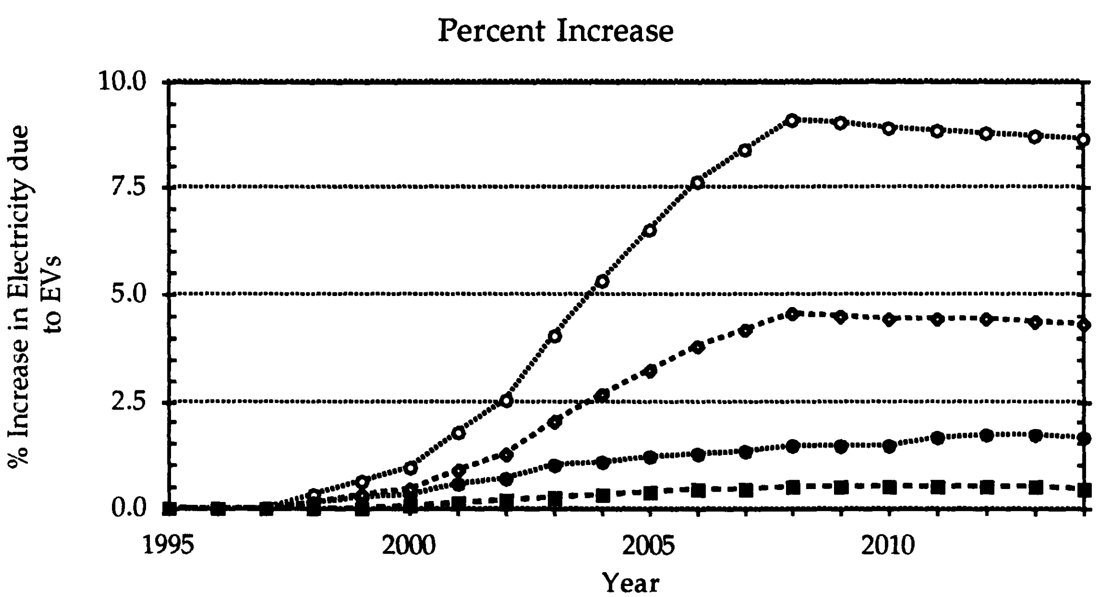
Table 3.1: Electric Vehicle Impacts on Regional Capacity Growth

EV Population Option	Maximum Load (MW)	Power System Peak Demand Increase (MW)	Incremental Capacity Addition (MW)
No EV's	25,892	0	0
Small Fleet	25,946	45	0
Moderate Fleet	26,367	475	655
Moderate Commuter Accent	25,988	96	250
Large Fleet	26,842	950	1,560

The EV impacts to electricity consumption (GWh) are relatively greater than those to peak load. The number of GWh consumed is an interesting parameter because it is used in setting energy rates. In cost-to-serve rate making, the more GWh consumed, the lower the average rates (operating costs are divided by the GWh to determine $/kWh rates). This effect is attractive to utilities, especially those saddled with exorbitant rates, frustrated customers, and impending increased competition. Figure 3.8 shows these impacts, the lower portion of the figure indicating that maximum impacts in later years range from 700 GWh to 12,600 GWh for the Small Fleet and Large Fleet, respectively. This corresponds to increases of 0.5% and 9% above the system's electricity consumption with no EVs.

Figure 3.8: Electric Vehicle Electricity Consumption Impacts





EV EMISSION RESULTS

The adoption of EVs leads to the elimination of tailpipe emissions and the increase of electric power sector emissions; the "net" change is of interest from a policy perspective. Though the ozone precursor emissions, NO_x and ROG, are highlighted in this study, the results for CO_2, SO_2, and CO are also reported. There are many avenues for evaluating emission impacts, each offering a slightly different perspective helpful for appreciating the dimensions of the problem. The results for each pollutant are presented sequentially, with a final review and discussion of sensitivities at the end. For each pollutant, the following will be addressed on a year-by-year and cumulative basis:

- "Net" impacts for each pollutant
- Breakdown of increases and decreases for each pollutant
- Fraction of "zero emission" reductions actually accomplished
- Highlights of differences across EV penetration options

NITROGEN OXIDES

The premier pollutant of interest for New England ozone is NO_x. For all EV population/mix options, the "net" NO_x emission levels are reduced after year 2003, as depicted in Figure 3.9. This means that after 2003, the reductions in tailpipe emissions outweigh the increases in power plant emissions. This year-by-year dynamic is shown in Figure 3.10. Prior to 2003, the net NO_x emissions are slightly positive, barely above the zero line. The offset tailpipe emissions do not exceed the increased power sector emissions in these early years. One explanation for this is that the incremental changes in the power system dispatch, due to the EV loads, in the early years is incrementally "dirtier." Indeed, a close inspection of the dispatch changes in the upper portion of Figure 3.4 indicates that Oil 6 fueled plants are used proportionately more in the early years. It is not until 2003 that EV loads are met with a higher fraction of natural gas, a fuel with a lower NO_x content.

The trend is that the NO_x emission reductions follow the general shape of the "in-service" EV populations, as shown in Figure 2.2. A steady-state value is eventually reached. For the Moderate Fleet, this value approaches 7,000 tons per year. To appreciate the relative size of this decrease, refer to Figure 3.12. This corresponds to a 5% NO_x year by year decrease from the no EV case.[1] On a 20 year cumulative basis, the total NO_x decrease is 52,000 tons.

An important final measure of the NO_x reductions is the fraction of alleged "zero emissions," as propagated by the term "Zero Emission Vehicle," that is actually achieved by EVs. Taking the electric power sector into account, Figure 3.11 displays the fraction of "zero emissions" that occurs. This measure is useful because it provides a sense of the relative impacts for any given EV penetation option and indicates the comparative effectiveness of taking gasoline engines off the road and replacing them with EVs. For fractions (expressed as percentages) less than zero, the electric power sector increases exceed the mobile source reductions. Vice-versa for fractions greater than zero. If the full "zero emission" benefits are realized, the fraction is 100%.

The results show that the net emissions exceed the offset mobile source emissions in the early years by as much as a factor of 3 (expressed as -300% in the figure for year 1998). Put another way, for every 1 ton of NO_x emissions eliminated in this year from tailpipes with EVs, another 4 tons are created by the electric power sector for recharging needs. In years 1999-2002, this effect ramps down. In year 2003, the offset mobile source emissions outweigh electric power sector emissions. Late in the study period, when approximate steady-state trends are observed, net emission levels allow 70-130% of "zero emissions" to be obtained. Fractions over 100% indicate that electric power sector emissions do not increase, but decrease with EVs, indicating that additional EV loads on the electric power sector lead to a cleaner system than if no EVs load been incurred. This takes place only in one case, with the Small Fleet only where no additional electric capacity had to be built to meet future EV loads. This effect has been claimed for California's electric power

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[1]The basis for the percentage calculation is the total emissions from the no EV case, where "total emissions" are those for the entire power system plus the gasoline vehicle emissions to be offset by EV's. A true definition of "total emissions" would include those from the entire mobile source sector plus the power system emissions. The former is not modeled in this study, so there is no consistent basis for comparison. Only incremental mobile source emissions are modeled. The percent calculation is, regardless, useful for communicating a sense of the relative magnitudes of the emission impacts.

sector, but does not generally apply for New England, evincing the disparities between the two systems.

With NO_x impacts, it is interesting to note that the Moderate Commuter Accent is nearly equivalent to the Moderate Fleet. Regardless of the type of EVs used (commercial fleet use vs. domestic commuter use), approximately the same reduction levels are achieved. This generalization does not hold for any of the other pollutants. An exception for NO_x is the fraction of "zero emission" achieved. The Moderate Commuter Accent consistently accomplishes a greater fraction than the Moderate Fleet, as much as two times the fraction of the Moderate Fleet.

Because the modeling of power plant NO_x emissions includes only Phase I RACT controls, these net decreases are understated for any degree of stricter NO_x controls above and beyond RACT. Such controls in New England are likely, as Phase II NO_x regulations are currently being developed. A sensitivity check on Phase II NO_x controls is included at the end of this section.

Figure 3.9: Net Regional NO_x Emission Impacts by EV Penetration Levels

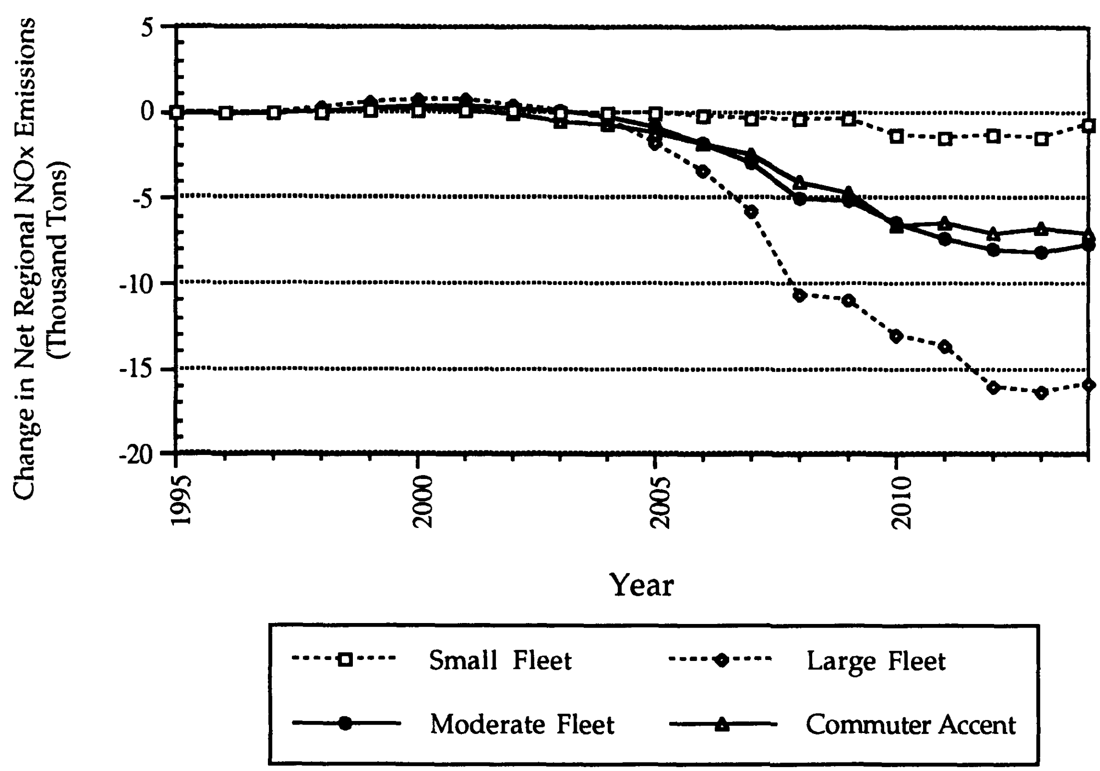


Figure 3.10: Intersectoral Dynamic for NO_x (Moderate Fleet)

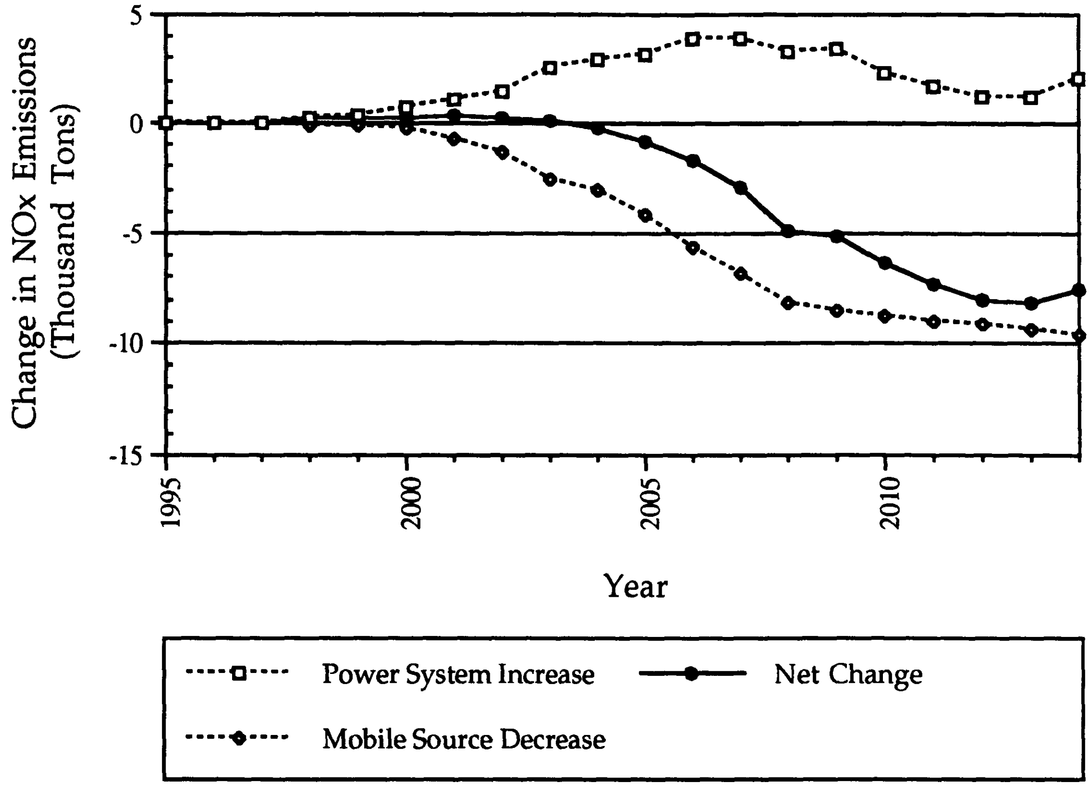


Figure 3.11: Fraction of "Zero Emissions" Achieved for NO_x

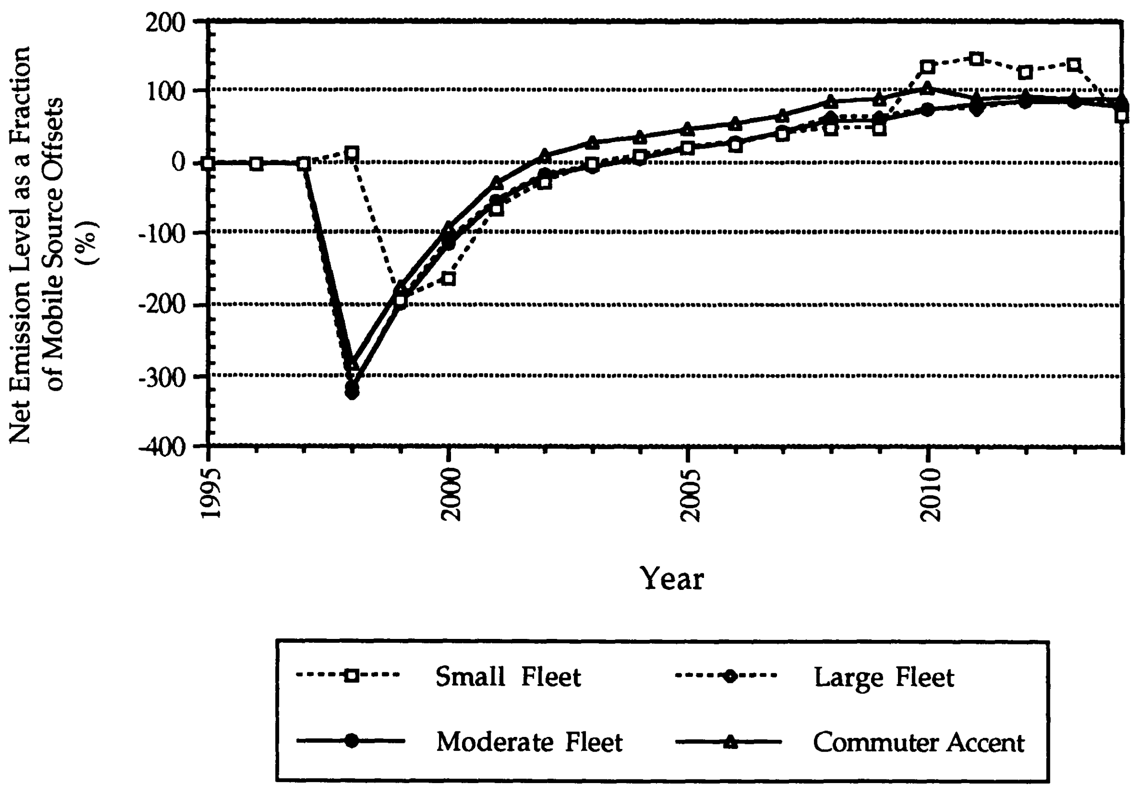
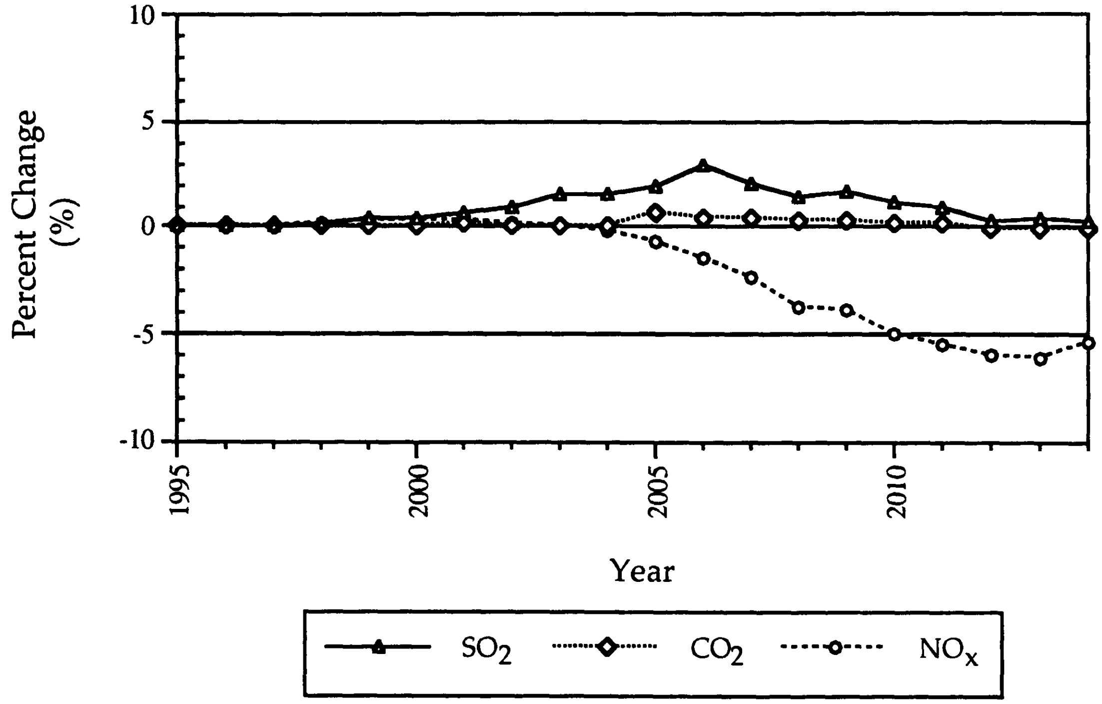


Figure 3.12: Percent Change from Original Emission Levels (Moderate Fleet)

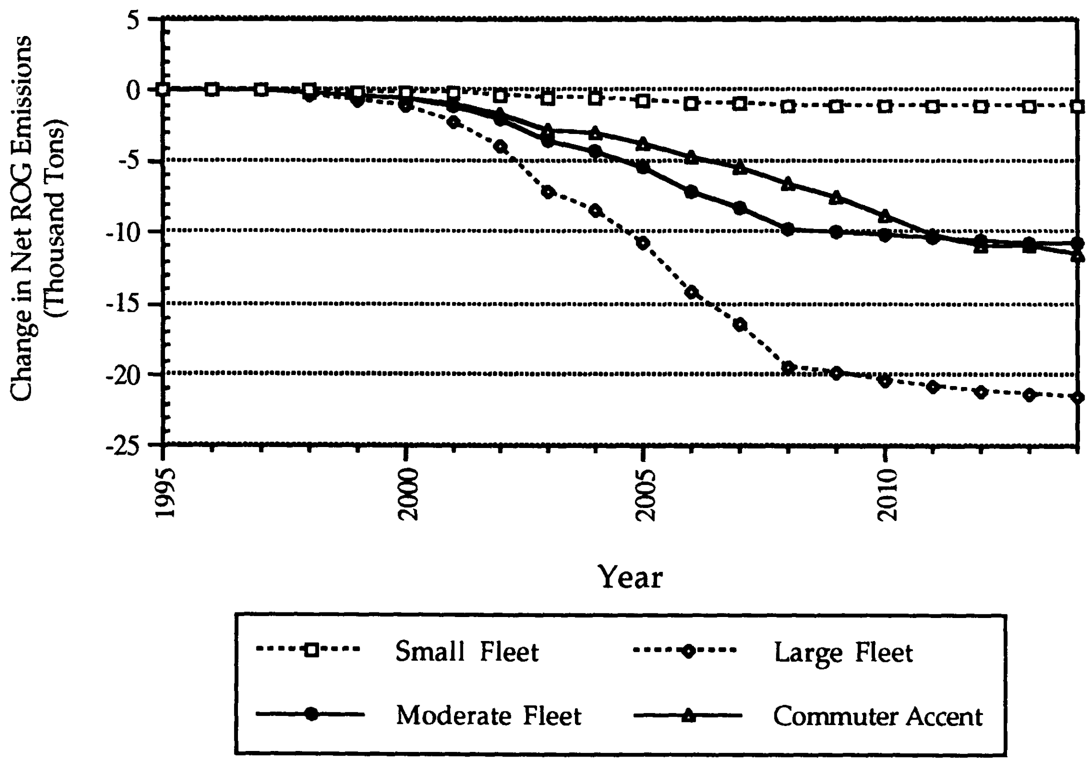


REACTIVE ORGANIC GASES

The other ozone precursor emission, reactive organic gases (ROG), is also reduced across all EV penetration levels. This is expected because the ROG emissions from power plants are very small (modeled as negligible in this study), so any ROG reductions from tailpipes are fully realized in a "net" calculation. From a pure emission reduction perspective, EVs are a very effective ROG strategy. ROG emissions are entirely eliminated when a gasoline vehicle is replaced by an EV. One hundred percent of the "zero emissions" are achieved. In the later years, the reduction approaches 11,000 ton/yr for the Moderate Fleet, as shown in Figure 3.13.

The shape of the reduction trend is similar to that of NO_X, with a steady state decrease of 11,000 tons per year in the later years for the Moderate Fleet. On a 20 year cumulative basis, the total ROG decrease is 104,000 tons. Once again, the Moderate Commuter Accent maps very closely to the Moderate Fleet. The Large Fleet is twice that of the Moderate Fleet.

Figure 3.13: Net Regional ROG Emission Impacts by EV Penetration Levels



CARBON DIOXIDE

Though not a ozone precursor, carbon dioxide (CO_2) is important for its relevance in the global climate change debate. Strategies for ozone must be evaluated in light of other environmental issues. As shown in Figure 3.12, the net CO_2 impacts on a percentage basis are very small, essentially negligible. This is because the power sector has very high CO_2 emissions to begin with. Indeed, EVs are effective at reducing CO_2 levels, but the power sector emissions more than offset these reductions. Figure 3.14 shows that there is a net increase in New England's CO_2 emissions for most EV penetration levels. In the very long term (2012), the tailpipe reductions and power sector increases balance one another. Figure 3.15 clearly shows this effect for the Moderate Fleet. On a twenty year cumulative basis, the net increase is 3,070,000 tons.

Interestingly, the Moderate Commuter Accent provides net CO_2 reductions in every year after 2001. The pattern is entirely different than that of the other fleets. Recall that the Moderate Commuter Accent differs from the other options because it contains mostly commuter passenger cars, which travel fewer miles, have higher motive efficiencies, draw less kW demand on recharging, and are assumed to do more recharging during the night than the day. Except for these differences, the quantity of EVs and the penetration schedule is exactly the same as the Moderate Fleet. The emphasis with the Moderate Commuter Accent is EV *type and use*, not EV quantities. Vehicle type and use do make a difference! A closer inspection of the dynamics reveals that the Moderate Commuter Accent and Moderate Fleet have comparable tailpipe reductions, but that the power sector increases differ by a factor of two. The specific characteristics of the power system energy impacts with commuter vehicles result in lower emissions than with commercial fleet vehicles. It must be qualified, however, that this reduction amounts to only two percent in later years. The dynamic is noteworthy to indicate that vehicle type and use can make a difference, but the overall magnitude of the impact to CO_2 remains very small.

The "zero emissions" comparison for CO_2 in Figure 3.16 shows that the early years experience gains in net emission levels as high as 50% (shown as -50% in the figure) of the so called mobile source emissions sought to be eliminated. This effect ramps down in years 1999-2006, but the net increases are as high as 20% for many years. As discussed, only the Moderate Commuter Accent leads to net decreases. In later years, this option accomplishes a steady state value of approximately 60%, i.e., rather than accomplishing 100% of "zero emissions," only 60% are realized. The first year of EV adoption for the Small Fleet exhibits a substantial net reduction, but all subsequent years match closely with the other commercial fleet-dominated options (Moderate Fleet and Large Fleet).

Figure 3.14: Net Regional CO_2 Emission Impacts by EV Penetration Levels

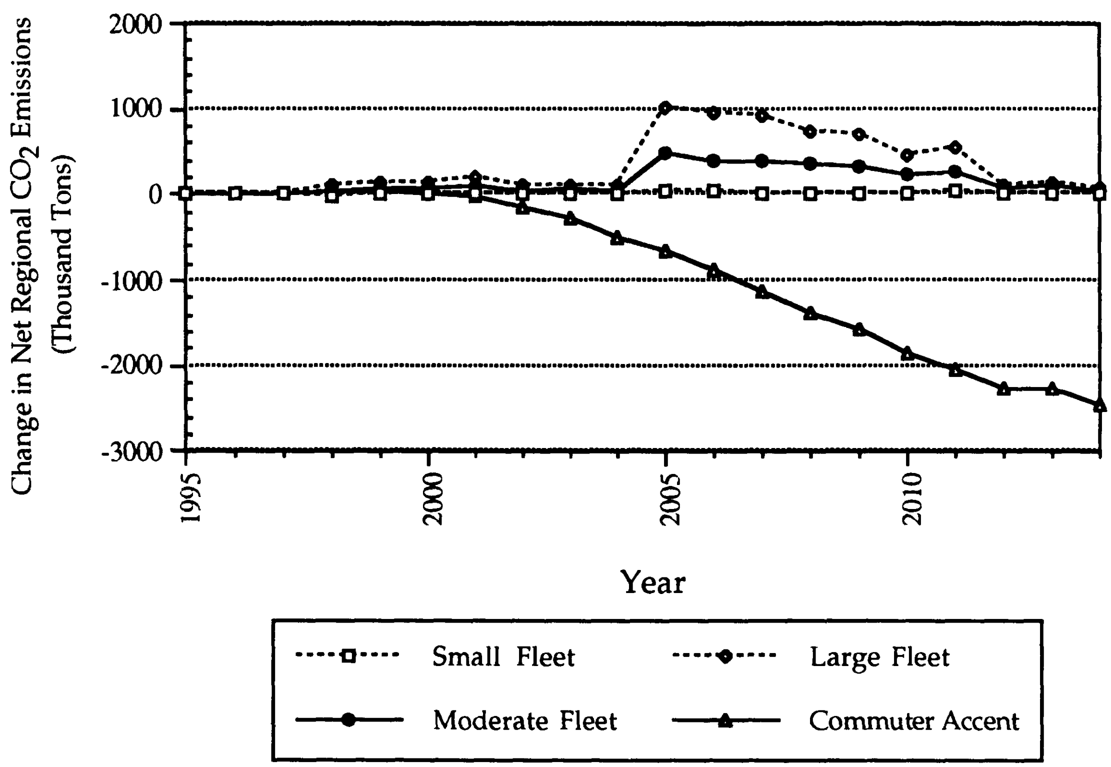


Figure 3.15: Intersectoral Dynamic for CO_2 (Moderate Fleet)

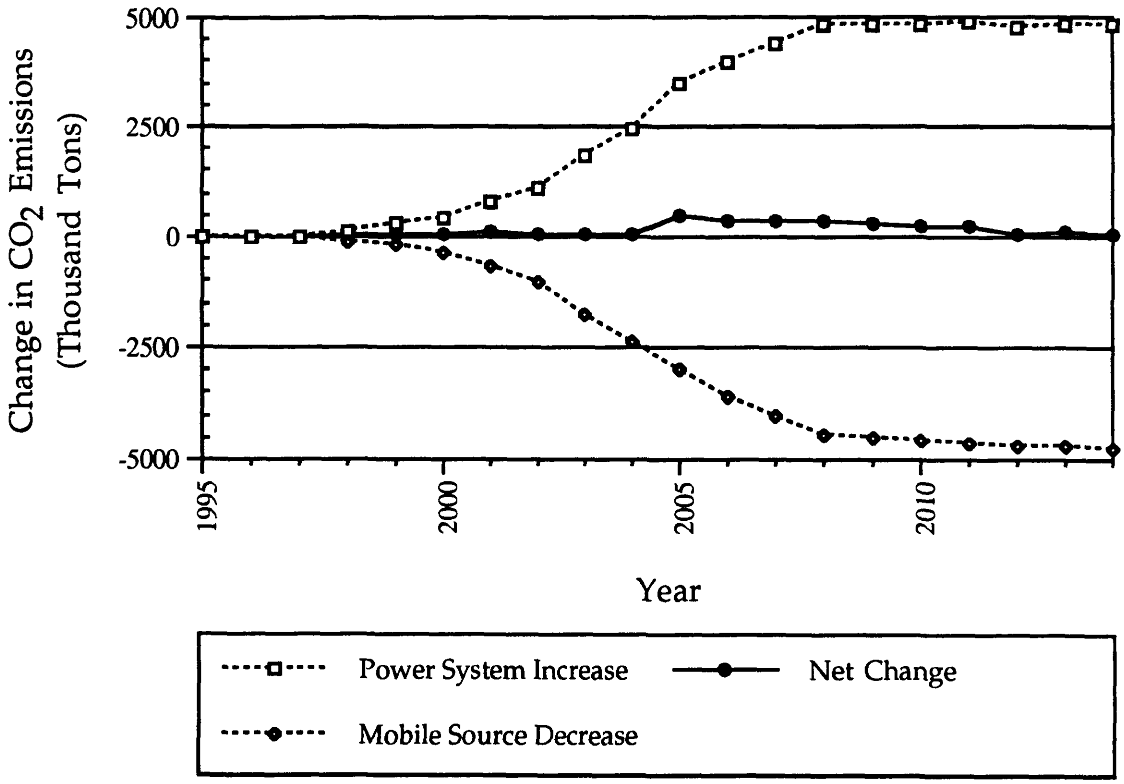
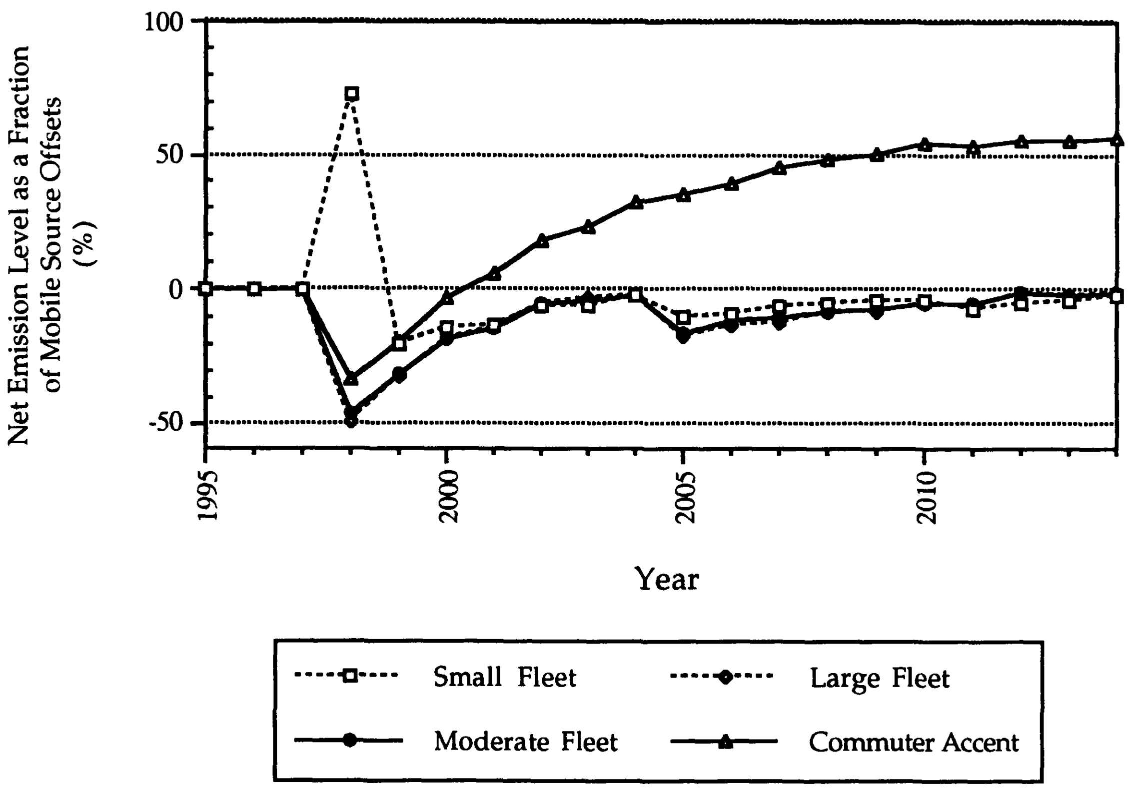


Figure 3.16: Fraction of "Zero Emissions" Achieved for CO_2



SULFUR DIOXIDE

Sulfur dioxide (SO_2) is an important acid rain emission. The results for SO_2 are roughly similar in form, but not magnitude, to CO_2. There are net increases in overall emission levels, but the impacts decrease and taper off in later years. As shown in Figure 3.17, the fleets with the smallest energy impacts (Small Fleet and Moderate Commuter Accent) have net impacts of approximately zero in all years. The Moderate Fleet exhibits an increase as high as 8,400 ton/yr in 2006, but only 1,000 ton/yr after 2012. On a percentage basis, as shown in Figure 3.12, the maximum net increase in 2006 is three percent. Figure 3.18 shows the intersectoral dynamics for the Moderate Fleet. The mobile source decrease is a smooth function while the power sector increase exhibits great variance, due to the attributes of the power system dispatch. On a twenty year cumulative basis, the SO_2 increase for the Moderate Fleet is 55,000 tons.

The shapes of the electric power sector curves in Figure 3.18 draw attention – there is a distinct peak in year 2006 and clear symmetry in surrounding years. An examination of a SO_2 trajectory for the no EV case reveals that this incident is unique to EVs. No analogous rise and fall of electric power sector emissions takes place in the no EV case. In fact, in the no EV case, SO_2 emissions gradually continue to increase in a stair step fashion. The peaking effect is entirely EV induced. This does not occur as dramatically for the Small Fleet or the Moderate Commuter Accent, signifying the importance of EV penetration level and EV type and use, respectively. Referring to the fuel trajectories in Figure 3.4, it can be seen that this effect is most likely linked to Oil 6, a high sulfur fuel, which has a parallel curve shape.

On a "zero emissions" comparative basis, as shown in Figure 3.19, the SO_2 net emission increases grossly outstrip the mobile source offsets. For example, the year 2000 shows that the net increase is 10 times as large as the offset mobile source emissions (expressed as -1,000% in the figure). In year 1998, the net increase is nearly 20 times as large. This effect decreases dramatically over time. The Commuter Accent fluctuates in later years with both positive and negative percentages. The Small fleet tracks with the fleet-dominated options except for the years 2010-2013, where the power sector emissions actually decrease substantially with additional EV load.

Figure 3.17: Net Regional SO_2 Emission Impacts by EV Penetration Levels

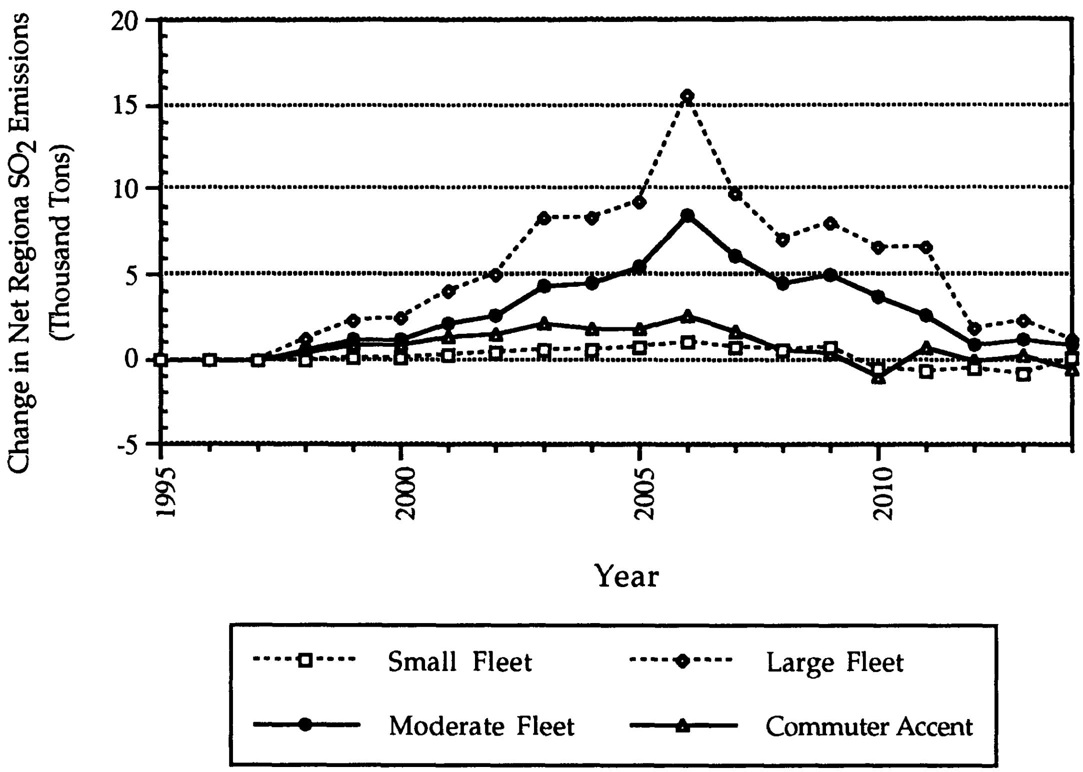


Figure 3.18: Intersectoral Dynamic of SO_2 Emission Levels (Moderate Fleet)

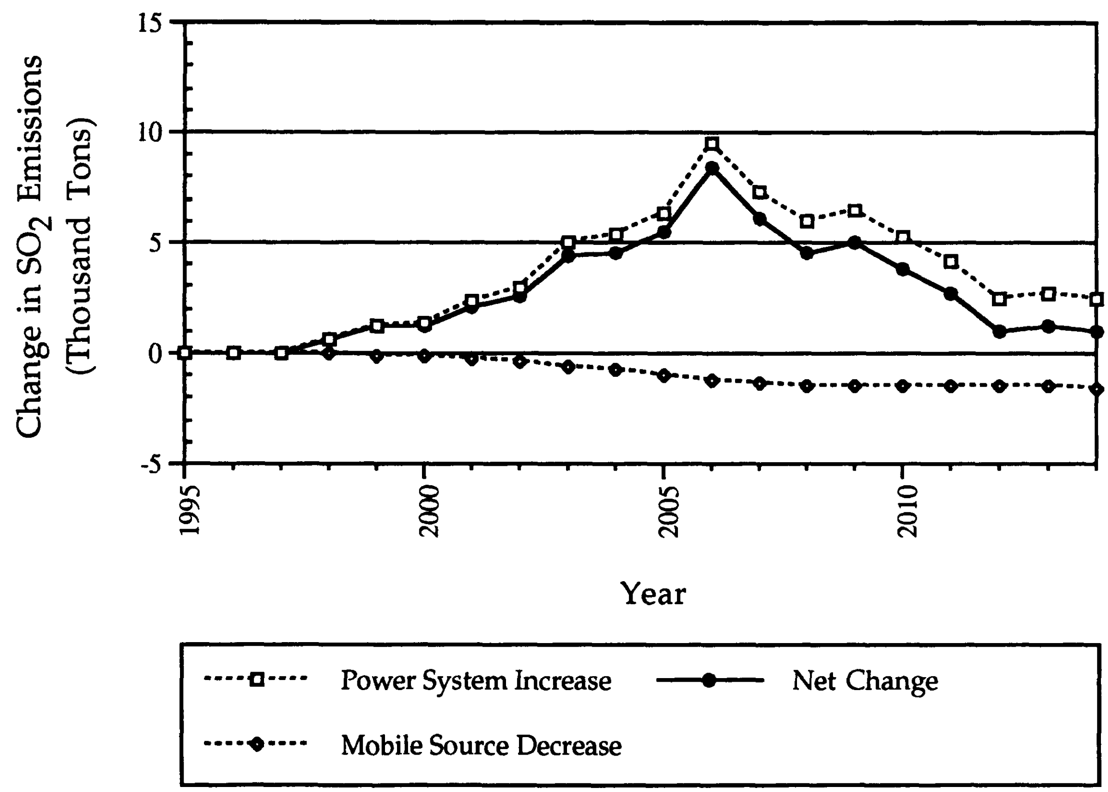
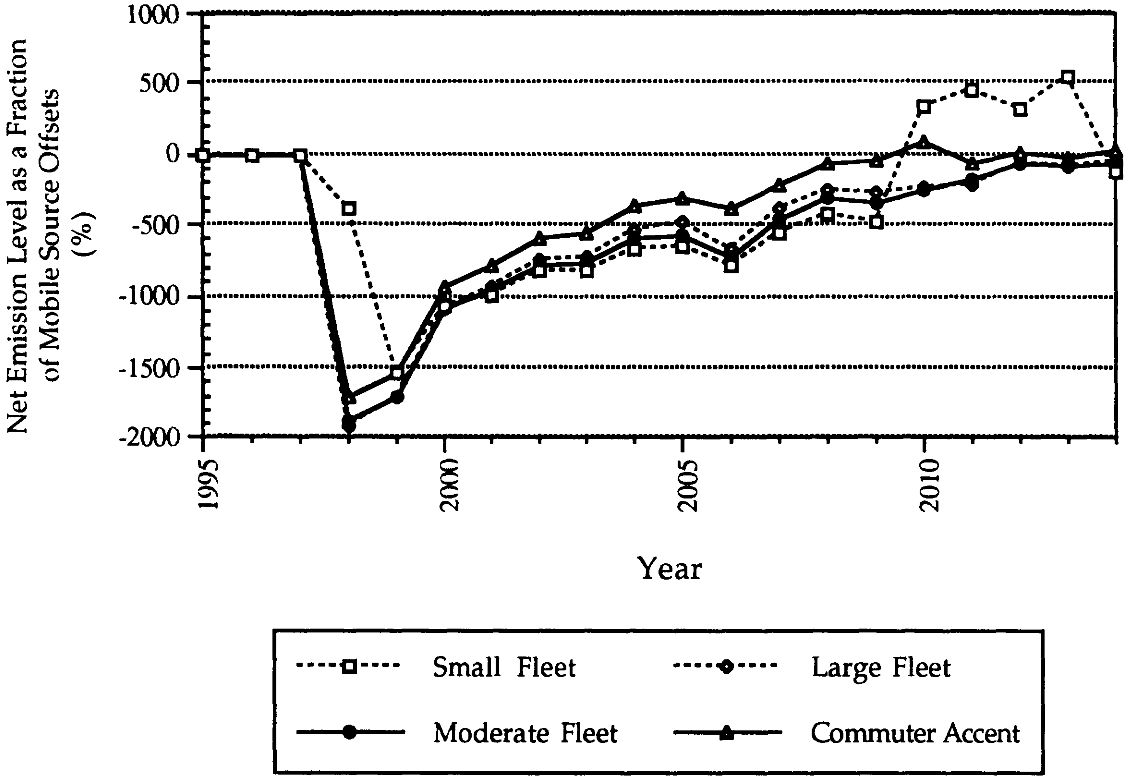


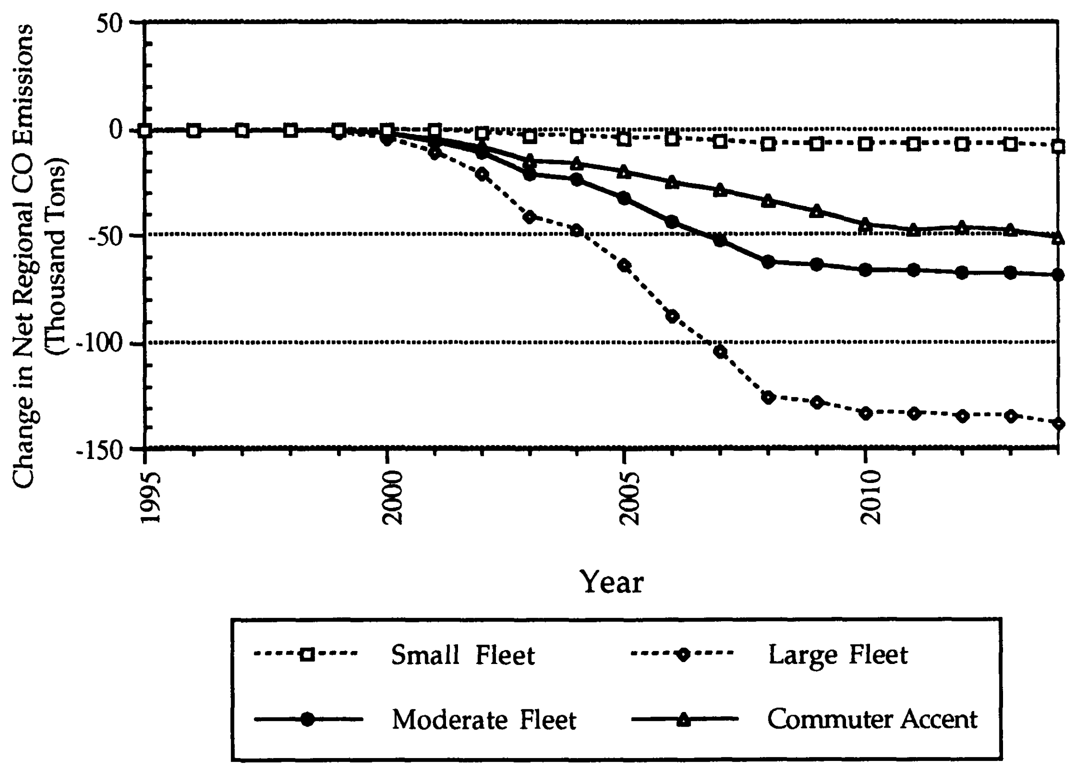
Figure 3.19: Fraction of "Zero Emissions" Achieved for SO_2



CARBON MONOXIDE

Carbon monoxide (CO) has a role in ozone formation (by contributing to increased NO_x levels through atmospheric chemical reactions), but is widely known for its poisonous effects on human health. Similar to ROG, it is also reduced across all EV penetration levels, as shown in Figure 3.20. This is expected because the CO emissions from power plants are very small (modeled as negligible in this study), so any CO reductions from tailpipes are fully realized in a "net" calculation. From a pure emission reduction perspective, EVs are a very effective CO strategy. Carbon monoxide emissions are entirely eliminated when a gasoline vehicle is replaced by an EV. In the later years, the reduction approaches 70,000 ton/yr for the Moderate Fleet. On a twenty year cumulative basis, the reduction is 650,000 tons.

Figure 3.20: Net Regional CO Emission Impacts by EV Penetration Levels



SENSITIVITY TO MOBILE SOURCE EMISSION RATES

As stated previously, there is great concern but little certainty about the extent to which tailpipe emission rates are understated by EPA's MOBILE5a program.

A sensitivity is completed which assumes that the model underestimates emission rates for NO_x and CO by 20%, and ROG by 30%. Because power plants are assumed to emit negligible CO and ROG, the effect of introducing this adjustment is a simple proportional increase in net emissions of 1.25 and 1.50, respectively. Because the power sector also emits NO_x, the effects are similar, but not as direct. Table 3.2 shows a comparison with adjusted and unadjusted MOBILE5a NO_x rates. This table shows that even with underprediction, the tailpipe emission increases still offset the decreases of the electric power sector in all EV penetration levels. Thus, the same general trends hold as before. However, the net impacts differ by 31-42%, showing that net emission impacts are indeed sensitive to assumed NO_x tailpipe rates. The more that suspected underpredicted MOBILE5a NO_x rates are adjusted, the greater the net emission benefits of EVs. Put conversely, to achieve no net emission benefits from EVs, the MOBILE5a NO_x rates would have to be understated (with lower gram/mile rates) by 60-80%.

Table 3.2: NO_x Sensitivity to Underpredicted Off-Cycle Emissions

With Unadjusted NOx MOBILE5a Emissions:

EV Population Option	Gasoline Vehicle Decrease	Power System Increase	"Net" Impact
No EVs	0	0	0
Small Fleet	-9,600	2,300	-7,300
Moderate Fleet	-87,400	35,700	-51,700
Commuter Accent	-60,800	12,500	-48,300
Large Fleet	-174,800	70,000	-104,800
	(20 Year Cumulative Tons)		

With Adjusted NOx MOBILE5a Emissions:

EV Population Option	Gasoline Vehicle Decrease	Power System Increase	"Net" Impact	% Difference from Unadjusted
No EVs	0	0	0	0%
Small Fleet	-12,000	2,300	-9,700	33%
Moderate Fleet	-109,250	35,700	-73,550	42%
Commuter Accent	-76,000	12,500	-63,500	31%
Large Fleet	-218,500	70,000	-148,500	42%
	(20 Year Cumulative Tons)			

Sensitivity to Electric Power Sector Fuel Prices

When analyzing strategies for stationary sources, it is important to examine results over a range of power plant fuel cost uncertainties. This is because fuel costs are a large portion of total operating costs, and the dispatch order of generators is based on total operating costs. All fuels are modeled with a degree of variance reflecting uncertain prices on a year to year basis. This sensitivity study is for a fuel price increase in natural gas, an appropriate fuel for three reasons: 1) historical prices have indeed exhibited variance, 2) the New England region is historically becoming more dependent on natural gas, with all new fossil plants likely to be natural gas fired, and 3) New England's natural gas supplies come from outside the region, signifying vulnerability and sensitivity to extra-region events. The projected year by year price increase is roughly 10%.

Table 3.3 shows the resulting emission impacts on a 20 year cumulative basis. The percentages shown for EV options are the changes in net emissions due to the higher priced fuel. By definition, the changes in ROG and CO emissions are zero (power plants are assumed not to emit ROG or CO). For NO_x, the net reductions from adopting EVs are essentially insensitive to higher natural gas prices. For CO_2, the Small Fleet net emissions increase by 15% on a 20 year cumulative basis. The Moderate and Large Fleets have 5% lower net emissions. For SO_2, the Small Fleet again experiences a large increase in net emissions. The other fleets have 12% to 20% decrease in net emissions. For all emission types, the shapes of the 20 year trends are the same as those shown previously; only the magnitudes differ. The sign of the net emission impacts – positive vs. negative – do not change in any case.

In the reference case of no EVs, the impacts of the increase in fuel price to the emission levels of NO_x, CO_2, and SO_2 are approximately 1%, 0%, and 2%, respectively. Essentially, the emissions to the power sector are unchanged. The reason that Table 3.3 shows large percentage changes is because the net emissions impacts are small to begin with. That is, the small changes in power sector emissions are large compared to the original net impacts. Because the original impacts are small in magnitude, the results are thus sensitive to the fuel price increase. If the EV impacts had been large, the results would be insensitive to the fuel price increase (as the power sector emissions in the no EV case).

Table 3.3: EV Emission (Net) Sensitivities to Power Plant Fuel Prices

EV Population Option	Effect of Higher Natural Gas Prices % Change in Emission Levels				
	NOx	ROG	CO2	SO2	CO
Small Fleet	-4%	0%	15%	18%	0%
Moderate Fleet	0%	0%	-5%	-15%	0%
Large Fleet	1%	0%	-6%	-20%	0%
Commuter Accent	0%	0%	0%	-12%	0%
	(20 Year Cumulative)				

SENSITIVITY TO THE LEVEL OF STATIONARY SOURCE NO_X CONTROLS

The Clean Air Act Amendments of 1990 require stationary source NO_x reductions in New England's non-attainment regions. The region has adopted Phase I RACT controls (Reasonably Available Control Technology) to begin in 1995. Phase I RACT controls on stationary sources are assumed in the reference case of this analysis and in all EV results thus far presented. Additional controls to begin in 1998 –Phase II controls– are being debated. Because EVs shift emissions to stationary sources, it is interesting to examine the effects of Phase II controls on the anticipated NO_x reductions achieved with EVs. Perhaps the NO_x reductions with EVs are increased significantly with tighter Phase II controls? Perhaps the improvement is negligible? Because the two options are being considered concurrently (EVs and Phase II controls), it is useful to examine their effects on one another.

Phase II NO_x Controls are modeled by applying advanced control technologies to existing power plants and then varying the NO_x emission rates accordingly. The advanced NO_x control technologies used in this case are steam injection and selective non-catalytic reduction. Twenty-three power plants receive modified emission rates, accounting for 4,850 MW of New England's installed capacity. The design of this Phase II control scheme is intended to provide a 50% reduction in 1990 stationary source emission levels. Accounting for the increased costs associated with these controls, the production cost model provides a least cost dispatch as before. The resulting region-wide emission levels simulate those expected if Phase II controls are adopted.

With no EVs, the results indicate a reduction of 510,000 tons of NO_X over 20 years with Phase II controls. This equates to a 22% reduction beyond those of the reference case (Phase I RACT controls). If EVs and Phase II controls are both adopted, the trends are very similar as those shown in Figure 3.9. Table 3.4 shows the results on a 20 year cumulative basis. For the Moderate Fleet, the NO_X reduction via EVs is improved by 8%. The same holds for the Large Fleet (9%). However, the improvement is halved when EV are used primarily for commuter uses, as shown for the Moderate Commuter Accent. Once again, EV vehicle use/type can make a difference! With the small pilot demonstration, the Small Fleet, the NOx reduction is negligible (1%). Overall, the tonnage reductions achieved with EVs are not reduced significantly with Phase II controls. While the EV improvement may be as large as 8-9%, the tonnage reductions (only 4,250 tons for the Moderate Fleet) are not compelling evidence that the adoption of EVs should significantly influence decisions about Phase II stationary source controls.

Table 3.4: NOx Emission Sensitivity to Stricter Stationary Source Controls

EV Population Option	Phase I NOx Controls (RACT) (Tons)	Phase II NOx Controls (RACT+SNCR) (Tons)	Change in Reduction with Phase II (%)
Small Fleet	7,292	7,352	1%
Moderate Fleet	51,700	55,958	8%
Large Fleet	104,748	113,666	9%
Commuter Accent	48,217	49,569	3%
	(20 Year Cumulative)		

EV COST RESULTS

Cost impacts allow the EV options, and EVs as a general ozone strategy, to be compared along a horizon of cost-effectiveness. This section describes the EV cost impacts both year-by-year and cumulative over the 20 year period. A cost uncertainty analysis provides a range of possible values. To address comparability, cost-effectiveness results are presented, along with caveats about interpretation.

The first result is that EVs do increase New England's regional costs. This is true for all EV penetration options. Cost savings from offset gasoline vehicles do not outweigh cost increases induced by EVs, as might have been hypothesized. The net result on the mobile side is an increase in costs. On the electric power side, costs are always increased with EVs, due to increased electric load requirements (and thus increased power plant fuel consumption). Figure 3.21 shows these results. Costs steadily increase through time until midway through the study period. Then, total costs steadily decrease and appear to level off in later years. The upswing cycle correlates to the gradual increasing population of EVs. At about the points when the EV populations achieve steady-state values, the noticeable downswing cycles begin. Note that all costs are in 1994 dollars, discounted from future values at a rate of 10%.

The breakdown of total costs shown in Figure 3.22 displays the dynamic between the mobile source costs and the power sector costs. Power sector costs increase steadily through time with a shape corresponding to the EV population curves shown in Figure 3.2. Offset gasoline vehicle costs provide the downswing previously described. There are four components of offset gasoline vehicle costs which can account for this downswing: incremental EV purchase costs, EV battery replacements costs, avoided O&M costs, and avoided gasoline fuel costs. Figure 3.23 reveals that EV purchase and battery replacement costs are the components which contribute to this downswing; other components achieve steady-state values after year 2005. In nominal terms, EV purchase and battery replacement costs reach steady-state values, but the effect of discounting to 1994 dollars explains the steady erosion shown in Figure 3.21.

Figure 3.21 shows that the Moderate Commuter Accent differs substantially in later years from the Moderate Fleet. This once again edifies the general result that the uses and types of EVs do make a difference! The difference in cost is explained by reduced power sector costs with the Moderate Commuter Accent. Recall the energy requirement differences between the Moderate Commuter Accent and the Moderate Fleet, as shown in Figure 3.1. The Moderate Commuter Accent requires less than half the energy (GWh) as the Moderate Fleet, and less additional capacity (MW), as shown in Table 3.1

Because of the speculative nature of expected EV costs, an uncertainty analysis is used to frame a possible *range* of cost impacts. As described previously, the uncertainty assumes three levels of cost impacts – low, medium, and high. The medium costs are used in the previously referenced figures. The cost uncertainties lever off of two components: incremental EV purchase costs and EV battery replacements costs. All other cost components remain the same across the three uncertainties.

Table 3.5 shows that the general trend for the previously described medium costs holds for both the low and high costs. In general, the costs are proportional to the number of EVs on the road. The Large Fleet is always roughly double the cost of the Moderate Fleet, a somewhat expected result as the Large Fleet has exactly twice as many EVs with the same use patterns. The Moderate Fleet has 15 times as many EVs on the road as the Small Fleet, but the cost impacts are consistently only eight times as high. The Moderate Commuter Accent consistently costs much less than its Moderate Fleet counterpart (20% to 75% less), showing that the uses and types of EVs do indeed make a difference. The range of costs for all programs is 230 to 14,258 million dollars on a cumulative 20 year basis. For the reference case - the Moderate Fleet - the range of costs is 1,813 to 6,966 million dollars. Such costs are difficult to gauge without a sense of cost-effectiveness, i.e., the tons reduced for the dollars spent.

In environmental policy analysis, cost-effectiveness comparisons can be made in numerous ways. By far, the most common means of comparing cost-effectiveness is by the "cost per ton" method. Unfortunately, this method is fraught with catastrophic misinterpretation, and the caveats must be delineated. The basic complication with the "cost per ton" approach is that the resulting values are averages, and averages are not very descriptive in isolation. For example, suppose that it is stated that the cost of adopting aggressive inspection and maintenance programs in Massachusetts vehicles is \$500/ton (1994\$) of NO_x reduced. Such a simple statement, though common, is left wanting. Over what timeframe does the figure apply – 1 month, 1 year, or 20 years? Over what quantity of tons does the figure apply – the first 1,000 tons, the first 20,000 tons, or all tons? What discount rate is used? Averages are convenient to use, but are very misleading. They do not adequately frame the variance that occurs for varying timeframes and quantities of pollution reduction. In policy formulation, knowledge of the potential variance – the potential financial risks – is critical. In addition, studies from multiple parties might all produce cost per ton figures which have the same units (\$/ton), but have very different assumptions about cost components or cash flow accounting. Unfortunately, once a figure is stated in the common units of dollars per ton (\$/ton), the varying assumptions are often neglected. The result is that cost per ton figures are compared which really have little common grounds for comparison. Rather than providing value, the simplified use of averages often misinforms.

With these qualifications in mind, cost-effectiveness comparisons on a cost per ton basis are attempted herein. Because the comparisons are only for EV options formulated in this study, all cost components and cost accounting methods are the same, i.e., the costs are directly comparable. Cost per ton figures are presented on a year-by-year basis, signifying annual averages. The variance within each year is unknown and might vary highly. This uncertainty is stated up front. Because year-by-year averages are presented, it is possible to get a rough idea of the variance through time for incrementally increasing levels of NO_x and ROG reductions.

Figure 3.24 shows the annual average cost per ton figures for NO_x reductions achieved via EVs. Nitrous oxide reductions for all fleet penetration options do not occur until the year 2004, so cost per ton figures prior to this year do not apply. The first salient characteristic of this graph is that the annual average cost per ton figures decrease rapidly through time. The first year of across the board NO_x reductions is very expensive, compared to later years. Because of the scale on the ordinate, it is difficult to observe the changes after year 2006. Table 3.6 shows the values for selected years. The values range from $64,000/ton - $36,000,000/ton in year 2004 to zero-$40,000/ton in year 2014. In this case, this zero cost per ton implies that the dollar savings from offset gasoline vehicles outweighs the increased power sector costs. For the reference Moderate Fleet, the costs range from $505,000/ton - $360,000/ton in the early start-up years to $14,000/ton - $40,000/ton in the final year. The second notable feature of the graph is the difference between EV penetration options. In the first two years of NO_x reductions, all EV penetration options vary from one another. However, by year 2006, the Moderate Commuter Accent option is once again lower than the other options – by approximately 50%! The other options, all commercial fleet dominated, track together for the remaining years. With a few exceptions, this holds true for all subsequent years across all three EV cost uncertainties.

Figure 3.25 shows the annual average cost per ton figures for ROG reductions achieved via EVs. Reactive organic gases reductions for all fleet penetration options begin immediately in the first year of EV introduction. The trend of decreasing cost per ton is the same as for NO_x. The same Moderate Commuter Accent trend also holds for the ROG, and the commercial fleet dominated options track fairly closely together. The values range from $22,000/ton - $1,500,000/ton in year 1998 to zero-$30,000/ton in year 2014. Once again, the zero cost per ton implies that the dollar savings from offset gasoline vehicles outweighs the increased power sector costs. For the reference Moderate Fleet, the costs range from $19,000/ton - $135,000/ton in the early start-up years to $10,000/ton - $28,000/ton in the final year. These cost per ton figures for NO_x and ROG reductions appear high, gauging roughly from ozone strategies documented in other studies. No conclusive comparison can be made, though, until cost assumptions in the other studies are compared. Compared to other NOx reduction strategies on stationary sources also modeled in this study (e.g., Phase II NOx controls on power plants), these EV figures are an order of a magnitude greater. Typical cost per ton figures for Phase II NOx controls range from $1,000/ton to $2,700/ton over the 20 year study period. In contrast, New England's energy efficiency programs provide cost per ton reductions of similar magnitude to EVs, but with even more tremendous year-to-year variance. Phase II controls and energy efficiency programs provide no ROG reductions (or CO reductions), though. Energy efficiency programs primarily provide CO_2 reductions. This mismatching of emissions across strategies makes direct cost per ton comparisons difficult.

The 20 year cumulative cost and emission impacts to New England are summarized in Table 3.8. In review, all EV penetration options incur positive additional costs to the region. The costs shown are conservative, in that no infrastructure costs are included. The emissions with across the board net reductions are NO_x, ROG, and CO. Both SO_2 and CO_2 increase in all EV cases, with one exception for CO_2 (the Moderate Commuter Accent option).

Figure 3.21: Total Cost Impacts to New England from Adopting EVs

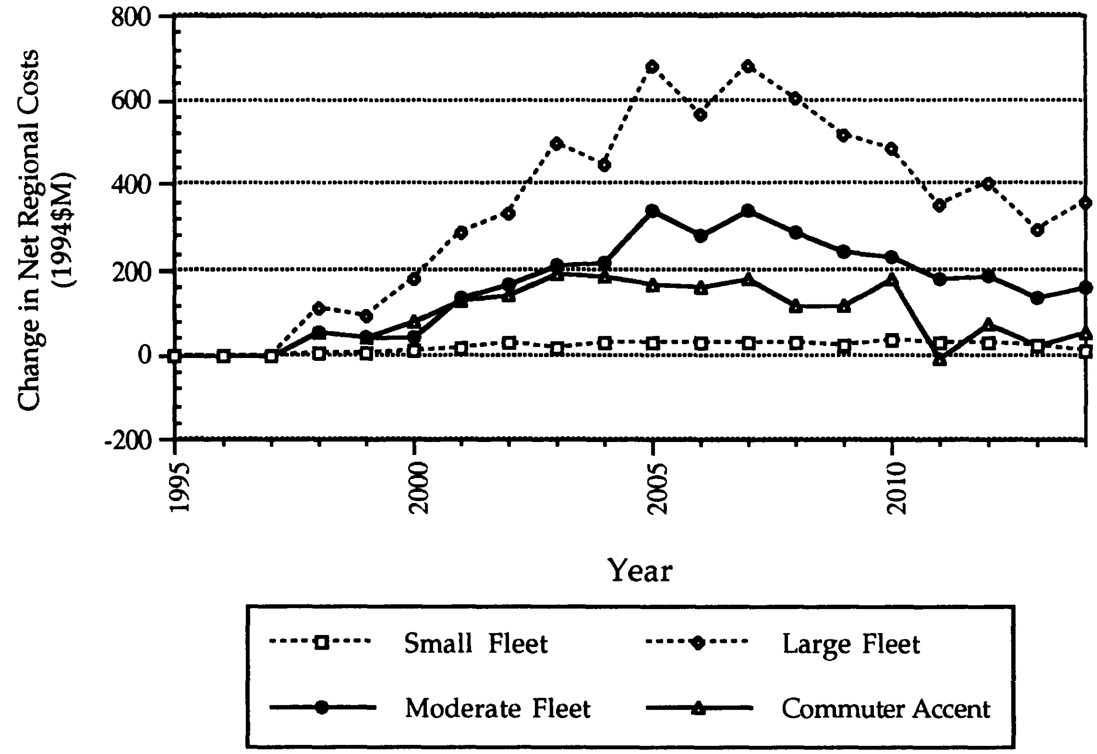


Figure 3.22: Breakdown of Cost Impacts (Moderate Fleet)

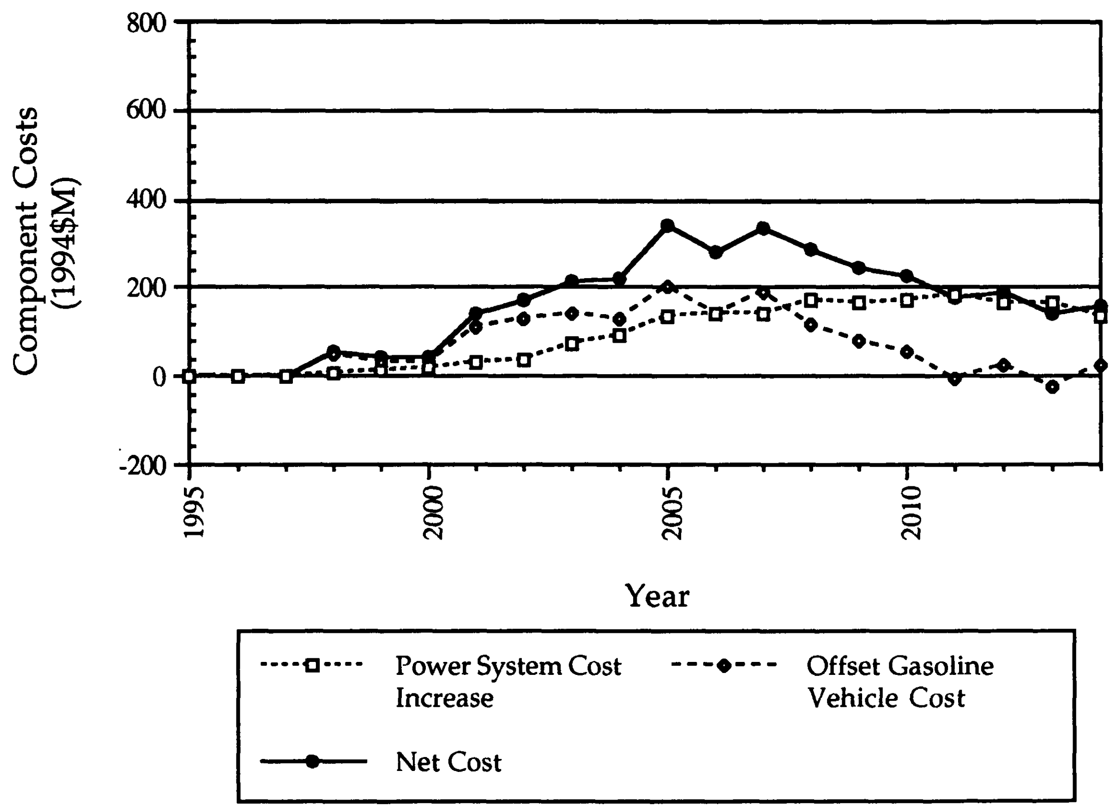


Figure 3.23: Components of Offset Gasoline Vehicle Costs (Moderate Fleet)

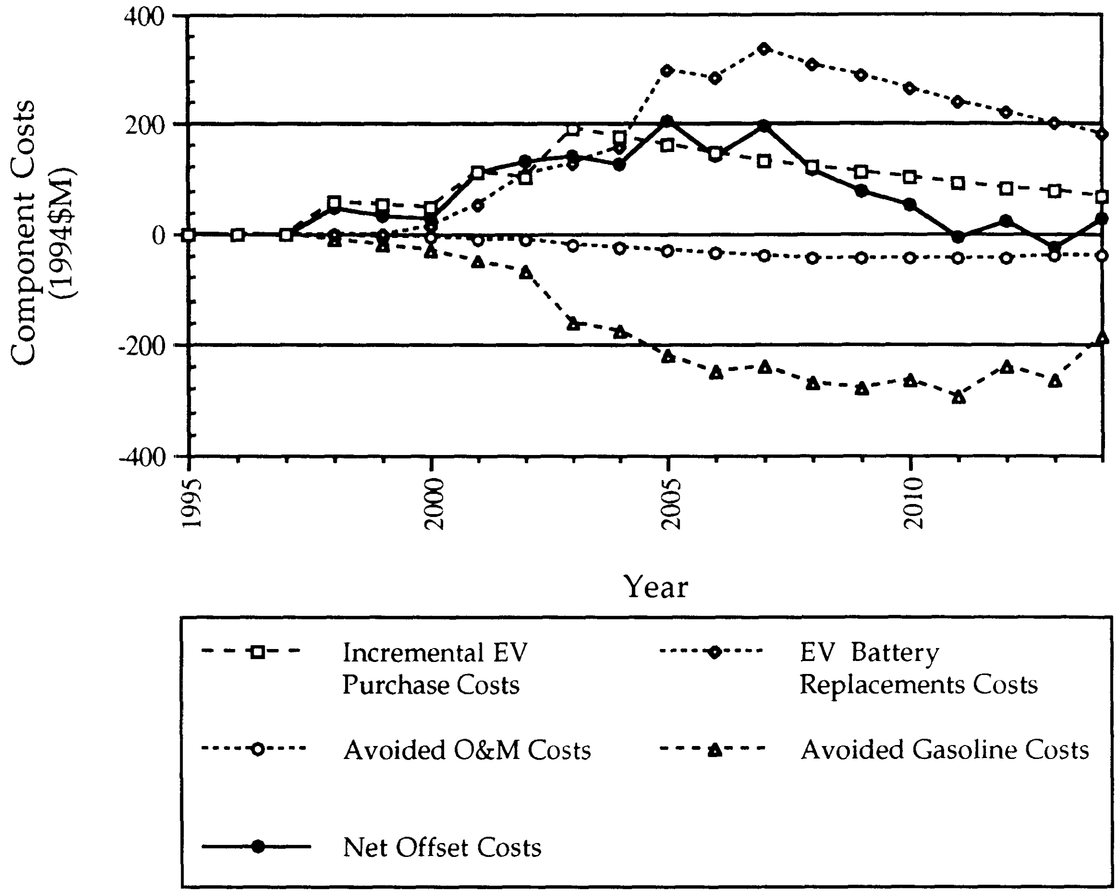


Table 3.5: EV Cost Uncertainties

	Net Regional EV Cost Impacts (NPV 1994$M)		
EV Population Option	Low Costs	Medium Costs	High Costs
No EVs	0	0	0
Small Fleet	230	390	792
Moderate Fleet	1,813	3,285	6,966
Large Fleet	3,952	6,897	14,258
Commuter Accent	426	1,899	5,580
	(20 Year Cumulative)		

Table 3.6: Annual Average Cost per Ton of NO_x Reduction

EV Population Option	Net Regional EV Cost Impacts Annual Average $/Ton (NPV 1994 1,000$)								
	2004			2010			2014		
	Low	Med.	High	Low	Med.	High	Low	Med.	High
Small Fleet	344	648	1,410	24	31	47	6	14	36
Moderate Fleet	505	1,384	3,582	23	36	67	14	21	40
Large Fleet	408	1,089	2,792	25	37	69	15	23	40
Commuter Accent	64	256	735	16	28	59	0	7	28

Table 3.7: Annual Average Cost per Ton of ROG Reduction

EV Population Option	Net Regional EV Cost Impacts Annual Average $/Ton (NPV 1994 1,000$)								
	2004			2010			2014		
	Low	Med.	High	Low	Med.	High	Low	Med.	High
Small Fleet	30	57	123	28	36	56	4	9	22
Moderate Fleet	19	52	135	15	23	42	10	15	28
Large Fleet	20	53	135	16	24	44	11	17	30
Commuter Accent	15	62	179	11	20	43	0	5	17

Table 3.8: 20 Year Cumulative Cost and Emission Impacts to New England

EV Population Option	EV Cost Impacts	Net Change in Emissions				
		NOx	ROG	SO2	CO2	CO
No EVs	0	0	0	0	0	0
Small Fleet	230 - 792	-7	-11	4	298	-72
Moderate Fleet	1,813 - 6,966	-52	-105	56	3,072	-654
Large Fleet	3,952 - 14,258	-105	-209	100	6,593	-1,309
Commuter Accent	426 - 5,580	-48	-89	16	-17,320	-427
	(1994$M)	(Thousand Tons)				

Figure 3.24: Average Cost per Ton of NO_x Reduction (Medium EV Costs)

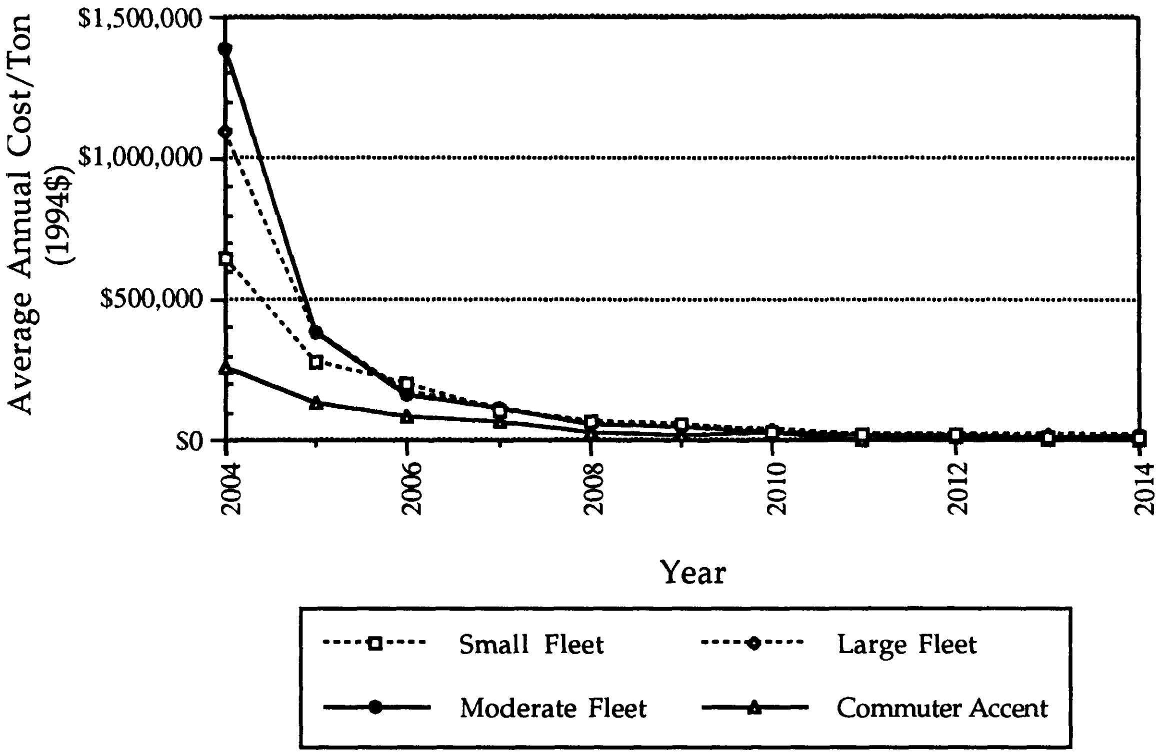
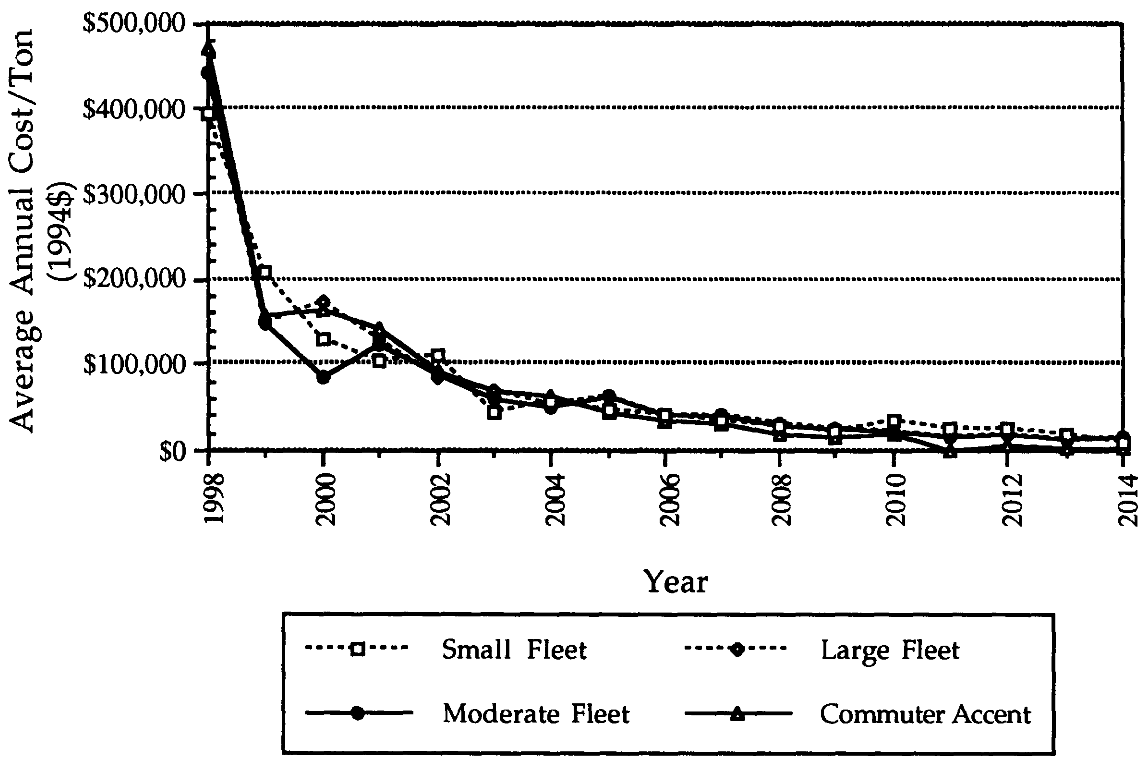


Figure 3.25: Annual Cost per Ton of ROG Reduction (Medium EV Costs)



∞ Chapter 4 ∞

IMPLICATIONS FOR POLICY

CONTEXT

Two states in New England have opted to adopt EVs, by exercising their legal right in the 1990 Clean Air Act Amendments to subscribe to the California LEV program for emission standards in lieu of the federal program. Massachusetts plans to phase-in EVs beginning in year 1998, while Maine's ruling contains a conditional trigger clause, which commits the state to EVs only in the case where a majority of other New England states have also agreed to pursue EVs. In the entire Northeast, 4 states have opted to adopt EVs (two with conditional trigger clauses). The Ozone Transport Commission has petitioned the EPA to grant the commission the authority to order the adoption of the LEV program, or standards and goals at least as rigorous as the this program, across the entire Ozone Transport Region. Under this initiative, EVs would become a part of every state's strategy for controlling ground-level ozone concentrations. A recent compromise made between the EPA, OTC, and the automobile manufacturers has granted the OTC the legal authority to adopt the LEV program, with the EV component being optional, rather than mandated, for individual states. However, some parties are not akin to this resolution, so the debates will surely continue. The results of this study may not be in time to influence the OTC's ultimate success, but they surely have useful implications for state's individual decisions whether or not to adopt EVs, and if adopted, what might be expected for New England. For those states already committed to the LEV program and to the adoption of EVs in 1998, the results of this study provide a more detailed understanding of the impacts which might occur and an awareness of the tradeoffs. Such understanding and awareness enables directed policy design, aimed at maximizing benefits (emission reductions) at minimum cost.

Because of the distinct region-wide approach used in this study for New England, the implications must be interpreted only within this context. The implications are most applicable to New England region-wide policy regarding EVs. Detailed emission tradeoffs for individual states will likely appear entirely different, as power plants with varying emission characteristics and dissimilar dispatch loading-orders are unevenly distributed throughout New England. The results of the study are useful for scoping out the magnitude and time-horizon of the potential impacts, and for understanding the subtle nuances relevant to policy decisions.

It is critical to recall that the results of this study are produced by a model (a collection of models in this case), and the results of any model are only as valid as the assumptions used within the model. In fact, the essence of a model is the assumptions – all other components assist only in the model's execution, the input and output interfaces, the mathematical manipulations, etc. Because of the extent of the arduous work and scientific backbone put into models, they are often taken for what they are not – tools which provide definitive answers. Models are only useful for testing hypothesis and generating new ones, but not for any notion of finding "the truth." When contemplating the future impacts of a policy directive, models provide a valuable service by enabling the visualization of potential results, the scoping-out of boundaries, and the exploration of uncertainties. The models used in this study, especially those of the electric power sector (EGEAS) and mobile source emission rates (MOBILE5a), are some of the best available in the industry. The other models, such as the vehicle usage models and EV load impacts models, were developed with careful attention to detail and were subject to peer review. Indeed, one of the motivations for this study was to improve on the previous models (including mental models) used to assess EVs. However, these caveats about models must always be kept in mind when extending model results to implication for policy.

First, implications for EV policy are discussed regarding both ground-level ozone and other air pollution concerns in New England. Second, generalized policy implications applicable to the evaluation of any set of strategies are presented.

ELECTRIC VEHICLES AS A GROUND-LEVEL OZONE REDUCTION STRATEGY

Taking net emission impacts into account, EVs are effective for reducing the ozone precursor emissions, NO_x and ROG. Emissions of NO_x are not reduced, however, until a sufficiently large number of EVs are on the road, many years after EVs are originally introduced. There will be no NO_x contribution to ozone mitigation until at least seven years after the program start date. Prior to that year, net NO_x emissions are increased, though minimally. Thus, delays in the program start date beyond the year 1998 for the sake of accomplishing other goals will only further delay the NO_x reductions (assuming the evolution of the electric power system as referenced in this study). If ozone reductions are sought in the near term, mobile source policies should not count on EV contributions. The net reductions which can be expected in the latter years are approximately equal to a three-fourths attainment of the levels had there been no electric power emission increases in the first place with EVs. Put another way, the net NO_x reductions are three-fourths of the emission reductions achieved by entirely eliminating the mobile source emissions.

Reactive organic gases, on the other hand, are entirely eliminated from the outset, as there are negligible electric power system emissions of ROG. As New England's ozone levels on the whole are considered to be NO_x limited, these reductions in the early years will not serve to reduce regional ozone levels. Not until NO_x emissions are also reduced (year 2005), are region-wide ozone reductions likely. However, as qualified in Chapter 1, these ROG reductions in the early years may help reduce local ozone levels in large densely populated cities. Such cases will be the exception, though, rather than the rule. It is important to realize that while NO_x and ROG emission benefits are realized with EVs, it is difficult to gauge the proportionality of the resulting effects on real-time ozone concentrations during the peak season. As stated in Chapter 1, this study only speaks to emissions levels, not to actual air quality.

The EV sensitivity studies for precursor emissions also indicate implications for ground-level ozone policies. For example, it was found that the adoption of EVs does not provide additional justification for pursuing stricter NO_x

controls on power plants, e.g., Phase II controls such as SNCR. Such controls may be attractive in and of themselves for the electric power sector, but the fact that EVs induce a transfer of all mobile NO_x emissions to the electric power sector does not provide any further justification for the stricter controls (on an emissions basis). This may appear somewhat counter-intuitive. It was also found that EV NO_x emission benefits are insensitive to electric power sector fuel cost uncertainties, as tested with a high-priced natural gas fuel uncertainty. Such fuel cost uncertainties typically influence the results of stationary source analyses, but the net NO_x reductions for EVs are not influenced.

Under the cost assumptions used in this study, it was found that EVs pose additional costs to the New England region, depending on the assumed EV penetration level. Costs increase in magnitude for greater numbers of EVs, but the cost increases are not directly proportional to the quantities of EVs. Using a range of cost uncertainties from low to high, it was found that the costs for assumed penetration levels may vary by as much as a factor of three. On an annual per ton basis (a basis which must be used with delicacy as qualified in Chapter 3), the costs are exorbitant in the early years and exhibit significant near-exponential reductions as time progresses. Until the year 2006, the cost per ton figures are at least twice as high as the steady-state values obtained in later years. In the very long run, the last four years of the study period, the electric power sector costs constitute nearly all of the EV costs to the region. Mobile source cost components balance essentially to zero (under the assumed discount rate of 10%). If it is desirable to design policies which will allow EVs to be more cost competitive with conventional vehicles in interim years, the components to target are the incremental EV purchase costs and the battery replacement costs. The former has the highest positive cost component to consumers, until midway through the study period where battery replacement costs dominate for consumers.

To the extent that policy directives can direct the number of EVs adopted (or alternatively stated, to the extent that EV sales exceed or undercut mandated levels), the amount of reductions in both NO_x and ROG emissions are roughly proportional to the quantity of EVs on the road. Twice the level of sales as required in the California LEV program results in approximately twice the emission reductions for NO_x and ROG.

To the extent that policy directives can direct the type and use of EVs (or alternatively stated, to the extent that expected EV uses might differ from those which are expected), the amount of net reductions in both NO_x and ROG emissions are unchanged. Whether primarily for commercial fleet purposes or domestic commuter use, the reductions are generally the same. Such generalizations do not hold for other pollutants. This result is significant, as other attributes vary substantially depending on the type and use of EVs. The type and use of EVs is found to make a difference in the NO_x sensitivity studies. Electric vehicles used primarily for domestic commuter purposes were less sensitive to power plant natural gas fuel prices (recall that all options were generally not sensitive to this, so it is only a question of degree). The NO_x reductions for the EVs used for the same end-use are also less sensitive to stricter NO_x controls. Most dramatic are the cost impacts, subject to the cost assumptions of this study. EVs used primarily for domestic commuter use, as opposed to commercial fleet purposes, have significantly reduced cost impacts to the New England region. The former has costs 25-75% less in some years – the same number of EVs, but different applications! The range of savings depends on EV cost uncertainties, but persistent reductions are achieved with domestic commuter EVs across the range of uncertainty modeled in this study. One aspect of this savings is the substantially reduced electric load requirements with domestic commuter EVs. Energy (GWh) sales per year and additional power generation capacity over the 20-year study period (via new power plants) are both only 40% of those required for EVs used primarily in commercial fleet applications.

It is important to appreciate the possible explanations for these differences between domestic and commercial applications of EVs. As modeled in this study, the factors which influence disparate load impacts between the Moderate Fleet and the Moderate Commuter Accent (modeled exclusively as passenger cars) are: 1) the superior motive energy efficiency of passenger cars, 2) the more limited usage of domestic vehicles, 3) the smaller electric demand (kW) impacts for recharging passenger cars, and 4) the higher off-peak charging allocation for domestic vehicles. The point is that a single factor cannot be pointed to as the explanation. The four factors collectively contribute to the differences in emissions/cost performance. Without sensitivity studies which characterize the influence of each of the factors, a policy initiative focusing on only one of them is misdirected. For example, if it is concluded from these results that off-peak recharging will provide improved cost/emission performance, and that policy initiatives should be taken which heavily incent consumers to recharge only at night, then a misinterpretation has indeed been made. The policy implications for EV type and end-use application are, therefore, somewhat restricted in this study and provide motivation for further sensitivity studies. Such studies are expected to be completed in 1995 by MIT's Analysis Group for Regional Electricity Alternatives.

Even in the absence of complete understanding of the individual levers, the general implication still emerges. If policy design can be driven to influence the end-use applications of EVs, there is great incentive to target domestic commuter EVs. This implication contrasts to the current predisposition towards using EVs primarily in commercial fleets. There are solid reasons for this disposition based on operational convenience (central fueling stations, central repair facilities, somewhat fixed routes, high proportions in the densest urban areas where ozone levels are sometimes the worst, etc.) Perhaps this disposition needs to be challenged? Perhaps some of the barriers to convenient EV operations in the domestic sector can be overcome with some innovative thinking and directed strategies? Based on the results of this study, these questions must be addressed.

ELECTRIC VEHICLE EFFECTS ON OTHER POLLUTANTS OF CONCERN

Viewed purely as a ground-level ozone reduction strategy, EVs appear attractive on an emissions basis. Compared to having an equivalent number of gasoline vehicles on the road, EVs provide considerable reductions in NO_x and ROG emissions levels. However, when considering the other pollutants which are impacted through the adoption of EVs – pollutants which figure prominently in other air quality problems – the results are less enticing. Albeit that this study is focused on ground-level ozone, it would be remiss in any policy assessment to neglect the impacts on other chemical species if they can be quantified. The following discussion summarizes the results for CO_2, SO_2, and CO, and some implications for policy.

For CO_2, the net emission impacts are positive with the adoption of EVs. Offset mobile source emissions do not exceed increased emissions from the electric power sector. In many years the electric power sector emissions are 120% those of the offset mobile source emissions, and as high as 150% in early years. The only exception for this is the option where EVs are primarily used for domestic commuting purposes. In stark contrast to all cases where EVs are used principally for commercial fleet purposes, the domestic commuter EVs achieve CO_2 emission reductions after year 2001; and these reductions grow steadily throughout the study period. Eventually, domestic commuter EVs attain 60% of the tailpipe emission eliminations, had there been no electric power sector increases in the first place, i.e., 60% of the full mobile source reductions are realized. The main reason for this result, once again, is the unique impact of the EV electric load on New England's power system. Only half of the power plant emissions occur with domestic commuter EVs. as compared to the emissions with commercial fleets. This finding gives even more incentive for designing policies which promote EVs to be principally used in the domestic sector, rather than the commercial sector as fleet vehicles. In this case, the downside of not directing EVs toward domestic purposes is assured increases in net CO_2 emissions.

For SO_2, the same trend is observed and even exacerbated, and there are no exceptions this time for EVs' end-uses or fleet sizes. The net SO_2 emission levels resulting from the adoption of EVs are higher than if no EVs had been adopted. For many years, the net emission impact is 10-15 times as large (1,000-1,500%) as all the eliminated tailpipe emissions, reaching 20 times in the early years. Electric vehicles used for domestic commuter vehicles provide a good hedge against the large net impacts, with net emission levels of 5-8 times as large. These trends gradually decrease through time, but the SO_2 impacts remain large. Across the board, EVs have a great effect on SO_2 levels, compared to the SO_2 levels originally emitted from the mobile sources. Mobile sources may not emit much SO_2 when fueled by gasoline, but they emit substantially more when fueled by electricity.

For CO, the trends are very similar to those observed for ROG. Because the electric power sector is assumed to emit negligible levels of CO, approximately 100% of the eliminated tailpipe emissions are realized. Thus, electric vehicles are a very effective CO reduction strategy. For the same quantity of EVs, those used for commercial fleet purposes provide slightly greater benefits than those used for domestic commuter uses.

The implications of these results for policy is that a thoughtful consideration of the adoption of EVs requires priorities to be set. Is the potential for ozone mitigation more important than increases in global climate change and acid rain pollutants? If so, to what extent? Where is the line drawn? How much does society value a relative ton of NO_x reduction versus SO_2? Does the answer depend on where you live? Does that valuation change over time? If EVs are adopted in New England, can measures be taken which minimize these negative impacts via a planned allocation of EVs primarily used for domestic commuting purposes? How should efforts be allocated among the domestic and commercial sectors to reduce operational constraints on EVs? Do these results provide motivation for coordinating this mobile source strategy with electric power sector planning? Can electric power sector strategies (clean generation technologies, energy efficiency, increased extra-region purchases, etc.) be designed for New England which provide a hedge against unfavorable EV emissions and cost impacts? Is cross-sectoral planning even a worthwhile endeavor, or should each sector pursue its own strategies and hope for the best? When expanding the scope beyond that of just ground-level ozone, the evaluation of EVs in New England is a much more challenging task.

Implications for Policy, in the General Sense

The experience gained from the process involved in this study, including both the initial formulation and then the analysis of results, allows one to infer yet other implications for policy. Such implications are useful as they are more generalized in nature and potentially applicable to the evaluation of any policy. These implications are by no means unique to this study, but they are effectively demonstrated here. They are normative by design. Though it often tempting to interject implications for policy across a very broad range, it is only reasonable to limit the range to those which can be directly inferred and supported by the study at hand. Thus, the author's experience in other aspects of energy and environmental policy (economics, regulation theory, political economy, and law) surely enables more informed implications, but will not serve as the focus here. The insertion of implications from such arenas would be interesting (and necessary for a complete policy analysis), but would not be adequately supported by the experience gained in this particular study. The general implications for policy which can be supported from this study are presented below in sequential order, with a discussion following each point.

Strategies must be evaluated in the largest context possible, within the limits of available resources and expertise.

This study of one strategy adds value beyond the existing knowledge base by expanding the previous scope of analysis. The emissions assessment includes the impacts in two sectors of the economy, rather just the transportation sector. Furthermore, multiple emissions are addressed, rather than just those directly related to ozone formation. Cost is also incorporated, allowing cost-effectiveness comparisons between EV options. The presence of uncertainty, e.g., in fuel costs, EV costs, and mobile source emission rates, is also acknowledged and incorporated. Such expansion of context enables a more informed scrutiny of strategy performance for two reasons: 1) comparisons can be made across more attributes of interest, and 2) the model comes that much closer to simulating the range of dynamics actually involved. An example of the latter is the accounting for cost and emissions impacts in two sectors. It was originally intended to also address upstream emissions, but this expansion was beyond the resources of the project. Enough information was gathered so that an attempt could have been made, but it would have lacked rigor and credibility. There are resource and knowledge limits to the extent that the context can be stretched, but attempts should always be made to expand the context as much as possible. It is tempting to expend all efforts on only one or two dimensions of the issue, but the results are left wanting. This implication is the justification for joint policy research programs, as it is impossible for any individual person or group to address or conceive of the full context of any given strategy.

Tradeoffs must be accepted as inevitable. The challenge is to identify and understand them sufficiently so that, first, evaluations are well-informed, and secondly (but just as important), strategy options can be revised to minimize particular tradeoffs or make strategies more robust.

The adoption of EVs in New England reduces ozone precursor emissions, but increases global climate change and acid rain emissions, as well as net costs to the region. The implication for policy is that tradeoffs are not unintended side effects, they are facts. Because a strategy is often motivated by a desired end result, e.g., EVs for ozone reductions and energy efficiency for carbon dioxide and cost reductions, it is natural to assess all countervailing results as unplanned and distressingly inconvenient. Policy makers must shed this mindset. The evaluation of strategies must anticipate tradeoffs and allow for a process of stepping through the them, as is done in Chapter 3. In this process, for example, it was learned that each EV penetration option exhibits unique tradeoffs, but that the tradeoffs are minimized and less sensitive to future uncertainties (more robust) for one of these options. Further, this suggests that the next look should be at that particular option, to understand the levers which enable this. Based upon the new insights, revised strategies can then be advanced which have even further improved performance.

Strategies must be evaluated on a sufficiently long time scale, else full costs and benefits, as well as year to year variation, are masked and likely to be misinterpreted.

If a 5 year planning horizon had been assumed for this study, as is typical in business practice, the core results would have been substantially different. Key conclusions would have been reversed, and the apparent trends inferred from such a study, used to imply anticipated future performance beyond the 5 year period, would have characteristically different appearances. Alternatively, if a snap-shot had been taken of the expected EV impacts at 20 years out, the results again would have been substantially changed, as well as the general conclusions and the assumptions of what took place in the intervening years. Time scale is crucial. Faced with data and time constraints, is often erroneously slighted in strategy evaluations - thus the main reasons for a proliferation of "back of the envelope" evaluations used to fuel debates. No one fixed duration is required of evaluations; it obviously depends on the situation. The time scale should be chosen so that the initial, transitional, and maturation effects of the strategy, and the systems it impacts, can be fully observed. Modeling the California EV penetration schedule, with its year to year variations, requires that many years be simulated. Also supporting at least a 10 time scale are the expected changes in mobile source emission rates, EV motive efficiencies, EV costs, New England electric load growth, fuel prices, and electric power supply. In the case of this study, any emission benefits of EVs are not realized until many years after their initial introduction, so a short time scale would be misleading (or perhaps an assertion that such future benefits have zero value today – equivalent to a very large discount rate).

The presence of large future uncertainties does not disqualify strategy evaluations or the rationale for doing them. On the contrary, it justifies such evaluations but drives the design of the study and frames the interpretation of the results.

The future is unknown. Decisions are made today. Today's decisions influence tomorrow's outcomes. If this was not the case, there would be no need for the concept of preparedness or strategy, and, likewise, many professions would no longer exist. Some things are known better than others. The place for discernment and experience is in the decisions of which uncertain factors have the widest possible range of values and are also the most likely to influence outcomes. With electric vehicles, vehicle costs and motive efficiencies are two highly uncertain parameters which meet these criteria. In the study of electric power sector strategies, load growth and fuel prices are two such uncertain factors. Though these parameters are entirely unknown, it is reasonable to evaluate strategies over a range of values to gauge responsiveness to the unknown parameter. It is possible (and popular) to assign probabilities to each estimate and calculate an "expected value," but such an approach is circuitous. The parameter is uncertain in the first place, so assigning a probability distribution is now claiming that it is not. Which is it? It is best to leave it to individual stakeholders to use their own best judgment in assigning probabilities.

Multiple strategies should be compared in any evaluation, providing relative comparisons and a common base for assumptions.

One of the key problems for decision makers who influence policy is getting good information about the performance of competing strategies. Often, studies are conducted which only attack one strategy or a very limited subset. With information packaged this way, the most convenient response is to compare results from studies. This is especially problematic in comparing multiple strategies, but can be troublesome even in evaluating a single strategy. In the former case, the comparisons can be invalid, as entirely different assumptions and analysis approaches are used. To best compare strategies, a common base is needed – for example, one that accomplishes simple things like applying the same discount rate on future cash flows, or assuming the same future growth in vehicle miles traveled, or sharing a common estimate of the current starting population of fleet vehicles in New England, etc. The inevitability of tradeoffs provides additional rationale for the incorporation of multiple strategies in a single evaluation study. Tradeoff analysis is debunk unless the underlying assumptions are consistent. Of course, as long as the details are tracked when reading various studies, comparisons of multiple studies will be elucidating. If not tracked (as is more likely), comparisons will likely be misleading. This EV study accomplished this to a certain extent, as multiple EV penetration levels and cost assumptions were compared, but more strategies should be incorporated by AGREA in the future.

Sharing ownership in the design and assumptions is a key ingredient for building ex post credibility and achieving influence with a strategy evaluation.

If decision makers who influence policy cannot understand the basics of the strategy evaluation or have are no familiarity with them, they are less likely to believe in them. This translates into common experience of spending an entire presentation describing and justifying in retrospect the assumptions of the study, without ever getting to the results or implications. In this EV study, conscious efforts were made to build consensus among stakeholders as the project developed. An issues task force was held for a subgroup of key stakeholders, and mailings were sent periodically to the broader audience to inform them of progress. Background assumptions and methodology will, and should always be discussed, but results and implications will go much farther in the influencing of actual policy decisions if ownership by the audience is established along the way.

Mechanisms for incorporating feedback must be explicitly designed into policies at the outset. Flexibility to adapt to changing conditions is essential.

The focus of this study is on policy options, not policy mechanisms. Thus, implications for market-based (or performance-based) regulation versus traditional technology-forcing regulation are not directly supported by this study. What is directly supported is that the cost and emissions benefits of EVs will require many years to accrue and are dependent on long-term assumptions of offset emission rates from gasoline vehicles and the supply mix/operation of the electric power sector. Undoubtedly, the passing of time will bring changes which will render today's assumptions about such matters as naive in retrospect. For example, the electric power sector in 10 years may not operate according to the current method of centralized economic dispatch? The future model might be an interconnected, but highly decentralized electricity market driven primarily by bilateral transactions and only residually by centralized coordinating functions? Emission rates from gasoline vehicles could vastly improve owing to technological innovation or could remain only at current levels owing to the inertia of the status quo? No one knows. The point is that policy design should account for our ignorance and provide options for adapting to change. This does not mean that firm directives cannot be taken, but that they should not be allowed to get the best of us. Re-regulation can be costly and inequitable. Allow for periodical feedback into program requirements, establish protocols for continually monitoring results, amortize programs over shorter time periods, utilize the forces of market competition where possible, etc.

∞ Chapter 5 ∞

DIRECTION FOR FURTHER RESEARCH

Based on the findings of this study, there are a number of areas which require further research to enable more informed policy decisions. Though the crux of difficult policy decisions is accounting for uncertainty, there are a number of questions which can be addressed in the short- and mid-term. The research initiatives required to do this are listed below, though not in any intended order of importance.

EXPAND THE SCOPE OF QUANTIFYING EMISSION IMPACTS AS FAR AS ANALYTICALLY POSSIBLE.

It is common in air pollution policy discussions to neglect upstream emissions (full fuel cycle emissions), and these emissions are likely very telling when quantifying emission levels for an entire region. The best justification for neglecting upstream emission is the difficulty found in estimating them. Regardless, there has been some pioneering research in this area, as referenced in Chapter 2, and reasonable attempts can be made starting from these sources. It is critical that full accounting be made for both sectors, however, including the upstream emissions for the transportation sector and the electric power sector. Research on New England's upstream emissions would provide meaningful information for the evaluation of any air pollution strategy, whether the targeted problem is ozone or air toxics, so there is tremendous justification for such research.

ADDRESS OTHER IMPORTANT ELECTRIC VEHICLE OPTIONS AND UNCERTAINTIES.

There are many EV options and uncertainties which should be rigorously explored, in addition to those incorporated in this study. Of primary interest will be the changes in New England's electric power sector impacts (both cost and emissions) when varying fractions of EV loads are distributed throughout the course of the day. This study's assumed distributions indicated an off-peak emphasis, but with some on-peak impacts. This approach was advanced as a likely distribution, even in the presence of rate signals and incentives to charge in the off-peak hours. Two additional and more extreme distributions would be informative. The first is the extreme case where nearly all recharging takes place during the off-peak hours. This would be provide a sense of the relative incremental impacts, which may or may not provide motivation for policies aimed at severely limiting daytime recharging. The second case is very high on-peak recharging, to provide a worst case extreme. The combination of these end points would effectively define a range of potential impacts. To further explore the range of these impacts, additional EV efficiency improvement uncertainties should be hypothesized. This study assumed one trajectory with only moderate improvement over 20 years. This trajectory is no more probable than either a worse or much more aggressive assumption of technology progression. These extremes should be explored, in combination with the hour-of-day distribution impacts. These options should also be explored in the context of the EV end-use and type. This would allow an identification of the relative influence of the four factors described in Chapter 4 which distinguish domestic and commercial EV applications.

DEVELOP A METHODOLOGY TO ACCOUNT FOR INFRASTRUCTURE COSTS.

Another important research item should be the design of a methodology for estimating infrastructure costs. It is expected that the regional cost impacts cited in this study are largely understated due to the exclusion of this item. A starting point would be understanding today's infrastructure for conventional vehicles and then comparing this, on a point-by-point basis, to the differences and similarities reasonably likely for EVs. Of course, any estimates of infrastructure costs would have to account for varying penetration levels and end-uses of EVs. Any future detailed emission evaluations should examine these options and uncertainties. The MIT AGREA team is well-equipped to address these improvements for New England in the short term.

SUGGEST AND STUDY MEANS FOR TARGETING ELECTRIC VEHICLE NICHES WHICH ARE MORE EFFECTIVE THAN OTHERS.

The findings of this study reveal that it is useful to research and propose methods by which specific EV niches can be targeted. As found here, domestic commuter applications for EVs offer superior emission and cost impacts compared to commercial fleet applications, due primarily to the different impacts to the electric power sector. The first step of such research is the identification of the barriers that would limit the higher EV penetrations for the desired end-use. Such an assessment includes considerations to consumer costs, operational constraints (recharging stations in homes, recharging durations, ease of maintenance, limited driving range, etc.), and consumer needs (a profile of the domestic market most likely to adopt EVs – age, family arrangement, distance to work, profession, income, etc.). On the reverse side, it is necessary to address the factors which make it attractive for any non-targeted end-uses to adopt EVs. These end-uses compete with the targeted end-use and they could, potentially, need to receive a disincentive.

The second step is the suggestion of various methods for overcoming the barriers, taking into account the impacts to various sectors of the economy and the ease of implementation and verification. The goal is to provide equity, with those reaping the greatest benefits sharing in the greatest portions of the costs; or put another way, with those taking the greatest risks being in a position to be rewarded the most. This goal appears impossible at the outset, as ground-level ozone is a pervasive problem and clean air is a classic public good, making the tracking of benefits or property rights an intractable task. Even if the air quality benefits are societal by nature, some risks and rewards can be aligned. For example, if EV manufacturers can gain market share and eventually achieve profits, then they have a stake in the costs of overcoming the barriers. Similarly, if electric utilities can become more efficient by achieving higher system load factors with minimal capacity additions, they too have a stake in the costs (especially true in the continuing transition of increased competition between electricity suppliers). This kind of policy and business research is by no means premature if EVs will be adopted in New England within the next decade, or as soon as 1998.

COMPARE ELECTRIC VEHICLES TO OTHER MOBILE SOURCE STRATEGIES.

For a legitimate evaluation in New England, EVs must be compared to other mobile source strategies. Mobile source pollution is an entirely different beast than stationary source pollution, and the most effective policy mechanisms account for the differences. Indeed, air pollution legislation in the U.S. has generally recognized the differences and set separate goals and mechanisms for each sector. However, it remains tempting to compare EVs on a cost-effectiveness basis to stationary source strategies because EVs have cross-sectoral impacts and because detailed analyses of these electric power sector impacts, such as this one, will likely be completed by those who have expertise in the electric power sector, but not on mobile sources. It is valid that if EVs are promoted, the evaluation of electric power sector strategies should account for this cross-sectoral energy, emissions, and cost shifting, but strategies *between* sectors should not be compared. The results of this study suggest that coordinated cross-sectoral planning is worthy of future study – to determine if some electric power sector strategies might provide a hedge against unfavorable EV emission and cost impacts.

Even within the category of mobile sources, however, EVs must be compared to other strategies with extreme caution. Each of the probable impacts must be separately delineated along horizons of cost, emissions, location, time, implementation, verification, impacts to each stakeholder, etc. for each strategy, first! Only then can strategies be compared side by side. In most cases, information constraints and large future uncertainties may preclude a full delineation of impacts, but this mental model has merits when retained as a goal. It provides an informed appreciation for the differences between strategies and policy mechanisms. Such comparisons should be made with EVs and other alternatively fueled vehicles (compressed natural gas, ethanol, methanol, reformulate, hybrid internal combustion), cleaner gasoline vehicles (e.g., LEVs and ULEVs under the California program), and more aggressive inspection and maintenance programs.

CONSIDER AND EXAMINE ALTERNATIVE POLICY MECHANISMS FOR MEETING ENVIRONMENTAL GOALS.

This study made no attempt at the evaluation of the broad host of policy mechanisms which might be employed to reduce ground level ozone. The EV segment of the California LEV program is technology forcing by design. This has never been the approach favored by the automobile industry, even though it has proved itself capable of getting some results in the past, though sometimes costly. Can EVs come to the market faster and less expensively under different regulatory schemes – schemes which do not pit the automobile industry against regulators and environmentalists? Perhaps the automobile industry could be given broad NO_x and ROG reduction goals for nonattainment areas (a performance standard) and then be allowed the discretion and flexibility to create their own solutions to mobile source pollution? The accelerated development of EVs might be a result, or the result may merely be a transfer of funds directly from the automobile manufacturers to consumers via old vehicle buyback programs. Perhaps a scheme of NO_x tradable permits which can be issued to the manufacturers could be employed? The options are endless, though such casual suggestions are admittedly unexamined. This EV study was framed on a "what if" basis, assuming specified EV penetration levels, applications, and costs, so that the range and type of impacts could be better understood. Policy mechanisms should be studied which model these parameters as a function of the particular mechanisms employed.

DEVELOP METHODS TO ACCOUNT FOR THE CHANGES TAKING PLACE IN THE STRUCTURE OF THE ELECTRIC POWER INDUSTRY – CHANGES WHICH MAY INFLUENCE ESTIMATES OF EMISSIONS AND COST IMPACTS.

The electric power sector is currently undergoing unprecedented deregulation, with the traditional vertically integrated monopoly structure being challenged by increasing demands for unbundled commodity-style competition and expanded customer choice. There is a prevailing sense that the rules of the game governing the relationships between suppliers, transmitters, distributors, and final consumers of electricity are all up for grabs. By default, the role of environmental planning has taken a distant back seat to the broader industry structure issues. There is a sense that there is "too much on the plate" already, let alone attempting to hypothesize about effective environmental approaches for the transitioning industry. We can only be overwhelmed by so much at once – one step at a time. In the same breath, it would be disastrous to resolve an industry structure which makes future environmental compliance even more difficult and costly to achieve. In a sense, the current transition is an opportunity to establish an innovative industry structure which expands the options available for compliance and puts the market based principles driving the reform at work for the environment (rather than at odds with the environment). Due to the impending reforms, any previously held notions about how the electric power sector operates and how load-modifying strategies (EVs, energy efficiency, renewables) affect power sector emissions and cost must be revisited. Indeed, even the foundational assumptions employed in this study, based on a power pool's centralized economic dispatch, are likely to be only partially represented in the future industry. The challenge is to refrain from throwing our hands in the air and chucking previous methods. We need to build upon what we have learned, and suggest alterations to our expensive models which can be used to explore ozone reduction strategies in the new industry. Multiple methods must be advanced, just as multiple methods are being proposed for the economics of the new industry structure. This is easier said than done, but this is an era for pioneers.

LINK AND COORDINATE RESEARCH EFFORTS TO ADDRESS ACTUAL AIR QUALITY.

The final and, perhaps, the most important area for further research has to do with actual air quality. Even though EVs reduce ozone precursor emissions, how much will actual ozone concentrations be influenced during the New England peak-ozone season? Which locations will experience the impacts? We must not lose sight of our original goal – improved air quality. Will upwind states dictate Boston's air quality? Will Massachusett's emissions dictate Maine's air quality? If so, to what extent? As cited in Chapter 1, much has been accomplished to better understand the science behind New England's ozone problem, but the gaps in information are still very large. Many gaps can be filled-in partially or adequately in the mid-term by research efforts which link strategy emissions/cost models (employed here) with air chemistry models (employed elsewhere), both with geographical considerations taken into account.

∞ Chapter 6 ∞

CONCLUSION

In taking final stock, it is helpful to return to the original intentions of this study. The hypothesis, stated in the form of a thesis argument at the outset of Chapter 1, was as following:

> "... evaluations of environmental strategies often employ simplistic, even superficial, methods and that an approach which incorporates the question of interest into the structure of the analysis, builds on fundamental engineering and economic precepts from the bottom-up, and accounts for potential effects on multiple polluting mediums, is much more elucidating for understanding the dynamics of a strategy, especially in regards to tradeoffs, uncertainties, and effects over time."

This hypothesis has been confirmed, with the electric vehicle used as a test case in the evaluation of an environmental strategy. The presentation of the results (Chapter 3) describes a wide range of dynamics which dictate the pros and cons of this strategy. Such dynamics are often not visible in other analysis approaches. Chapter 4 further reinforces the hypothesis with an extension of the results and dynamics of Chapter 3 into 1) policy implications specific to EVs, and 2) suggestions of generalized guidelines to improve any future evaluations of environmental strategies.

Because curiosity about a mitigation strategy for ground-level ozone was a primary motivation for this study, the remainder of this Chapter is used to summarizes the main findings regarding EVs. These findings are subject to the assumptions and constraints described in Chapter 2 and the Appendix.

Even accounting for the emissions produced by the electric power sector, the adoption of EVs will eventually reduce ground-level ozone precursor emissions (NO_x and ROG) in New England.

This general result is insensitive to several future uncertainties: the presence of stationary source CAAA Phase II NO_x levels, the suspected underprediction of mobile source emission rates due to off-cycle emissions, and the potential fuel price increase (natural gas) for the electric power sector which changes the dispatch order of New England's power plants. There is an important time dynamic involved, as net NO_x emissions increase in the early years and do not decrease until several years later. For EVs adopted in the year 1998, net NO_x reductions are not achieved until year the year 2005. For a fleet composition most likely to be acquired under the mandated sales levels of the California LEV program, the NO_x decrease approximates a 5% year-by-year decrease from original emission levels (taking into account all electric power sector emissions and those of the replaced gasoline vehicles). In later years, the reduction is about 7,000 tons per year, and on a 20 year cumulative basis the total NO_x decrease is approximately 52,000 tons. Finally, put another way, the increase in electric power sector emissions allows 60% of the "zero emission" benefit of EVs to be realized. Emission of ROG are entirely eliminated, because ROG emissions from the electric power sector are very small (approximated as zero here). As NO_x plays a central role in ozone formation in New England, reductions in both emissions are beneficial, with ROG reductions aiding in densely populated cities and both reductions aiding in the regional problem.

The end-use applications of EVs can affect substantial changes in the net emissions and cost impacts, even reversals of trends, with domestic commuter end-uses appearing favorable compared to commercial fleet end-uses. To the extent that policy design can be driven to influence the end-use applications of EVs, there is great incentive to target domestic commuter end-uses.

For a schedule of EV introductions similar to that under the mandated sales levels of the California LEV program, EVs used for domestic commuter purposes versus commercial fleet purposes have roughly similar NO_x and ROG impacts, with ROG reductions being slightly less for the former. However, the cost impacts to the region differ significantly, with domestic commuter applications having cost impacts as much as 25-75% less in some years and a similar range of savings on a 20-year cumulative basis. One aspect of this savings is the substantially reduced electric load requirements with domestic commuter EVs, where energy (GWh) sales per year and additional power generation capacity (MW) over the 20-year study period (via new power plants) are both only 40% of those required with commercial fleet applications. In addition, the unique load impacts of domestic commuter EVs result in net CO_2 reductions, in contrast to net CO_2 increases when the emphasis is on commercial fleet vehicles. Finally, net SO_2 levels increase with all EV scenarios, but much less (40% less) with domestic commuter end-uses. This finding contrasts sharply to the popular predisposition and increasing momentum for using EVs primarily in commercial fleets. When extending this result to policy initiatives, the four main factors which influence this finding must be taken into account on aggregate, until sensitivity studies can reveal the relative influence of each level, i.e., if it is concluded from these results that off-peak recharging will provide improved cost/emission performance and that policy initiatives should be taken which heavily incent consumers to recharge only at night, then a misinterpretation has occurred. Such generalizations cannot be inferred from this study.

> *Although EVs are useful for reducing emissions of ozone precursors and carbon monoxide in New England, they cause large net increases in other air pollutants, namely CO_2 and SO_2.*

The net CO_2 and SO_2 emission levels resulting from the adoption of EVs are higher than had no EVs been adopted. While the increases may be less than 5% of the original electric power sector emissions, they greatly exceed the decreases caused by the elimination of gasoline vehicles. The latter should be the basis for comparison because EVs are a mobile source strategy. With the exception of the aforementioned domestic commuter applications, EV applications of all penetration levels increase net emissions of CO_2. In many years, the electric power sector emissions are 120% of those of the offset mobile source emissions, and as high as 150% in the early years. This trend is only worse for SO_2, and there are no exceptions for EV end-uses in this case. For many years, the electric power sector emissions are 11-16 times as large as all the eliminated SO_2 tailpipe emissions, reaching 20 times as large in the early years. Mobile sources may not emit much SO_2 when fueled by gasoline, but they emitted substantially more when fueled by electricity in New England. Because the fuel consumption of natural gas, oil 6, and oil 2 increases the most for the electric power sector with EVs (designed with mostly off-peak load impacts in this study), it is not conclusive whether policies which limit EV recharging to only the nighttime hours would serve to mitigate CO_2 and SO_2 emission increases.

The adoption of EVs imposes significant additional future costs to the New England region.

For a schedule of EV introductions similar to that under the mandated sales' levels of the California LEV program (and for the likely default commercial fleet end-uses), cumulative 20-year cost impacts range from 1,810 to 6,970 million dollars (1994$ at a 10% discount rate), with electric power sector costs accounting for 55% of the increase and mobile source costs accounting for the remaining 45%. These figures are conservative, as no infrastructure cost impacts are included. Additional costs to the electric power sector typically are about 160 million dollars per year in later years. Costs are presented with a range of values, because all cost impacts are subject to future uncertainties. No probability weightings are assigned to the cost uncertainties, as any assignment would be purely speculative and, therefore, potentially misleading. For the spread of cost uncertainties modeled in this study, the cost impact magnitudes typically vary by a factor of three. On a cost-effectiveness basis, EV NO_x and ROG reductions are expensive in early years and more affordable in later years, decreased at least by a factor of two by the year 2006. The incremental EV purchase costs and the battery replacement costs are the chief cost adders throughout the study period. Compared to additional NO_x controls on power plants (Phase II), the costs of EVs is an order of magnitude greater, though power plant controls provide no ROG benefits. The most valid comparison will be to other mobile source NO_x and/or ROG strategies, and other comparisons must be made to validly address the cost-effectiveness of EVs.

Rather than repeating some of the other key findings, the reader is referred to Chapter 4 for implications for policy (both EV-specific and in the general sense) and Chapter 5 for suggested directions for further research. The main ideas to take away from Chapter 4 are that 1) policies aimed at influencing EV adoption must take the results and dynamics (as summarized above) into account, and 2) attempts to evaluate environmental strategies will likely suffer unless certain guidelines are incorporated into the evaluation. Though Chapter 5 delineates specific future research initiatives, the underlying point is that there remains much opportunity for work which will 1) enable more informed policies, and 2) help fill the gaps in our general understanding. Given what we know at any point in time, such gaps do not dictate that measures of "no regrets" should be set aside. Rather, the point is that in the evaluation of the details and intricacies of our options, the reality of our ignorance should not escape us.

APPENDICES

Appendix A

DESIGN OF EV PENETRATION LEVELS, POPULATION, AND FLEET COMPOSITION

The designs for the four penetration level options are shown in Tables A.2, A.3, A.4, and A.5. The second column of each table contains a sales forecast for car and light duty truck sales in the New England. This forecast is comprised of three components: 1) total existing population of cars and light duty trucks, 2) expected annual growth rate of the population, and 3) the percentage of the existing population expected to be annually replaced by new vehicles. The total existing populations are benchmarked from 1991 data and are shown in Table A.1. The expected annual growth rate of the total population is assumed to be 0.5%.[1] The annually replacement rate for new vehicles is assumed to be 8.7% (for all years 1995 through 2014), based on a ten year average of historical data.[2] For commercial fleets, it is assumed that one-third of the vehicles are passenger cars; the remaining two-thirds are light duty trucks.

Table A.1: Existing Vehicle Stock in 1991[3]

	All Sectors		Government Sector	
State	PC's	LDT's	PC's	LDT's
Connecticut	2,443,651	136,605	10,827	22,765
Maine	755,300	220,699	4,238	9,041
Massachusetts	3,159,888	493,280	13,689	28,863
New Hampshire	709,408	195,371	3,436	9,519
Rhode Island	520,389	106,418	3,085	5,462
Vermont	327,593	117,442	2,838	5,774
New England Totals	7,916,229	1,269,815	38,113	81,424

[1] An average based on historical annual registration data found in Ward's Automotive Yearbook, 1993, p. 244.
[2] An average based on 10-year historical data. Motor Vehicle Manufacturers Association of the United States Inc., Facts and Figures '92, Detroit, Michigan, 1992, p. 13, 35, and 37.
[3] Federal Highway Administration, Highway Statistics 1991, Washington, D.C., 1991, p.17.

Table A.2: "Small Fleet" Penetration Level

Year	Total New Veh. Sales	% EV's	Percent EV Sales Dom-estic	Fleet	New PC's Domestic	New PC's Fleet	New LDT's Fleet	Total EVs in Service # EVs	% All Veh.
1995	11,068	0.0	32	68	0	0	0	0	0.0
1996	11,123	0.0	32	68	0	0	0	0	0.0
1997	11,179	0.0	32	68	0	0	0	0	0.0
1998	11,235	10.0	32	68	0	363	760	1,123	0.0
1999	11,291	20.0	32	68	0	730	1,528	3,382	0.0
2000	11,348	30.0	32	68	0	1,100	2,304	6,786	0.1
2001	11,404	40.0	32	68	0	1,474	3,087	11,348	0.1
2002	11,461	50.0	32	68	0	1,852	3,879	17,078	0.2
2003	11,519	60.0	32	68	0	2,234	4,678	23,989	0.2
2004	11,576	75.0	32	68	0	2,806	5,876	31,548	0.3
2005	11,634	75.0	32	68	0	2,820	5,906	38,016	0.4
2006	11,692	75.0	32	68	0	2,834	5,935	43,380	0.4
2007	11,751	75.0	32	68	0	2,848	5,965	47,632	0.5
2008	11,809	75.0	32	68	0	2,862	5,995	50,758	0.5
2008	11,869	75.0	32	68	0	2,877	6,025	52,748	0.5
2010	11,928	75.0	32	68	0	2,891	6,055	53,012	0.5
2011	11,987	75.0	32	68	0	2,906	6,085	53,277	0.5
2012	12,047	75.0	32	68	0	2,920	6,115	53,544	0.5
2013	12,108	75.0	32	68	0	2,935	6,146	53,811	0.5
2014	12,168	75.0	32	68	0	2,949	6,177	54,080	0.5

Table A.3: "Moderate Fleet" Penetration Level

Year	Total New Veh. Sales	% EV's*	Percent EV Sales Dom-estic	Fleet	New PC's Domestic	New PC's Fleet	New LDT's Fleet	Total EVs in Service # EVs	% All Veh.
1995	782,694	0.0	0.0	0.0	0	0	0	0	0.0
1996	786,607	0.0	0.0	0.0	0	0	0	0	0.0
1997	790,540	0.0	0.0	0.0	0	0	0	0	0.0
1998	794,493	2.0	10.0	90.0	1,589	4,290	10,011	15,890	0.2
1999	798,465	2.0	10.0	90.0	1,597	4,312	10,061	31,859	0.3
2000	802,458	2.0	10.0	90.0	1,605	4,333	10,111	47,908	0.5
2001	806,470	5.0	10.0	90.0	4,032	10,887	25,404	88,232	0.9
2002	810,502	5.0	10.0	90.0	4,053	10,942	25,531	128,757	1.3
2003	814,555	10.0	10.0	90.0	8,146	21,993	51,317	210,212	2.2
2004	818,628	10.0	10.0	90.0	8,186	22,103	51,574	277,774	2.8
2005	822,721	10.0	10.0	90.0	8,227	22,213	51,831	345,674	3.5
2006	826,834	10.0	10.0	90.0	8,268	22,325	52,091	413,913	4.2
2007	830,969	10.0	10.0	90.0	8,310	22,436	52,351	460,719	4.6
2008	835,123	10.0	10.0	90.0	8,351	22,548	52,613	506,170	5.1
2009	839,299	10.0	10.0	90.0	8,393	22,661	52,876	515,193	5.1
2010	843,496	10.0	10.0	90.0	8,435	22,774	53,140	524,261	5.2
2011	847,713	10.0	10.0	90.0	8,477	22,888	53,406	530,955	5.2
2012	851,952	10.0	10.0	90.0	8,520	23,003	53,673	537,683	5.3
2013	856,211	10.0	10.0	90.0	8,562	23,118	53,941	540,371	5.3
2014	860,492	10.0	10.0	90.0	8,605	23,233	54,211	543,073	5.3

* Based on California LEV Program in this case

Table A.5: "Large Fleet" Penetration Level

Year	Total New Veh. Sales	% EV's*	Percent EV Sales Dom-estic	Fleet	New PC's Domestic	New PC's Fleet	New LDT's Fleet	Total EVs in Service # EVs	% All Veh.
1995	782,694	0.0	0.0	0.0	0	0	0	0	0.0
1996	786,607	0.0	0.0	0.0	0	0	0	0	0.0
1997	790,540	0.0	0.0	0.0	0	0	0	0	0.0
1998	794,493	4.0	10.0	90.0	3,178	8,581	20,021	31,780	0.3
1999	798,465	4.0	10.0	90.0	3,194	8,623	20,121	63,718	0.7
2000	802,458	4.0	10.0	90.0	3,210	8,667	20,222	95,817	1.0
2001	806,470	10.0	10.0	90.0	8,065	21,775	50,808	176,464	1.8
2002	810,502	10.0	10.0	90.0	8,105	21,884	51,062	257,514	2.7
2003	814,555	20.0	10.0	90.0	16,291	43,986	102,634	420,425	4.3
2004	818,628	20.0	10.0	90.0	16,373	44,206	103,147	555,549	5.7
2005	822,721	20.0	10.0	90.0	16,454	44,427	103,663	691,348	7.0
2006	826,834	20.0	10.0	90.0	16,537	44,649	104,181	827,827	8.4
2007	830,969	20.0	10.0	90.0	16,619	44,872	104,702	921,438	9.3
2008	835,123	20.0	10.0	90.0	16,702	45,097	105,226	1,012,339	10.1
2009	839,299	20.0	10.0	90.0	16,786	45,322	105,752	1,030,386	10.3
2010	843,496	20.0	10.0	90.0	16,870	45,549	106,280	1,048,522	10.4
2011	847,713	20.0	10.0	90.0	16,954	45,777	106,812	1,061,910	10.5
2012	851,952	20.0	10.0	90.0	17,039	46,005	107,346	1,075,365	10.5
2013	856,211	20.0	10.0	90.0	17,124	46,235	107,883	1,080,742	10.5
2014	860,492	20.0	10.0	90.0	17,210	46,467	108,422	1,086,146	10.5

* Twice levels mandated in California LEV Program

Table A.4: "Moderate Commuter Accent" Penetration Level

Year	Total New Veh. Sales	% EV's*	Percent EV Sales Dom-estic	Fleet	New PC's Domestic	New PC's Fleet	New LDT's Fleet	Total EVs in Service # EVs	% All Veh.
1995	782,694	0.0	0.0	0.0	0	0	0	0	0.0
1996	786,607	0.0	0.0	0.0	0	0	0	0	0.0
1997	790,540	0.0	0.0	0.0	0	0	0	0	0.0
1998	794,493	2.0	30.0	70.0	4,767	3,337	7,786	15,890	0.2
1999	798,465	2.0	40.0	60.0	6,388	2,874	6,707	31,859	0.3
2000	802,458	2.0	50.0	50.0	8,025	2,407	5,617	47,908	0.5
2001	806,470	5.0	60.0	40.0	24,194	4,839	11,291	88,232	0.9
2002	810,502	5.0	70.0	30.0	28,368	3,647	8,510	128,757	1.3
2003	814,555	10.0	80.0	20.0	65,164	4,887	11,404	210,212	2.2
2004	818,628	10.0	90.0	10.0	73,676	2,456	5,730	280,952	2.9
2005	822,721	10.0	90.0	10.0	74,045	2,468	5,759	353,643	3.6
2006	826,834	10.0	90.0	10.0	74,415	2,481	5,788	428,302	4.3
2007	830,969	10.0	90.0	10.0	74,787	2,493	5,817	495,269	5.0
2008	835,123	10.0	90.0	10.0	75,161	2,505	5,846	561,857	5.6
2009	839,299	10.0	90.0	10.0	75,537	2,518	5,875	623,108	6.2
2010	843,496	10.0	90.0	10.0	75,915	2,530	5,904	691,247	6.8
2011	847,713	10.0	90.0	10.0	76,294	2,543	5,934	743,597	7.3
2012	851,952	10.0	90.0	10.0	76,676	2,556	5,964	792,156	7.8
2013	856,211	10.0	90.0	10.0	77,059	2,569	5,993	804,303	7.8
2014	860,492	10.0	90.0	10.0	77,444	2,581	6,023	808,325	7.8

* Based on California LEV Program in this case

Appendix B

VEHICLE USAGE PATTERNS

Table B.1 shows the assumptions about annual usage. The first column of each section is the "target" miles. This is what gasoline vehicles might reasonably drive. The starting values in year 1995 are projections based on historical data.[4,5] Due to limitations on EV efficiencies and battery capacities, "target" values are not able to be achieved in some years. The percentage "Elec/Gas" is the ratio of achievable EV miles (dubbed "Actual") to gasoline vehicle "Target" miles. As shown, fleet passenger cars cannot drive 100% of "Target" miles until year 2003. Fleet light duty trucks are never capable of "target" miles, only reaching 79% in year 2014. Accordingly, this may be interpreted as meaning that some EVs would have to fit a market niche where lower than average miles are acceptable.[6]

The interpretation of the "Elec/Gas" percentages for domestic use vehicles is an exception to this explained methodology. These percentages were specified a priori, before it was observed that the specific vehicle efficiencies and battery capacities used in this study would also limit EV range. Thus, they are directly assumed, rather than calculated from information on energy requirements (note the integer percentages stated in discrete 5% intervals). They were assumed as shown to reflect reasonable expectations of how domestic users would attempt to use EVs in the face of unspecified range limitations and a lack of EV infrastructure. Thus, the percentages increase through time as EVs improve and EV infrastructure proliferates. This approach is revised in future analyses for consistency.

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[4]For domestic use vehicles, the "target" mile figure in year 1995 is based on Federal Highway Administration data. A 1991 figure was escalated by an observed historical increase of 1% per year to get the 1995 figure. This same rate was applied to generate miles driven for years 1996 - 2014. Federal Highway Administration, "Summary of Travel Trends: National Personal Transportation Survey," FHWA-PL-92-027, Washington, D.C., March, 1992, p. 28.

[5]For fleet use vehicles, the "target" mile in year 1995 is based on data from the National Association of Fleet Administrators (NAFA). The same method of escalation is used as with domestic use vehicles. The starting value is based on weighted averages of 1990 and 1991 data. NAFA Fleet Executive, "1994 Used Vehicle Marketing Survey," July, 1994.

[6]These limitations are a direct function of the *assumed* energy requirements for EVs, so they are by no means hard and fast. Nonetheless, they correspond to reasonable projections.

Allocations of annual miles to daily miles are shown in Table B.3. For domestic use vehicles, the allocation is based on reference data and design assumptions as shown in Table B.2. For fleet use vehicles, the annual miles are allocated equally to weekdays.[7] Daily miles are eventually used to determine daily charging requirements.

Table B.1: Assumptions About Annual Miles Driven

Year	Domestic Passenger Cars			Fleet Passenger Cars			Fleet Light Duty Trucks		
of	Gasoline	Electric	Elec/	Gasoline	Electric	Elec/	Gasoline	Electric	Elec/
Purchase	"Target"	"Actual"	Gas	"Target"	"Actual"	Gas	"Target"	"Actual"	Gas
1995	17,701	10,620	60%	26,930	20,250	75%	26,930	14,208	53%
1996	17,887	10,732	60%	27,213	20,250	74%	27,213	14,208	52%
1997	18,074	10,845	60%	27,499	20,250	74%	27,499	14,208	52%
1998	18,264	10,958	60%	27,788	20,250	73%	27,788	14,208	51%
1999	18,456	11,996	65%	28,079	22,011	78%	28,079	15,444	55%
2000	18,650	12,122	65%	28,374	23,925	84%	28,374	16,787	59%
2001	18,846	12,250	65%	28,672	26,005	91%	28,672	18,247	64%
2002	19,043	13,330	70%	28,973	27,665	95%	28,973	19,411	67%
2003	19,243	13,470	70%	29,278	29,278	100%	29,278	20,650	71%
2004	19,445	13,612	70%	29,585	29,585	100%	29,585	21,072	71%
2005	19,650	14,737	75%	29,896	29,896	100%	29,896	21,502	72%
2006	19,856	14,892	75%	30,209	30,209	100%	30,209	21,940	73%
2007	20,064	15,048	75%	30,527	30,527	100%	30,527	22,388	73%
2008	20,275	16,220	80%	30,847	30,847	100%	30,847	22,845	74%
2009	20,488	16,390	80%	31,171	31,171	100%	31,171	23,311	75%
2010	20,703	16,562	80%	31,498	31,498	100%	31,498	23,787	76%
2011	20,920	17,782	85%	31,829	31,829	100%	31,829	24,273	76%
2012	21,140	17,969	85%	32,163	32,163	100%	32,163	24,768	77%
2013	21,362	18,158	85%	32,501	32,501	100%	32,501	25,273	78%
2014	21,586	19,428	90%	32,842	32,842	100%	32,842	25,789	79%
	(mi/yr/yr of purchase)			(mi/yr/yr of purchase)			(mi/yr/yr of purchase)		

[7]The allocation assumes 52 weeks per year with 10 holidays of no operation.

Table B.2: Design of Domestic Annual Miles Allocated to Day of the Week[8]

Design with Reference Data								
	1990 Ref. data		Trip Purpose Allocation to Day of Week					
Trip Purposes	Avg. mi/yr	% of	Mon.-Fri.		Sat.		Sun.	
	allocation	total	%	miles	%	miles	%	miles
Home to work	4,853	32%	100	4,853	0	0	0	0
Shopping	1,743	12%	50	872	40	697	10	174
Other family and personal business	3,014	20%	45	1,356	35	1,055	20	603
Social and recreation	4,060	27%	50	2,030	35	1,421	15	609
Other (school, church, doctor...)	1,430	9%	70	1,001	20	286	10	143
Total	15,100	100%		10,112		3,459		1,529
Results			Mon.-Fri.		Sat.		Sun.	
% of mi/yr per day of week			67.0%		22.9%		10.1%	

Table B.3: Allocations of Annual Miles to Day of the Week[9]

	Electric Vehicles for Domestic Use				Fleet Vehicles	
Year of	Vehicle Use	Mon.-Fri.	Sat.	Sun.	Vehicle Use	
Purchase	(mi/yr)	(mi/day)			(mi/yr)	(mi/wkday)
1995	10,620	27.4	46.8	20.7	26,930	107.7
1996	10,732	27.6	47.3	20.9	27,213	108.9
1997	10,845	27.9	47.8	21.1	27,499	110.0
1998	10,958	28.2	48.3	21.3	27,788	111.2
1999	11,996	30.9	52.8	23.4	28,079	112.3
2000	12,122	31.2	53.4	23.6	28,374	113.5
2001	12,250	31.6	54.0	23.9	28,672	114.7
2002	13,330	34.3	58.7	26.0	28,973	115.9
2003	13,470	34.7	59.3	26.2	29,278	117.1
2004	13,612	35.1	60.0	26.5	29,585	118.3
2005	14,737	38.0	64.9	28.7	29,896	119.6
2006	14,892	38.4	65.6	29.0	30,209	120.8
2007	15,048	38.8	66.3	29.3	30,527	122.1
2008	16,220	41.8	71.5	31.6	30,847	123.4
2009	16,390	42.2	72.2	31.9	31,171	124.7
2010	16,562	42.7	73.0	32.3	31,498	126.0
2011	17,782	45.8	78.3	34.6	31,829	127.3
2012	17,969	46.3	79.2	35.0	32,163	128.7
2013	18,158	46.8	80.0	35.4	32,501	130.0
2014	19,428	50.0	85.6	37.8	32,842	131.4

[8]Reference data is from the Federal Highway Administration, p. 18. Percentage allocation for trip purposes is assumed the same as the reference data. Percentages for allocation to day of week are hypotheticals used for EVs in this study. Note, the resulting allocations are assumed constant throughout the study period.

[9]Values for miles driven are shown for years 1995 - 1997, even though EVs are not introduced until 1998. Any values preceding the date of EV introduction are not used in calculations.

Appendix C

OPTIONS AND UNCERTAINTIES FOR ELECTRIC POWER SECTOR SIMULATIONS

As described in Chapter 2, each EGEAS simulation run for the electric power sector provides output data for one scenario. The components of the scenarios used in this study are shown in Table C.1. This table references many options that are not self-explanatory, but nonetheless these options are listed for completeness for those familiar with AGREA's past scenarios and anticipated 1995 scenarios. This complete listing provides the most descriptive historical record of the assumptions used in the scenarios. Most options and uncertainties are explained in the project's background information document.[10] For this EV study, 240 scenarios were completed.

[10] Massachusetts Institute of Technology, Energy Laboratory, Analysis Group for Regional Electricity Alternatives, Background Information for the 1992/1993 Scenario Set - Second Tier/Summer 1993, MIT Energy Lab Working Document, September, 1993.

Table C.1: Electric Power Sector Scenario Components Used in Study

Planning Options	
Type of New Capacity Additions 155 MW Combustion Turbine 250 MW Combined Cycle	Retirement/Repowering Option Life Extension
NOx Controls Region-wide Phase I RACT controls Region-wide Phase II controls	DSM Levels No DSM Reference Levels of DSM
EV Penetration Levels No EVs Small Fleet Moderate Fleet Moderate Commuter Accent Large Fleet	EV Recharging Distribution Off Peak EV Efficiency Improvement Trajectory Evolutionary
End-use Fuel Switching None	Advanced Electrotechnologies None
Emission Offsets None	Fuel Contracting All Economic Dispatch
Power Purchases As Scheduled	NOx Operational All New England
DSM Cost Allocation All Utility	

Future Uncertainties	
Load Growth Base/Low	Fuel Taxes None
EV Costs Low Medium High	Fuel Costs Base High Gas
Offset Gasoline Vehicle Emissions Reference MOBILE5a Adjusted MOBILE5a	Nuclear Attrition As Scheduled

Appendix D

OFFSET EMISSIONS FROM GASOLINE VEHICLES

The emission rates for NO_x, CO, and ROG are determined by EPA's MOBILE5a program. As this program is designed and most commonly used for aggregate fleet-wide emission rates, several revisions to the standard input records are required. The program is executed in batch-mode for 20 runs (1 per study year) to generate vehicle class emission rates for vehicles of ages 1-20 years old (only vehicles ages 1-10 are used, however). In batch-mode, the input parameters varied to accomplish this are the "registrations by distribution by age" and the "annual mileage accumulation rates." Other unique one-time inputs which are common to all runs include federal Tier II standards, a generic Boston I/M program, and reformulated gasoline. The reference Federal Tier I and Tier II standards used in MOBILE5a are shown in Table D.1 The output emission rates for NO_x, CO, and ROG, used to calculate offset emissions from gasoline vehicles, are shown in Tables D.2, D.3, and D.4

Table D.1: Federal Tier I and Tier II Standards used by MOBILE5a[11]

50,000 Mile Standards (100,000 Mile Standards)

EPA Standard	Effective	Gram per Mile Emission Rates NOx	CO	ROG
Tier I	1994	0.4 (0.6)	3.4 (4.2)	0.25 (0.31)
Tier II	2004	(0.125)	(1.7)	(0.2)

Assumed Emission and Deterioration Rates for Tier II Vehicles

Vehicle Type	NOx ZML (g/mi)	NOx DR (g/mi/10K mi)	ROG ZML (g/mi)	ROG DR1 (g/mi/10K mi)	ROG DR2 (g/mi/10K mi)
PC	0.089	0.042	0.093	0.030	0.42
LDT	0.185	0.065	0.103	0.042	

**ZML is zero-mile emission rate*

**DR applies every year*

**DR1 applies to first 50,000 miles*

**DR2 applies after 50,000 miles*

[11]Tier II assumptions are the same as those used in recent studies by the Sloan Automotive Laboratory. Assumes phase-in of Tier II cars as follows for the MOBILE5a model: 40% of new vehicles in year 2004, 80% in year 2005, and 100% in year 2006. Jonathan Fox, John Heywood, and Gregory McRae, "Aggregate Vehicle Emission Estimates for Evaluating Control Strategies," Sloan Automotive Laboratory, Massachusetts Institute of Technology, 1994, p. 12-13.

Table D.2: NO_x Emission Rates for Mobile Sources[12]

Purchase Year		1995		1998		2001		2004	
Vehicle Type		LDT	PC	LDT	PC	LDT	PC	LDT	PC
Year of	1	0.29	0.16	0.23	0.14	0.22	0.14	0.21	0.10
Operation	2	0.53	0.30	0.38	0.18	0.36	0.18	0.35	0.16
	3	0.98	0.54	0.64	0.25	0.60	0.25	0.60	0.25
	4	1.81	0.73	1.07	0.37	0.97	0.32	0.96	0.32
	5	2.54	0.92	1.59	0.64	1.33	0.39	1.31	0.39
	7	3.96	1.57	3.87	1.55	1.87	0.64	1.75	0.55
	10	5.62	2.62	5.93	2.54	5.79	2.49	2.42	0.76

Purchase Year		2007		2010		2013	
Vehicle Type		LDT	PC	LDT	PC	LDT	PC
Year of	1	0.22	0.14	0.22	0.14	0.22	0.14
Operation	2	0.34	0.14	0.36	0.18	0.36	0.18
	3	0.57	0.18	0.60	0.25	0.60	0.25
	4	0.93	0.27	0.96	0.32	0.95	0.32
	5	1.30	0.38	1.29	0.35	1.31	0.39
	7	1.74	0.55	1.72	0.50	1.74	0.55
	10	2.30	0.66	2.29	0.66	2.27	0.60

Table D.3: CO Emission Rates for Mobile Sources

Purchase Year		1995		1998		2001		2004	
Vehicle Type		LDT	PC	LDT	PC	LDT	PC	LDT	PC
Year of	1	2.16	1.22	1.65	1.22	1.62	1.22	1.62	1.22
Operation	2	3.83	1.48	2.80	1.48	2.63	1.48	2.63	1.48
	3	7.54	2.78	4.85	1.85	4.30	1.85	4.30	1.85
	4	16.70	5.12	9.04	2.19	7.44	2.19	7.39	2.19
	5	24.67	7.08	14.06	2.58	10.59	2.58	10.28	2.58
	7	38.35	13.58	38.91	13.84	16.79	3.40	14.63	3.40
	10	50.57	21.93	58.09	23.08	58.66	23.38	22.49	3.88

Purchase Year		2007		2010		2013	
Vehicle Type		LDT	PC	LDT	PC	LDT	PC
Year of	1	1.61	1.22	1.62	1.22	1.62	1.22
Operation	2	2.08	1.48	2.63	1.48	2.62	1.48
	3	3.29	1.85	4.29	1.85	4.28	1.85
	4	7.38	2.19	7.36	2.19	7.35	2.19
	5	10.27	2.58	7.16	2.58	10.23	2.58
	7	14.58	3.40	14.55	3.40	14.51	3.40
	10	20.31	3.88	20.25	3.88	20.21	3.88

[12] Only a subset of the emission rates are shown in all emission rate tables, sufficient to communicate the changes over time and degradation effects due to aging.

Table D.4: ROG Emission Rates for Mobile Sources

Purchase Year		1995		1998		2001		2004	
Vehicle Type		LDT	PC	LDT	PC	LDT	PC	LDT	PC
Year of	1	0.62	0.72	0.46	0.45	0.40	0.38	0.37	0.36
Operation	2	0.75	0.79	0.58	0.57	0.46	0.40	0.45	0.39
	3	1.04	0.87	0.79	0.71	0.58	0.43	0.58	0.43
	4	2.11	0.99	1.39	0.83	0.97	0.47	0.96	0.46
	5	3.09	1.17	2.03	0.96	1.41	0.60	1.32	0.51
	7	4.86	2.03	4.89	2.03	2.29	1.02	1.94	0.74
	10	7.24	3.24	7.39	3.26	6.36	2.80	3.21	1.31

Purchase Year		2007		2010		2013	
Vehicle Type		LDT	PC	LDT	PC	LDT	PC
Year of	1	0.40	0.38	0.40	0.38	0.40	0.38
Operation	2	0.44	0.38	0.46	0.40	0.46	0.40
	3	0.51	0.38	0.58	0.43	0.58	0.43
	4	0.76	0.43	0.96	0.46	0.96	0.46
	5	1.17	0.50	1.29	0.48	1.32	0.51
	7	1.93	0.72	1.33	0.68	1.92	0.72
	10	2.80	0.98	2.78	0.97	1.78	0.93

The emission rates for CO_2 and SO_2 are approximately proportional to the carbon and sulfur content of gasoline. These rates are calculated by using a starting value (based on the carbon and sulfur content of gasoline) and adjusting it proportionally to fuel economy for both improving new vehicles and aging used vehicles. The assumed carbon and sulfur content of gasoline is 9,440 and 3 grams per gallon, respectively. These values are benchmarked from data used in previous studies[13] and are assumed constant throughout the study period.

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[13]For CO_2, EPRI uses a value of 11,000 grams per gallon. Darrow uses a value of 8,468 grams per gallon. The Tennis study assumes a value of 8,855 grams per gallon. A value of 9,440 grams per gallon is benchmarked from these. For SO_2, the rate is derived from an Auto Oil Study by a consortium of U.S. auto and oil companies. A reasonable estimate from the data in this study is 500 ppm (weight). This gives a value of 3.05 grams of SO_2 per gallon. EPRI, "Electric Van and Gasoline Van Emissions: A Comparison," Technical Brief, Palo Alto, CA, 1989. K.G. Darrow, "Light Duty Vehicle Full Fuel Cycle Emission Analysis," for the Gas Research Institute, Chicago, Il, April, 1994. Michael Tennis, "Impact of Battery-Powered Electric Vehicles on Air Quality in the Northeast States," prepared for the Northeast States for Coordinated Air Use Management, July, 1992. Auto Oil Study, "Phase I Final Report," Air Quality Improvement Research Program, May, 1993.

Rates specified in grams per gallon are transferred to gram per mile rates via fuel economy (MPG–miles per gallon). This assumes that approximately 100% of the liquid sulfur and carbon content is realized in gaseous products in the combustion process. Rather than assuming an aggregate fuel economy trajectory for all vehicles based on Corporate Average Fuel Economy, separate trajectories for passenger cars and light duty trucks are assumed. From historical data by the Department of Transportation, the average 1990 fuel economies are 27.8 and 20.5 MPG for passenger cars and light duty trucks, receptively.[14] From the same source, the annual improvement in fuel economy in the previous 10 years is found to be 2% and 1.3% for passenger cars and light duty trucks. Lacking any transcendent knowledge on expected fuel economy improvements, these growth rates are assumed throughout the study period. Scaling the 1990 data with these rates gives a starting value in 1995 of 31 and 22 MPG for passenger cars and light duty trucks. By 2014, these values reach 45 and 28 MPG. These trajectories are for new vehicles. For aging vehicles, it is assumed that fuel economy degrades for cars and trucks at a rate of 1 MPG every four years (0.25 MPG decrease per year). Combining the gram per gallon rates and these assumptions about fuel economies, the resultant emission rates for CO_2 and SO_2 are as shown in Tables D.5 and D.6.

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[14]Department of Transportation, "National Transportation Statistics Annual Report," Cambridge, MA, June, 1992, p. 88-89. The data used for passenger cars includes only those for "Subcompact," "Compact," and "Midsize" classes, as these are likely candidates for EVs. The data for all classes of light duty trucks are used.

Table D.5: CO_2 Emission Rates for Mobile Sources

Purchase Year		1995		1998		2001		2004	
Vehicle Type		LDT	PC	LDT	PC	LDT	PC	LDT	PC
MPG		22.0	31.0	22.9	32.9	23.8	34.9	24.7	37.0
Year of	1	**429**	**305**	**413**	**287**	**397**	**270**	**382**	**255**
Operation	2	434	307	417	289	401	272	386	257
	3	439	309	422	291	405	274	390	258
	4	444	312	426	294	410	276	394	260
	5	449	314	431	296	414	278	398	262
	7	459	320	441	300	423	282	406	265
	10	475	327	455	307	436	288	418	271

Purchase Year		2007		2010		2013	
Vehicle Type		LDT	PC	LDT	PC	LDT	PC
MPG		25.7	39.3	26.7	41.7	27.8	44.3
Year of	1	**367**	**240**	**354**	**226**	**340**	**213**
Operation	2	371	242	357	228	343	214
	3	375	243	360	229	346	216
	4	378	245	364	230	349	217
	5	382	246	367	232	352	218
	7	389	249	374	235	359	221
	10	401	254	384	239	369	224

Table D.6: SO_2 Emission Rates for Mobile Sources

Purchase Year		1995		1998		2001		2004	
Vehicle Type		LDT	PC	LDT	PC	LDT	PC	LDT	PC
MPG		22.0	31.0	22.9	32.9	23.8	34.9	24.7	37.0
Year of	1	**0.138**	**0.098**	**0.133**	**0.093**	**0.128**	**0.087**	**0.123**	**0.082**
Operation	2	0.140	0.099	0.135	0.093	0.129	0.088	0.125	0.083
	3	0.142	0.100	0.136	0.094	0.131	0.089	0.126	0.083
	4	0.143	0.101	0.138	0.095	0.132	0.089	0.127	0.084
	5	0.145	0.101	0.139	0.095	0.134	0.090	0.128	0.084
	7	0.148	0.103	0.142	0.097	0.136	0.091	0.131	0.086
	10	0.153	0.106	0.147	0.099	0.141	0.093	0.135	0.087

Purchase Year		2007		2010		2013	
Vehicle Type		LDT	PC	LDT	PC	LDT	PC
MPG		25.7	39.3	26.7	41.7	27.8	44.3
Year of	1	**0.119**	**0.077**	**0.114**	**0.073**	**0.110**	**0.069**
Operation	2	0.120	0.078	0.115	0.073	0.111	0.069
	3	0.121	0.078	0.116	0.074	0.112	0.070
	4	0.122	0.079	0.117	0.074	0.113	0.070
	5	0.123	0.079	0.118	0.075	0.114	0.070
	7	0.126	0.080	0.121	0.076	0.116	0.071
	10	0.129	0.082	0.124	0.077	0.119	0.072

Appendix E

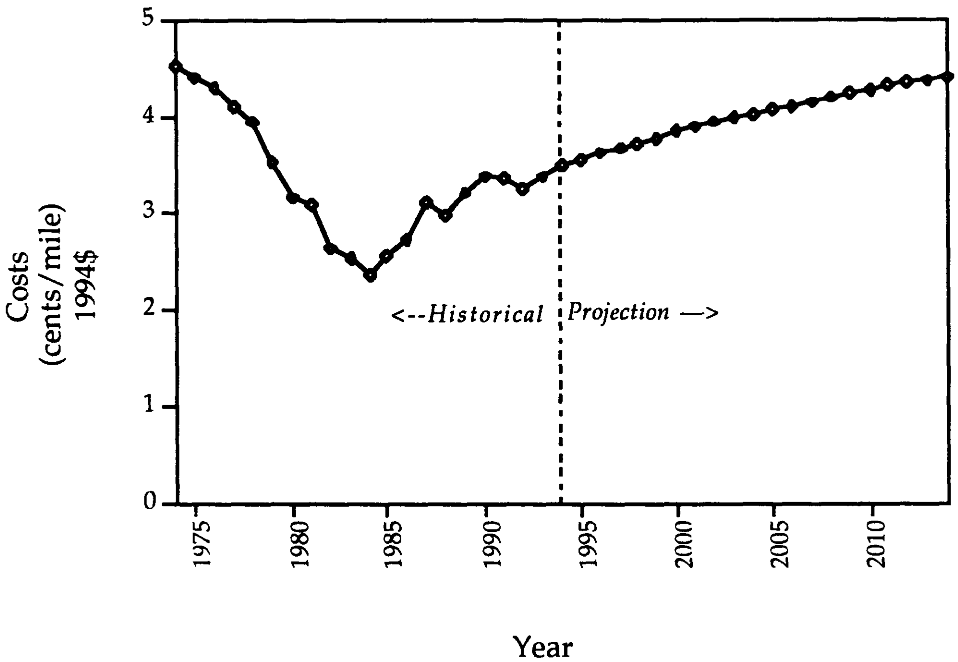
ELECTRIC VEHICLE VARIABLE O&M COST MODELING

Variable O&M costs associated with the use of EVs are modeled by assuming that they are a fraction of gasoline vehicle variable O&M costs. The fraction used throughout the study period is 50%. Costs for new vehicles (domestic passenger cars, fleet passenger cars, and fleet light duty trucks) are first determined, and then costs for aging vehicles. Variable O&M for new gasoline vehicles is based on historical data. Both the 1995 starting value and a hypothetical trajectory a for future values are based on this data. As shown in Figure E.1 for domestic passenger cars, it is assumed that the 1994 value will increase over time, with smaller increases in latter years.

For commercial fleet vehicles, the variable O&M for new passenger cars and trucks is based on the historical data in Table E.1. Unlike domestic passenger cars where consistently recorded data is readily available for the previous 20 years, only a one-time snap-shot is available for fleet vehicles. The trajectory for expected increases over time is the same as that assumed for domestic passenger cars. Both trajectories for new vehicles are shown in Figure E.2.

These costs described so far are for new vehicles in the first year of operation. To capture aging effects and the associated increased maintenance requirements, it is assumed for all vehicles that variable O&M expenses increase 15 percent per year. The results of this assumption are shown in Table E.2. These final values for gasoline vehicles are de-rated by 50% for EVs.

Figure E.1: Variable O&M for New Domestic Gasoline Passenger Cars[15]



[15]Motor Vehicle Manufacturers Association of the United States Inc., Facts and Figures '92, Detroit, Michigan, 1992, p. 51. These data are for cars on a four year, 15,000 mile per year retention cycle, and thus do not represent strictly "new" cars. These average values are assumed for the first four years, after which degradation effects are assumed. Costs components in the figure include those listed for "maintenance" and "tires." Costs for "gasoline and oil" are aggregated by this source, so this information is not used (a separate gasoline price trajectory is used and the gallons necessary are calculated based on specific MPG and mile/year assumptions). Oil costs are added to other O&M costs by assuming, on average, four oil changes per year at $23 each (assumed to track with inflation).

Table E.1: Variable O&M for New Commercial Fleet Gasoline Vehicles[16]

	Fleet Passenger Cars			
Year of Operation	One		Two	
Maint. Category	Average $/Vehicle	Cents/mi	Average $/Vehicle	Cents/mi
Lube & Oil	30.13	0.121	81.62	0.328
Brakes	6.76	0.027	72.73	0.293
Tuneups/Adjustments	3.56	0.014	39.17	0.158
Cooling System	1.18	0.005	17.51	0.070
Heat & A/C	0.27	0.001	9.16	0.037
Electrical	2.93	0.012	14.74	0.059
Suspension & Alignment	2.84	0.011	21.92	0.088
Misc. Mechanical	8.5	0.034	52.34	0.211
Tires/Rotation & Balance	21.93	0.088	95.71	0.385
Total		0.314		1.629
Average of 1 & 2 year data	0.97 Cents/mile			

[16]"How Much Do Fleets Spend on Maintenance?", Automotive Fleet Magazine, March, 1994, p. 20-23. This data is based on a survey of two nationally dispersed commercial fleets, which submitted information on 14,126 vehicles. Variable O&M expenses differ for fleet passenger cars and trucks differ in this report, especially because the "trucks" category includes off-road vehicles and those used for towing (unlikely applications for EVs). Thus, the results for trucks are overstated for the purposes of this study. According to recent information from the American Automobile Association/Runzheimer International, variable O&M expenses for passenger cars and light duty trucks of similar use patterns are approximately equivalent. Such equivalency is assumed in this study and the data for fleet passenger cars is used for both passenger cars and light duty trucks. The report qualifies that many of the vehicles in the first year of operation are brand new at the time of the survey, so first year maintenance figures are understated. To address this, an average of the data for the first and second years of operation is used as the starting value in 1994.

Figure E.2: Assumed Variable O&M for Domestic and Fleet Gasoline Vehicles (1^{st} Year of Operation)

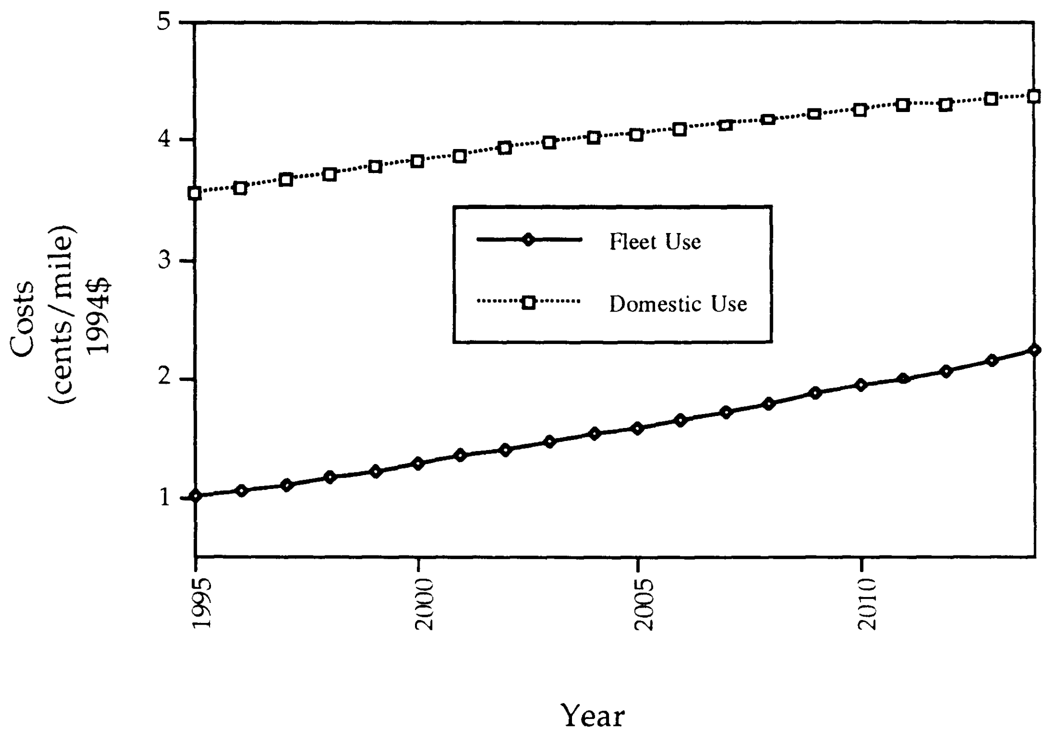


Table E.2: Assumed Variable O&M for Fleet and Domestic Gasoline Vehicles

Purchase Year=>		1995		1998		2001		2004	
Vehicle Type=>		Fleet	Dom.	Fleet	Dom.	Fleet	Dom.	Fleet	Dom.
Year of	1	0.99	3.55	1.03	3.71	1.08	3.88	1.12	4.02
Operation	2	1.13	3.55	1.19	3.71	1.24	3.88	1.28	4.02
	3	1.30	3.55	1.36	3.71	1.43	3.88	1.48	4.02
	4	1.50	3.55	1.57	3.71	1.64	3.88	1.70	4.02
	5	1.73	4.09	1.80	4.27	1.89	4.47	1.95	4.63
	7	2.28	5.40	2.39	5.65	2.49	5.91	2.58	6.12
	10	3.47	8.22	3.63	8.59	3.79	8.98	3.93	9.30

Purchase Year=>		2007		2010		2013	
Vehicle Type=>		Fleet	Dom.	Fleet	Dom.	Fleet	Dom.
Year of	1	1.15	4.14	1.19	4.27	1.21	4.36
Operation	2	1.32	4.14	1.36	4.27	1.39	4.36
	3	1.52	4.14	1.57	4.27	1.60	4.36
	4	1.75	4.14	1.80	4.27	1.84	4.36
	5	2.01	4.77	2.07	4.91	2.12	5.01
	7	2.66	6.30	2.74	6.49	2.80	6.62
	10	4.05	9.58	4.17	9.88	4.25	10.07

All values are in Cents/Mile

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