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Economic Incentives to Introduce Electric and Natural-Gas Vehicles and Reduce Mobile Source Emissions

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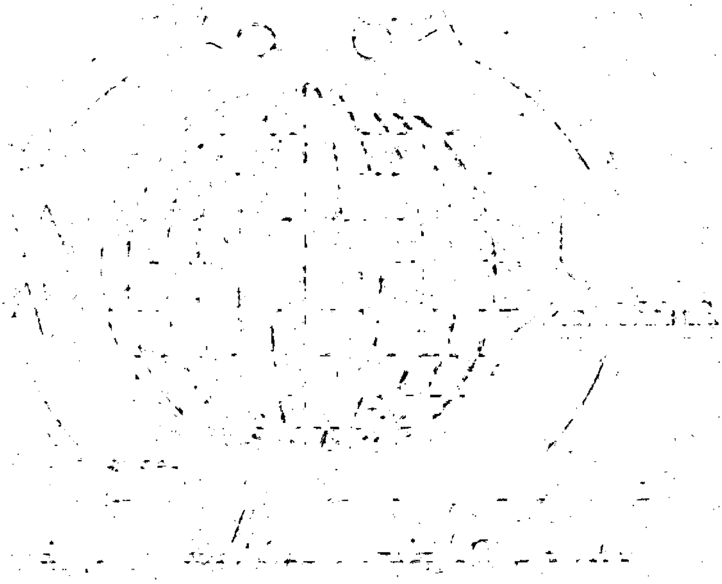

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ECONOMIC INCENTIVES TO INTRODUCE ELECTRIC AND NATURAL GAS VEHICLES AND REDUCE MOBILE SOURCE EMISSIONS

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Research Report

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Abstract: Economic Incentives to Introduce Electric and Natural Gas Vehicles and Reduce Mobile Source Emissions

This research project addresses the form of government intervention for introducing electric and natural gas vehicles. The primary focus of this research is the cost savings from employing a marketable permit system (MPS) relative to traditional regulatory approaches for meeting current and future emission control standards. The research project is divided into two parts. In the first part, marketable permits for the introduction of alternative fuel vehicles (AFVs) are examined. In the second part, a permit system for the adoption of alternative fuels is addressed. This document reports on the work completed to date on marketable permits for vehicles.

To estimate the costs of emission control with a MPS, data on emission control costs for conventional gasoline vehicles were collected. A survey of car dealers for twelve vehicle manufacturers in the Sacramento area was performed from January 1991 through July 1991. Dealers were asked to provide cost information on emission control parts for a variety of engine families. These data were combined with information on manufacturers' and dealers' markup and assembly costs to estimate the total costs of emission control per vehicle. These data suggest that, on average, vehicle manufacturers spend about $840 per vehicle for emission control purposes. There is substantial variation among manufacturers, with American producers reporting the lowest emission control costs and European reporting the highest. Total emission control costs for new cars sold in California in 1990 are estimated to be about $1.3 billion. Data on the emission characteristics of conventional vehicles were obtained from CARB's certification data. These data provide an important baseline for establishing the economic competitiveness of EVs and CNGVs.

Cost functions relating the total cost per vehicle to emissions per vehicle were estimated using the data collected for conventional vehicles. Significant differences were found in the cost functions by manufacturer and

vehicle class. A simulation model of manufacturers' behavior was built wherein manufacturers are assumed to minimize the costs of emission control subject to meeting an emission standard. The effects of emission averaging and trading on the costs are estimated in this framework.

In our simulation model, we used the current certification levels rather than the true standards so that emissions are not allowed to increase over current levels. The cost savings estimated by the model can then be attributed to the marketable permit system rather than to a worsening of air quality.

In the first series of simulations using this model, the cost savings of using a permit system for gasoline vehicles to meet 1990 HC emission levels was estimated. In this system, manufacturers were allowed to average emissions by vehicle class (small, medium, and large cylinder) and to trade emissions across manufacturers. Preliminary results indicate cost savings attributable to the permit system to be up to $170 per vehicle, depending upon assumptions regarding changes in vehicle sales and functional form of the cost functions.

In the second set of results, a permit system similar to CARB's low-emission vehicle program is simulated and the value of emission reductions from clean fueled vehicles is estimated. These values are found to be largest for the lowest emitting vehicles. The values increase over time as emission standards tighten, as long as the vehicle meets the standards in that period.

The results presented here are preliminary and should be viewed as a first attempt to quantify the benefits of a MPS for automobile manufacturers. However, they do suggest that there may be significant cost savings associated with a permit system relative to an inflexible standard.

Economic Incentives to Introduce Electric and Natural Gas Vehicles and Reduce Mobile Source Emissions

List of Tables and Diagrams

Economic Incentives to Introduce Electric and Natural Gas Vehicles and Reduce Mobile Source Emissions

Chapter I. Introduction

The transition from gasoline-powered vehicles to electric and natural gas vehicles will stimulate increased demand for electricity and natural gas. This transition will thus have an important effect on the markets for these products. In addition, electric and natural gas vehicles provide a number of potential benefits over gasoline powered vehicles, including lower automobile emissions, reduced greenhouse gases, and increased energy security. However, these benefits accrue to society at large rather than to individual consumers or producers of these vehicles. As a result, government intervention to encourage the use of alternative fuel vehicles (AFVs) will likely be needed for their timely introduction.

This research project addresses the form of government intervention needed to introduce electric and natural gas vehicles. Traditionally, government regulation of environmental quality follows the format of mandates or standards. Once an environmental goal is determined, firms are required to employ particular technologies or meet uniform standards at each plant or point of production.

An alternate regulatory stance that is receiving increasing attention in the environmental regulation arena is the use of economic incentives. Rather than mandating particular technologies or requiring each firm to meet uniform standards, these approaches apply the power of the profit motive to gain improvements in environmental quality. By allowing firms flexibility in their control methods, incentive systems promote improved environmental quality at less cost to manufacturers and hence to society at large.

A. Air Quality and Mobile Source Emissions

Recent data indicate that many U.S. areas still fail to meet federal ambient air quality standards for one or more pollutants. For example, in

1989, 96 U.S. metropolitan areas violated the ambient standard of ozone, and 41 areas violated the standard for carbon monoxide (CO) (EPA, 1990a). A major contributor to air quality problems are motor vehicles which produce emissions of hydrocarbons (HC), carbon monoxide (CO), nitrogen oxides (NO_x), sulfur oxides (SO_x), and particulate matters (PM). Nationwide, mobile sources account for 33% of total volatile organic gases (VOC) emissions, 67% of CO, 41% of NO_x, 4% of SO_x, and 20% of PM (EPA, 1990a). Due to motor vehicle emission regulations and the consequent extensive efforts to reduce vehicle emissions, emissions of HC and CO from the transportation sector have been reduced by over 40% in the last 20 years (EPA, 1990a).

However, the continuous increase in vehicle miles traveled (VMT) poses a difficult impediment for further decreasing total emissions from mobile sources. Facing this challenge, the Clean Air Act Amendments (CAAA) of 1990 establishes more stringent per-mile vehicle emission standards for gasoline vehicles, and introduces transportation control measures to reduce VMT in nonattainment areas. Beginning in 1995, the CAAA requires the sale of cleaner burning reformulated gasoline in the nine cities with the worst ozone pollution. For carbon monoxide non-attainment areas the CAAA requires a second clean fuels program which takes effect in 1992.

The CAAA also establishes a California clean-fueled vehicle pilot program. This program requires the production, sale, and distribution in California of 150,000 clean-fueled vehicles each year beginning with model year 1996, and 300,000 such vehicles annually in model year 1999 and subsequent years. The CAAA also requires the State of California to adopt a program to ensure the production, distribution, and availability of fuels for these vehicles. These fuels will likely include natural gas, methanol, and electricity.

Recently adopted regulations by the California Air Resources Board (CARB) require the production of low emission vehicles and the availability of clean fuels. The regulation of vehicle emissions is based upon the concept of marketable permits, whereby standards are set on automobile manufacturers who are allowed to average, trade and bank emissions credits. Thus, it seems clear that expanded regulation of alternative fuel vehicles and alternative transportation fuels is inevitable, and that a marketable permit approach is a primary alternative to mandated, "inflexible", standards.

Interest in marketable permits in California extends beyond transportation applications. In 1991, the South Coast District initiated a feasibility study on using marketable permits to control air pollution in the South Coast air basin (South Coast Air Quality Management District, 1992). The purpose was to reduce total emission control costs, to increase flexibility of meeting emission requirements, and to stimulate the innovation of emission control technologies.

Based on the feasibility study, the South Coast district proposed a program called RECLAIM (Regional Clean Air Incentives Market). RECLAIM allows companies to achieve their required emission reductions of reactive organize gases (ROG) and nitrogen oxides (NOx) through add-on controls, the use of reformulated products, and/or by purchasing excess emission reductions from other sources. Through the RECLAIM, equipment permits are replaced with facility permits, emission rates are replaced with mass emission limits, and retrofit control rules are replaced with annual emission reductions.

RECLAIM is based on the concept of bubbling stationary sources at the facility level, limiting total mass emissions from the facility, and requiring each source to meet prescribed annual facility emission targets. Through RECLAIM, mass emission limits for facilities will be established, and companies are required to meet these limits. To achieve established air quality goals, facilities must reduce ROG by 6% and NOx by 8% each year. RECLAIM includes all sources with emissions greater than 4 tons per year in the South Coast air basin. This will create a ROG market of approximately 2,000 facilities, and a NOx market with approximately 700 facilities.

B. Background

Economic incentives in a variety of forms have been suggested as a means to reduce environmental pollution at less cost than would be possible through more restrictive and prescriptive "command and control" strategies (Baumol and Oates, 1988). However, the extent of the cost savings will depend on the particular application.

A range of economic incentives for encouraging the introduction of alternative fuels and AFVs has been proposed. Some incentives are directed at consumers such as the DRIVE+ program proposed by Gordon and Levenson (1989). They suggested imposing a sales tax surcharge on vehicles with high emissions that would pay for tax deductions on more efficient, low-emitting vehicles. Other possible consumer incentives include: taxes on gasoline, subsidies for alternative fuels, home refueling and recharging, and the leasing of batteries and CNG tanks.

An alternative approach, and the one that is the focus of this study, is to create markets for the reduction of pollution. In this approach, firms are required to meet a standard, but there is flexibility in how they must meet the standard. If they more than meet the standard, they earn credits which can be banked for future use or sold to other firms. Alternatively, if they do not meet the standard, they can purchase credits from other firms to meet their statutory obligation.

The advantages of a marketable credits approach include the following: (1) large emission reductions and energy shifts can be achieved without imposing large taxes or fees; (2) the approach is inherently more efficient than uniform standards and mandates; (3) credits are politically more palatable than taxes and fees; and (4) the approach is more amenable to region-specific solutions (in the case of marketable credits for fuels).

C. Objectives of this study

The primary objectives of this study are twofold: (1) to examine economic incentive systems to introduce alternative fuels and AFVs; and (2) to estimate the costs savings associated with the use of these economic incentives. The first phase of the research project focusses specifically on economic incentives for manufacturers of AFVs. The second phase, which is now underway, will focus on incentives for suppliers of fuels. Although the focus of the research is on the introduction of electric and natural gas vehicles, methanol-fueled vehicles will also be included for completeness since methanol vehicles are likely to play an important part in the future of AFV's.

A variety of economic incentive proposals will be evaluated in the study. The proposals evaluated will range from those that closely mimic economic incentive regulations currently in place (such as the CARB regulations) to others that have been proposed but not instituted. The primary purpose is to provide information for policy makers and industry concerning current policies and possible cost savings from incentive systems.

A secondary objective of the research is to assess the overall feasibility of emissions trading as a means to introduce alternative fuels and AFVs. Questions relating to the market structure of permit schemes, costs of enforcement, and acceptability to industry and environmental groups may be addressed in the second stage of the project.

To accomplish these objectives, data on the costs of meeting emission control standards for conventional vehicles has been collected. These data are used to estimate cost functions for conventional vehicles that are used in a simulation model of manufacturers' behavior. This simulation model is used to estimate the costs of obtaining environmental standards with a permit system and with the current command and control approach.

The results reported in this report are preliminary; they should be viewed as a first analysis of the data. Additional work examining the sensitivity of the results to different specifications of the cost functions and simulation model are necessary before the results of this research will be complete.

This report is organized as follows. The second chapter discusses regulatory approaches to controlling emissions. The chapter contains an overview and brief assessment of marketable permit schemes with particular attention paid to comparing marketable permits to traditional command and control regulation. The third chapter examines the use of marketable permits for the control of mobile source emissions. CARB's low-emission vehicle program and other mobile source permit systems are discussed, and the permit schemes addressed in this research are described.

Chapter IV describes the data collection effort as well as providing summaries of the data. The cost functions estimated for gasoline vehicles using that data are described and summarized in chapter V. Chapter VI contains a description of the data for electric, natural gas, and methanol vehicles. The appendix to that chapter includes detailed summaries of the results of studies on the emission characteristics of AFVs.

In chapter VII, we describe our simulation experiment and the results. A marketable permit system for gasoline vehicles alone as well as a permit system including AFVs are examined, and some preliminary results on estimated cost savings and emissions value of AFVs are provided. In the next phase of our research, we will begin to examine a marketable permit system for the introduction of alternative fuels. Chapter VIII contains a discussion of the issues associated with such a system and a brief description of our intended work. Finally, chapter IX contains conclusions and directions for future work.

Chapter II. Regulatory Approaches to Mobile Source Emissions Control

Air pollution is a classic example of an external cost imposed by the production of goods onto society at large. The social cost of an activity can be defined as the sum of the private costs and the external costs (such as pollution) created by the activity. Hence, in the case of motor vehicles, the social costs of producing a vehicle are the direct costs of producing the vehicle plus the costs of damages from pollution emissions.[1]

From a social perspective, all of the costs of motor vehicle use should be considered in the decision of what type and how many vehicles to produce and use. However, firms produce their products based only on the private costs of production. The private decisions do not include pollution costs borne by society. Consequently, with no government intervention or regulation, there is not likely to be an efficient mix and quantity of vehicles produced and used.

Economists have proposed and discussed a number of ways to regulate firms when the private costs and social costs diverge. These approaches can be divided into two broad classifications: (1) command and control and (2) incentive (or market) based approaches. The following discussion outlines the basic properties of each approach as it applies to the regulation of emissions from motor vehicles.

A. Command and Control

Since California first required vehicle emission control in the early 1960s, especially since the 1970 CAAA, air pollution control goals have been established and enforced through legislation and administrative commands. These goals are achieved through direct control on polluting firms. This method, termed "command and control" (CAC) authorizies governmental bodies to establish pollution standards and/or technology requirements and requires individual polluting agents to meet these standards and requirements. CAC is the traditional tool employed by both the Federal and State governments to

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[1] There are likely to be additional external costs associated with motor vehicle use such as congestion and accidents.

control air pollution.

In particular, Congress establishes overall air quality goals for the nation and directs the Environmental Protection Agency (EPA) to generate control measures that will achieve these goals. The EPA establishes National Ambient Air Quality Standards (NAAQS), identifies pollution sources, sets up emission standards for each air pollutant at these sources, and enforces the emission standards with state and federal agencies. Polluters are required to control emission from their sources to levels at or below the specified standards. Often, the EPA requires that specific emission control technologies (such as best achievable control technology or lowest achievable emissions rates) be installed on specific emission sources. If a polluter fails to meet the standards or technology requirements, the EPA and state agencies have the authority to shutdown the polluter's facility.

Under the CAC approach, firms may be required to install specified control technologies even if, through better knowlege and technical expertise, they could more cheaply control emissions another way. Thus, the CAC approach does not provide firms with any flexibility in meeting emission standards. As a result, there is no incentive provided to firms to control emissions below specified levels or to seek new, more effective means of control.

Historically, the regulation of motor vehicle emissions has been CAC in nature (though as discussed in chapter III, there have been some recent exceptions for diesel trucks). Manufacturers are responsible to control vehicle emissions below allowable ceilings. The current federal passenger car emission standards on the three regulated tailpipe pollutants are 0.41 grams per mile (gpm) for HC, 3.4 gpm for CO, and 1.0 gpm for NO_x. Beginning in 1994, the standards will be tightened to 0.25 for NMHC, 0.41 for NO_x, and the CO standard will remain unchanged.

To meet the emissions goals established by Congress, EPA sets emission standards on vehicles which must be met on each and every vehicle. As a result, under the current vehicle emission regulations, vehicle manufacturers have very little flexibility in meeting these standards.

B. Drawbacks of the Command and Control Approach for Mobile Source Control

Although per-mile vehicle tailpipe emissions have been reduced by more than 90% in the last 20 years (CARB, 1988), further control of mobile source emissions through CAC may become more difficult. In particular, there are a number of important drawbacks to the CAC approach.

1. Unnecessarily high costs of emission control

Kappler and Rutledge put the annual expenditure on abating motor vehicle emissions at close to $18 billion in 1984. They calculate that constant dollar expenditures on motor vehicle emission control have increased at an average annual rate of 22% between 1968 and 1984 (Kappler et al., 1985). It is reasonable to expect this trend to continue.

The CAC approach requires every vehicle to meet uniform per-mile emission standards. Since vehicles differ, emission reduction costs are likely to be quite different. These differences are ignored by CAC regulations, thereby raising the cost of emission control. For example, it may be cheaper to control one gram of NO_x from a four cylinder car than from an eight cylinder car. Therefore, it would be less costly to allow more control of NO_x on small cars and less control on large cars, rather than to require the same amount of control on both vehicles.

2. Delays in Complying with Emission Standards

Under the current CAC approach, per-mile emission standards are set and manufacturers must certify that their vehicles meet these standards before they can be sold in the U.S. market. While such a stringent regulation is intended to eliminate non-compliance, it does not allow manufacturers flexibility in meeting the standards. If manufacturers collectively claim that they cannot meet the standards, the only real option for EPA has been to delay the deadline for meeting the standards or to give individual manufacturers exemptions. For example, the HC and CO standards for 1975 model year vehicles established in the 1970 CAAA were delayed to 1980 model year vehicles.

3. Difficulty of Incorporating AFVs into Emission Control Strategies

Alternative fuel vehicles (AFVs) have the potential to reduce vehicle emissions relative to conventional gasoline vehicles. Three types of AFVs have received the most attention: methanol-fueled vehicles (flexible- or dedicated-fuel vehicles), natural gas-fueled vehicles (compressed natural gas, (CNG), or liquified natural gas, (LNG), and electric vehicles (battery-powered, roadway-powered, or fuel cell-powered)). The magnitude of emission reductions for the criteria pollutants from AFVs depends on the maturity of the AFV technologies, vehicle designs, emission control technologies installed on the AFVs, tradeoffs between vehicle emissions and vehicle performance, fuel characteristics, and the manner in which the fuels are produced.

Under a CAC approach to introduce AFVs, technology requirements for each AFV would be outlined and emission standards would be established. This approach forces the regulatory authority (EPA or the respective state agencies) to specify a particular technology and fuel and to require vehicle manufacturers to produce and sell a certain number of AFVs. Since AFV technologies are still immature and developing, emission standards and technology requirements cannot be based on a firm foundation. Consequently, the resulting standards and technology requirements may turn out to be too strict or not strict enough in meeting emission reduction goals. Sales requirements for AFVs means further government intervention in manufacturers' production and marketing decisions and are likely to face strong resistence.

A main cause of the above problems is the lack of flexibility inherent in the CAC approach. In contrast to the inflexibility of CAC, market-based measures offer manufacturers incentives to produce low-emission vehicles and disincentives to produce high-emission vehicles.

C. The Least Cost Strategy to Vehicle Emission Control

An important component in the choice of regulatory methods is the cost of achieving the desired outcome. As a consequence, it is important to understand from an economic perspective how emission reductions should be allocated between sources to minimize the costs of meeting an environmental standard. This section outlines the necessary conditions for achieving predetermined emission goals at minimum costs (for much more complete discussions see Baumol and Oates, Dales, and the references therein).

A necessary condition for achieving an emission standard at the least cost is that the marginal cost of emission control be equal across all sources of the emissions. The marginal cost of emission control is defined as the cost of the last unit of emissions controlled, i.e., it is the additional cost of controlling the last unit of emissions. This least-cost condition can be simply demonstrated by example.

Suppose there are two sources of emissions. Further suppose that the marginal emission control costs for the two sources increase when the amount of emissions controlled increases and that the marginal emission control cost of source 1 is smaller than that of source 2. In this case, if source 1 cleaned up one more unit of emissions and source 2 emitted one more unit, the total amount of emissions would be the same. However, the total cost of emissions control would have fallen since source 1 has controlled the additional unit of emissions at a lower cost than did source 2. The reduction in emission control cost is equal to the difference in the marginal emission control costs between the two sources. As long as there is a divergence in the marginal costs of emission control, the total costs of emission control can be reduced by reallocating the emissions clean up between the sources.

This result can also be demonstrated mathematically. Again, suppose for simplicity there are two sources of emissions. Then our problem is to minimize the total costs of clean up subject to achieving the predetermined standard. This problem can be written

$$\begin{aligned} &Min\ TC = C_1(e_1) + C_2(e_2) \\ &subject\ to\ \ e_1 + e_2 \leq S, \end{aligned} \tag{1}$$

where TC is the total cost of emission control, $C_i(e_i)$ is the emission control cost of source i to achieve emission level of e_i, and S is the predetermined standard.

The solution to this problem will characterize the least cost means of achieving the standard, S. The first order conditions for the solution to this constrained optimization problem are

$$\frac{\partial C_1(e_1)}{\partial e_1} = \frac{\partial C_2(e_2)}{\partial e_2}. \qquad (2)$$

The partial derivative of C_i with respect to e_i is the additional cost associated with one more unit of emissions, i.e., its negative is the marginal cost of emission control. The result in equation (2) then confirms the result above that the total cost of emission control will be minimized when the marginal costs of emission control are equated across sources.

Having established the importance of the marginal costs of emission control for achieving the least cost solution, we can analyze the CAC approach as a method for achieving emission standards. The requirement of CAC regulation that all sources (i.e., all vehicles) attain the same level of emissions control suggests that marginal costs are likely to be quite different between sources; hence, the total costs are not likely to be minimized. For this reason, the CAC approach does not promote the least cost solution to emissions reductions in vehicles. An alternative interpretation is that by reallocating emissions among sources, more emmisions control could be obtained for the same total cost of emissions control.

Whether more emissions control is obtained at the same total cost, the same emissions control is obtained at less cost, or some combination of the two, it seems clear that an alternative to CAC that could reallocate emissions in a more efficient way is socially desirable.

D. Incentive-Based Approaches to Motor Vehicle Emissions Control

Two forms of incentive-based regulation commonly suggested by economists are taxes and marketable permit systems (MPS). One form of a tax system suggested is a Pigouvian tax or tax per unit of emissions. Under this system, polluters are required to pay a tax for each unit of pollution they generate. Thus, emitters are subject to two types of costs related to emissions: emission control costs and emission tax payments. To minimize the sum of these two costs, a firms would control emissions to a level where the marginal emission control cost just equalled the per unit emission tax. Since each firm would be minimizing its total costs in the same way, each firm would control emissions to the point where their marginal emission control costs were just equal to the per unit tax. In this way, the marginal control costs would be equalized between firms, and the total emission control costs from all firms would be minimized.

The second alternative commonly recommended by economists is a MPS. In such a system, the environmental authority creates a limited number of emission permits and distribute them among firms. Each permit allows a given amount of emissions. Firms must hold enough permits to cover their quantity of emissions. Additionally, the permits would be tradeable among firms, so that a firm could choose to clean up additional units of pollution and sell its permits to another firm. In the permit trading market, a market-clearing price per permit would emerge that would indicate the opportunity cost of emissions. Under perfect competition, all polluters would face the same market clearing price. A firm whose marginal emission control cost is lower than the permit price will reduce emission further and sell their extra permits. A firm whose marginal control cost is higher than the permit price will choose to purchase permits and emit more, thereby lowering total costs. Through this process, emissions will be allocated between firms so that their marginal control costs are equal and total costs of emission control will be minimized.

Although both the tax system and marketable permits can achieve predetermined emission standards with minimum costs, the MPS has some important advantages over the tax system:

1. Political and Institutional Opposition to Taxes.

Although taxes are a transfer cost from society's perspective, they raise the costs to firms of doing business. As a result, firms typically oppose emission taxes. Some evidence regarding the likely large tax payments necessitated by Pigouvian tax schemes has been collected. For example, Seskin et al. (1983) estimated the emission control costs and tax payments under different tax systems to meet the NO_2 standard in the Chicago Air Quality Region. They found that firms' tax payments could be from 44-136% of the total costs firms already spent on emission control. In the current political arena, this type of tax would be difficult to establish.

An additional political concern centers on firms' rights to pollute. A tax system, it has been argued, gives firms the right to pollute. By paying a tax, they can produce as much emissions as they desire. Emission taxes, thus, can create opposition by environmental groups by seeming to sell away a clean environment. In contrast, a CAC approach retains the rights to clean air with the public, since firms are not allowed to emit beyond a specified standard. This is also true of a MPS since an explicit standard is set and the environmental authority retains control over the aggregate level of emissions.

2. Uncertainty of Emission Reductions with a Tax System

Using a MPS, the number of permits issued can be directly based on standards set by Congress or the EPA. Thus, emission reduction goals can be met with certainty.[2] In contrast, under a tax scheme, a firm will determine how much emissions it will control based on its emission control costs and the emission fee. Since environmental authorities do not know precisely what firms' control costs are, they cannot project the exact level of emission reductions generated by a particular tax. Emission reductions become known only after the system is implemented, making air quality planning difficult. Over time the tax can be changed to achieve a given air quality objective, but such changes are costly and politically difficult.

Given the current regulatory interest in marketable permits evidenced by the CAAA's inclusion of a MPS for SO_x emissions, the SQACMD plan, and CARB's MPS for vehicle emissions, it seems clear that marketable permits have enough political support to be viable.

E. An Overview of the Literature on Marketable Permit Systems

Dales (1968) first proposed marketable permits for pollution control.

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[2] Of course, there may be important enforcement issues regarding these systems, but this issue will not be addressed here.

He argued that properly defined property rights would induce firms to allocate the correct amount of resources to pollution control efforts. To create these property rights, he envisioned the creation of pollution rights and a market for their purchase and sale.

Montgomery (1972) conducted a detailed analysis of marketable permits. He demonstrated the conditions under which permits would be an efficient instrument for attaining pollution reduction goals. Montgomery also raised the issue that emission permit trading among sources in different locations might cause higher than desirable ambient pollution concentrations in some locations. Thus, it may be desirable to define permits in terms of emissions effects on ambient air quality rather than in terms of emissions.

Krupnick et al. (1983) proposed a permit system they termed "pollution offsets" to deal with the spatial problem identified by Montgomery. Under their pollution offset scheme, permits would be defined in terms of emissions, but sources of emissions would be free to trade permits only as long as the trading did not lead to the violation of ambient air quality standards. That is, emission trading between two sources would not necessarily be allowed on a one-to-one basis.

Applied researchers have estimated the potential cost savings that might accrue using marketable permit schemes of the sort envisioned by Dales, Montgomery, or Krupnick et al. These studies typically describe a permit system, define a baseline CAC system, perform simulations of pollution control costs under both systems for achieving a given pollution reduction goal, and estimate the costs of the permit system relative to the CAC system. A few examples of such studies are provided here as background.

Atkinson et al. (1974) estimated the control costs of particulate emissions from 27 sources in the St. Louis Air Quality Control Region for three approaches: the state implementation plan (SIP) under the CAC approach, the ambient least-cost approach, and the emission least-cost approach. Under the ambient least-cost approach, marketable permits were defined in terms of ambient concentrations, while under the emission least-cost approach, the permits were defined in terms of emissions. They estimated that to meet the federal primary and secondary particulate standard, the cost of the SIP strategy was 6-10 times as much as the cost of the ambient least-cost strategy, and 1.3-6 times as much as the cost of the emission least-cost strategy.

Hahn et al. (1982) estimated cost savings of a MPS for controlling SO_x emissions in the Los Angeles area. They estimated cost savings of a MPS over a CAC system for meeting two different SO_x standards in the area. The annual cost savings ranged from $8 to $23 million (1977 dollars), representing 3-19% of the annual control costs under the CAC system.

Maloney (1984) estimated the HC emission control cost at DuPont domestic plants for different levels of emission reduction. For HC emission reductions of 60-99%, the annual control cost under the CAC approach was between $25.502 million and $200.221 million (1975 dollars), and the cost using marketable permits was between $3.825 million and $141.146 million.

McGartland et al. (1985) designed a MPS for attaining air quality standards, and for preventing any additional air quality deterioration in areas that were already cleaner than the given standards. They estimated the control costs of achieving federal ambient standards of total suspended particulates in the Baltimore Air Quality Control Region under the permit system and a baseline CAC system. The annualized control cost under the CAC system was estimated to be $112.9 million (1980 dollars), while the control cost under the MPS were $46.3 million, resulting in an annual cost savings of $66.6 million by the permit system.

Diemer et al. (1988) applied the marketable permit concept to control SO_x emissions from electric power plants in Illinois and estimated its cost savings relative to the SIP strategy. Based on different assumptions about nuclear plants to be added to the electric system in Illinois, they estimated that the cost savings of the permit system was 40-60% of the cost of the SIP strategy.

Finally, Tietenberg (1985) summarized the cost savings of eight MPSs studies for air pollution control. He calculated the ratio of control costs under the baseline CAC system to that under the permit system for each study. The cost ratios range from 1.07 to 22.0 with the majority showing large cost savings under permit systems.

In summary, previous studies estimating the costs of meeting air quality goals indicate, without exception, large potential cost savings from the use of permit systems as compared to CAC systems. However, none of these studies examine the results of any actual permit markets in practice. The next section examines the limited empirical evidence available on permit systems and emission trading systems as they have been used in practice.

F. Previous Experience with Marketable Permit Approaches

In the United States, there have been only limited experiences with marketable permit type regulation schemes. Two of the more important experiences are described here, while chapter III presents some details of systems for diesel trucks. The most widely applicable system, is EPA's stationary source emission trading program which is not a MPS per se, but has characteristics of such a system. A second system is the lead trading program that was a veritable permit program. Each of these experiences will be briefly discussed.

The 1970 CAAA required emission standards for major stationary sources to be met on a large number of specific emission points such as stacks, vents, or storage tanks. The Amendments required that each source meet individual emission standards, even for sources located at one plant.

In addition to these strict requirements, the 1970 CAAA required that new facilities that generated emissions could not be built in regions where the NAAQS were not met. To prevent growth in these nonattainment areas from coming to a complete standstill, EPA proposed an emission trading program for stationary sources to allow some flexibility in emission control in a plant or region. The EPA's emission trading program includes four separate policies: bubble, netting, offset, and banking. All of these policies involve the creation of surplus emission reductions in certain sources, and their use for meeting or redefining emission control requirements applicable to other sources (51 FR 43814).

The bubble policy allows an existing plant to increase emissions at one or more sources in exchange for decreases in emissions at other sources. In addition, bubbles in primary nonattainment areas must achieve a 20% reduction in emissions after bubbles are applied. The netting policy exempts modifications of an existing major source from the new source review procedure, as long as there is no net emission increase within the source after the modification. Without the netting policy, the modification of an existing source would be treated as a new source, which is subject to new source review procedures for complying with new source performance standards (NSPS).

The banking policy allows plants to deposit emission reduction credits (ERCs) for their own future use in bubbles, offsets, or netting. States are authorized to design emission banking rules and operate emission banking. Finally, the offset policy requires that new major sources in nonattainment regions demonstrate that there exists sufficient emission reductions from other sources to more than "offset" their emissions. This allows qualified new or expanded sources to operate in nonattainment areas without interfering with the progress of attaining and maintaining air quality standards.

In its January 1986 emission trading status summary report, the EPA presented its emission trading program (EPA, 1986a). By January 1986, the EPA had directly approved or proposed 50 bubbles. Of these, the EPA estimated that $300 million were saved for their users, relative to the conventional control approach. In addition, 34 bubbles had been approved by states under generic rules of the emission trading program. Overall, more than 250 bubbles had been approved, proposed, or were under development in 29 states. The total estimated lifetime cost savings from these bubbles, relative to the cost of conventional controls was nearly $1 billion.

A second major experience the U.S. has had with marketable permits has been EPA's trading program for the phase-out of lead in gasoline. To protect public health and prevent catalytic converters from being poisoned, EPA began in 1973 to require refiners to provide unleaded gasoline and to reduce lead content of leaded gasoline. This first regulation established an average amount of lead allowable in each gallon of gasoline when leaded and unleaded gasoline were averaged together over a quarter. Fuel suppliers could meet the average lead standard through two approaches: reducing lead in leaded gasoline, and selling more unleaded gasoline.

The second phase of EPA's lead regulations, established in late 1982 and early 1983, introduced lead trading. To further the phase-out of lead in gasoline, the standard was changed from a pool averaging standard (leaded and unleaded gasoline together) to a standard applied strictly to leaded gasoline. EPA granted lead credits to refiners who produced leaded gasoline with a lead content below the standard; this credit could then be traded among refiners.

Then in 1985, the EPA tightened the lead standard of leaded gasoline from 1.1 gram per gallon of leaded gasoline (gpglg) to 0.5 gpglg on July 1, 1985, and from 0.5 gpglg to 0.1 gpglg on January 1, 1986. To give refineries additional flexibility in meeting the stringent lead standards, the EPA introduced a lead banking program.

Under the banking program, a refiner was allowed to bank lead credits below the 0.5 gpglg standard during the four quarters of 1985. The banked lead credits could be used internally or transferred to other refiners to meet the more stringent lead standard of 0.1 gpglg during 1986 and 1987. The lead trading and banking program was terminated in 1987.

EPA's lead averaging, trading, and banking programs allowed refineries flexibility in meeting the overall lead reduction goals and helped accelerate the phase-out of lead in motor gasoline. The total lead used in gasoline has been reduced to less than 1% of the lead used in the peak year of 1970 (Nussbaum, 1990).

No estimate of actual cost savings from the lead trading program is available. An EPA study for its rulemaking proposal of the lead banking program predicted lead trading activities and projected the cost savings of the lead trading program as $228 million (1985 dollars) (Schwartz et al., 1985).

G. Summary and Conclusions

This chapter has presented an overview of approaches to regulating mobile source emissions with particular attention paid to MPSs. Potential advantages of marketable permits over CAC implementation of standards and tax schemes were outlined. A description of the cost minimizing attributes of the permit system was discussed. Finally, a brief literature and discussion of marketable permit type systems that have been applied in practice was provided.

Several important points are worth noting. First, MPSs have some distinct advantages over both a CAC approach and a tax scheme. CAC approaches are inherently unable to meet emission standards at least cost, since they do not allow sources the flexibility to choose different emission levels at different sources. Marketable permits appear more politically acceptable than a tax scheme to both industry and environmental groups. Further, permits have the additional advantage of retaining direct control over the quantity of emissions with the environmental authority.

A second point that emerges from this discussion is that emission control cost savings resulting from MPSs have been estimated to be substantial. Whether such cost savings will extend to a permit system for mobile source emissions and alternative fuel vehicles is unknown. This is, of course, the main focus of the current reseach.

Chapter III. A Marketable Permit System for Mobile Source Emission Control

This chapter outlines MPSs for controlling mobile source emissions. A number of proposals for using MPSs to control emissions from vehicles has been considered, and a summary of these proposals is provided here. In addition, a MPS for mobile source emission reductions has been initiated by CARB, and the elements of that system will be outlined here. Finally, the elements of the MPSs that will be analyzed in the simulations are identified in the final section of the chapter.

A. Current Vehicle Emission and Fuel Economy Regulation

The regulation of vehicle emissions in the U.S. has been based on the emission performance of each individual vehicle. Emission standards are established for each vehicle type (passenger cars, light-duty trucks, medium-duty trucks, and heavy-duty trucks) in grams per mile (gpm) (grams per brake-horse-power for medium- and heavy-duty trucks). Vehicle manufacturers are required to have their vehicles meet uniform emission standards for vehicles within a vehicle type, regardless of differences in vehicle weight and other vehicle specifications within the vehicle type.

Compliance with emission standards is certified on the basis of vehicle engine-families. An engine-family is defined by emission control technologies employed and engine configurations, and usually contains several vehicle models. Each year, manufacturers and the EPA test some vehicle models within an engine-family (usually two vehicle models for each engine family, one with potentially high emissions, another with the highest sales potential). Manufacturers submit an application form for each engine-family to the EPA or CARB for vehicle emission certification. Detailed information on emission test results, emission control systems, engine specifications, and vehicle operation parameters are included in the application form. The EPA and CARB certify vehicle emissions based on data submitted by manufacturers. During the model year, the EPA and CARB also select some vehicles from manufacturers' production lines through the selective auditing enforcement (SAE) process and test these vehicles to confirm the test results from manufacturers. If a high percentage of vehicles within a vehicle model fails the SAE test, manufacturers are required to recall all vehicles of this model from consumers and fix the defective emission parts for these vehicles at the expense of manufacturer. The SAE is intended to prevent manufacturers from choosing vehicles with low emissions for emission certification, and ensure that vehicle emissions do not increase substantially during the useful life of a vehicle (defined as 50,000 miles).

Another aspect of vehicle regulation with relevance to emission control strategies is the treatment of corporate average fuel economy (CAFE) credits for passenger cars and light-duty trucks (LDTs). In 1975, Congress established CAFE standards for passenger cars and light-duty trucks by enacting the Energy Policy and Conservation Act of 1975. This Act requires vehicle manufacturers to have their CAFE equal to or above prescribed standards. If a manufacturer's CAFE is below the standard, a fine of $5 per car for each 0.1 mile per gallon (MPG) below the standard is levied. If a manufacturer has its CAFE above the standard, the manufacturer can earn a credit equal to the difference between its CAFE and the standard multiplied by total vehicle sales. CAFE credits from the previous three years and for the next three years are bankable; thus, banked credits can be used to offset lower CAFE for the current or future years.

A manufacturer's CAFE for a given model year is calculated by the average fuel economy (MPG) of all vehicle models produced by a manufacturer weighted by projected sales of the models. The current CAFE standard is 27.5 MPG for passenger cars, and 20.2 MPG for LDTs.

The regulation of fuel economy at the manufacturer's fleet level, rather than at each vehicle model level, allows some models with low fuel economy (usually large cars), as long as the low fuel economy of these cars is offset by high fuel economy of other models. Manufacturers have more flexibility to meet standards under this fleet performance approach than under a vehicle model performance approach (such as current vehicle emission regulation). For

CAFE regulation, manufacturers can meet the standards either by employing fuel efficient technologies, by changing vehicle sales mix, or by both.

To encourage manufacturers to produce alternative-fuel vehicles to help reduce the nation's heavy dependence on foreign oil, Congress enacted the Alternative Fuel Vehicle Fuel Economy Act of 1988 to give CAFE credits to alternative fuel vehicles. This feature of the CAFE credit may have profound effects on the economic viability of AFVs.

B. Previous Proposals for a Marketable Permit System for Mobile Sources

At least three different permit systems have been proposed at various times for use with mobile sources. Each of these proposals will be discussed in turn.

1. White's Proposal for Emission Averaging.

White (1982) argued that the U.S. vehicle emission control program was too costly and that the design of the program was too rigid. He suggested the following system of marketable permits to control vehicle emissions. At the beginning of each model year, the EPA would allocate emission permits among vehicle manufacturers through a bidding process. Manufacturers would be required to have total emissions from all vehicles sold during a model year equal to or below their emission permits. Permits could be bought or sold between manufacturers and since a manufacturer's sales in a given model year are unknown at the beginning of that year, a manufacturer who fails to bid for the correct number of permits at the beginning of the year would buy enough permits during the year to cover the difference.

As a middle ground between the current CAC approach and a full fledged permit system, White proposed fleet average emission standards. Under the emission averaging approach, sales-weighted average emissions of the vehicle fleet within a manufacturer must be equal to or below the fleet average standards. In order to reduce emission control costs, a manufacturer can meet its fleet average emission requirements by controlling more emissions from vehicles with lower control costs and less emissions from vehicles with higher control costs. White did not analyze the emission and cost impacts of the emission averaging system.

2. EPA's Study of Emission Averaging and Trading for Light-duty Vehicles

In 1981, an EPA staff report proposed economic approaches to vehicle emission control (Larson et al., 1981). The authors proposed emission averaging within a company and emission trading among companies for determining the compliance of emission certification. The authors further proposed fines on the vehicles not meeting standards during the SAE process as an alternative to the current requirement of vehicle recalls.

In the early 1980s, the U.S. EPA office of Policy and Resource Management supported a study estimating the control cost savings of light-duty vehicle emission averaging and trading, relative to the uniform emission standard requirements (TCS Management Group, Inc., 1984). A MPS was designed to include emission averaging within a manufacturer, emission trading among manufacturers, emission banking over time, and emission charges (allowing manufacturers to pay fees for the emissions in excess of emission standards). Cost savings were then estimated for each of the components.

The study calculated vehicle emission control costs as a function of emission levels using data on vehicle certification emissions and the estimated emission control costs of new vehicles between 1979 and 1982. Individual emission control cost functions were estimated for eight major manufacturers and for three light-duty vehicle classes (4-, 6-, and 8-cylinder) (Sobotka and Company, Inc., 1983; Jack Faucett Associates, Inc., 1982). An optimization model was used to estimate total emission control costs of meeting different emission control requirements (i.e., emission averaging, emission trading, emission banking, emission charges, and uniform emission standards). The optimization model assumed that manufacturers minimized control costs to meet given emission requirements.

The cost savings estimated by the study are shown in Table 3.1 and Table 3.2. Table 3.1 shows the cost savings of meeting 1981 emission standards using different regulatory approaches, while Table 3.2 shows the cost savings at the 1981 certification levels. Large cost savings were attributed to the permit system to meet the 1981 emission standards (Table 3.1). However, most of the cost savings resulted from increases in actual emissions, due to the decrease in or elimination of an emission safety margin (the difference between emission standards and actual emissions).

If emission levels were held constant at the 1981 certification levels, cost savings from the permit system were relatively small (Table 3.2). For example, emission averaging resulted in only a 0.4% reduction in emission control costs. Emission averaging and trading together reduced control costs by 12%.

Table 3.1. Emission Control Cost Savings of Marketable Permit System: Meeting 1981 Standards (Source: TCS, 1984)

	Dollar Savings (1981 $, million)	Percentage of Emission Control Cost
Averaging	353	18
Averaging and trading	737	37
Averaging, trading and banking	1050	54

Table 3.2. Emission Control Cost Savings of Marketable Permit System: 1981 Certification Emission Level (Source: TCS, 1984)

	Dollar Savings (1981 $, million)	Percentage of Control Cost
Averaging	9	0.4
Averaging and trading	234	12

For a number of reasons, the results of this study probably do not accurately reflect the potential cost savings associated with a MPS for current and future levels of emission control. First, the cost functions in the study estimated emissions control costs per vehicle to be less than $200. This is much lower than most people would consider reasonable for current emission control costs. Moreover since vehicle emission standards will become much more stringent after 1994, future emission control costs can be expected to be substantially larger still. Second, although the MPS is designed to allow trading based on vehicle engine families, the simulation was based on only three vehicle classes. Since manufacturers might often be expected to average emissions over as many as 30 engine families, there is likely to be much more flexibility for manufacturers than the simulation represents.

The EPA further analyzed the impacts of averaging and trading on the competitive ability of manufacturers and passenger car market structure (Sobotka and Company [SCI], Inc., 1984). The analysis concluded that the averaging and trading program would be very unlikely to have any significant impacts on either individual manufacturers or the competitiveness of the vehicle market.

3. Emission Averaging in the proposed Clean Air Act Amendments of 1989 (the White House, 1989; EPA, 1989a).

In the Clean Air Act Amendments proposed in 1989 by the Bush administration, stringent vehicle tailpipe emission standards were established to help attain the NAAQS in many U.S. areas. To achieve the stringent emission standards and to encourage production of alternative fuel vehicles, the proposed amendments suggested a permit system for vehicle manufacturers, and a permit system for vehicle fuel suppliers (called a fuel pooling averaging system). Under the vehicle emission trading program, vehicle manufacturers would be required to meet corporate average emission standards. Manufacturers could earn transferable credits from the vehicles with emissions lower than the standards. The credits could be used to bring down the manufacturer's average fleet emissions, or sold to other manufacturers. This permit system would provide manufacturers incentives to produce alternative fuel vehicles with low emission characteristics in order to earn emission reduction credits.

To ensure alternative fuels available to alternative fuel vehicle users in a region, fuel suppliers would be required to supply a certain amount of alternative fuels, based on sales projections of alternative fuel vehicles. To help meet alternative fuel requirements, the Amendments established a fuel pooling program through which fuel suppliers could obtain transferable credits for exceeding applicable requirements. The credits could be sold to other suppliers. Neither the vehicle MPS nor the fuel pool averaging system was adopted in the 1990 CAAA.

C. Previously Adopted Averaging Systems for Vehicle Emission Control

There have been two averaging systems that have been employed in the control of vehicle emissions. The first such program is the particulate matter (PM) averaging program for emissions from light-duty diesel vehicles. In 1981, the EPA proposed an averaging program for controlling PM emissions from light-duty diesel vehicles (passenger cars and light-duty trucks) (EPA, 1981). The EPA adopted the program in 1983 to help meet the proposed stringent diesel PM standard for 1985 model-year diesel cars and light-duty trucks (EPA, 1983). The EPA claimed that the averaging program would give manufacturers flexibility in meeting the stringent PM standard, and, therefore, would result in control cost savings. The EPA estimated cost savings for the averaging program ranging from $50 to $111 million per year, depending on control technologies and the NO_x standard. The PM averaging program required two-steps in emission compliance: compliance with engine-family emission limits (EFELs) and compliance with the average standard. For each of its engine families, a manufacturer establishes EFELs that are certified by the EPA. Vehicle models within an engine family must not emit PM above the EFEL. The certification of complying with the EFEL is similar to that of certifying emission standards under the conventional regulatory system. The EFEL must be met during the useful life of a vehicle. To comply with the average PM emission standard, production-weighted PM emission rates of all light-duty vehicles produced by the manufacturer must be equal to or below the average standard.

Vehicle manufacturers supported the emission averaging concept in general. Some manufacturers even proposed the use of emission banking in complying with the PM emission standard. However, manufacturers disagreed with the EPA on some technical issues of the averaging approach. For example, manufacturers suggested that vehicle configurations, not engine family, should be used as the basis for emission averaging to allow greater flexibility in the averaging program.

To limit the possible emission increases in different regions due to the averaging program, the EPA does not allow averaging between non-California engine families and California engine families, and between low-altitude engine families and high-altitude engine families. Averaging between gasoline-fueled vehicles and diesel-fueled vehicles is not allowed because the inherent low PM emissions of gasoline vehicles could cause an increase in total PM emissions, and because allowing PM trading between gasoline vehicles and diesel vehicles could have adverse impacts on emissions of other pollutants (especially NO_x and SO_x). However, averaging between light-duty diesel cars and light-duty diesel trucks is allowed.

Environmental groups argued that total PM emissions under the averaging program may increase, relative to an each-and-every vehicle PM standard, because of the foregone safety margin of complying with a uniform standard. The EPA claimed that the safety margin within an engine family under the averaging program should remain, because vehicle models within the engine family still needed to meet the uniform EFEL.

Since the early 1980s, diesel light-duty vehicles sales have declined dramatically, due to technical problems with diesel vehicles and the diminished difference between diesel fuel prices and gasoline price (Kurani et al., 1988). The share of PM emissions from diesel light-duty vehicles and trucks, therefore, is small, and the averaging program has not been used extensively by manufacturers.

The second marketable permits type system that has been employed is the emission averaging, trading, and banking policy for heavy-duty trucks (HDTs). In 1984, the EPA proposed an averaging program for heavy-duty diesel engines to meet the proposed PM emission standard (EPA, 1984). Since the gross vehicle weight rating (GVWR) of heavy-duty vehicles (HDEs) varies widely (from 8,500 lbs up to 40,000 lbs or more), the cost of meeting a uniform emission standard by large HDEs would have been prohibitively expensive.

Like the averaging program for light-duty diesel vehicles, the proposed heavy-duty engine PM averaging program required two steps in emission compliance: compliance with EFELs and compliance with average emission standards. The EFELs of engine families are established by manufacturers and certified by the EPA. Engines within an engine family must not emit PM greater than the EFEL of the engine family, and the production-weighted fleet average PM emissions of a manufacturer must meet the average standard. Both gasoline and diesel HDEs are included in the program.

In designing the HDE program, the EPA considered four criteria: (1) the program must be workable for EPA's enforcement and for industry's compliance; (2) the program must be consistent with the provisions of the Clean Air Act; (3) the program must not result in increases in total emissions; and (4) the program should, to the extent possible, minimize inequitable impacts on the affected manufacturers (EPA, 1986b).

Based on these criteria, the EPA applied the following restrictions to its permit program. First, the averaging program applies only to the same fuel type. Emissions from gasoline HDEs may not be averaged with emissions from diesel HDEs. This restriction helps alleviate potential adverse equity impacts on manufacturers, and adverse tradeoffs of NO_x and PM from different engines due to different emission characteristics and usage patterns of different vehicle and types/engine types. Second, averaging of heavy-duty diesel engines (HDDEs) is restricted within each of the subclasses: light HDDE, medium HDDE, and heavy HDDE. Averaging between these subclasses is prohibited because of the wide variations of lifetime mileage accumulation. Third, averaging is based on engine families. EFELs are established by a manufacturer for each family that participates in the applicable averaging program, and the weighted emissions by production and power are compared to the applicable standards to determine compliance. Fourth, ceilings on EFELs are applied to HDE NO_x and HDDE PM averaging programs for preventing the introduction of gross-emitting vehicle families that could cause significant localized environmental impacts. Fifth, regional restrictions in averaging are applied. Manufacturers are prohibited from averaging together emissions from non-California and California-certified engine families, as well as from high-altitude and low-altitude engine families. Finally, urban buses are excluded from the HDDE PM averaging program, because inclusion of these vehicles could have significant urban air quality impacts.

In 1989, the EPA further proposed to include emission trading and banking in the averaging program, creating a complete MPS for controlling HDE PM and NO_x emissions (EPA, 1989b). Besides gasoline- and diesel-fueled HDEs, methanol-fueled HDEs are included in the MPS. The EPA claims that the MPS would help reduce the cost of controlling HDE NO_x and PM emissions. The EPA claimed that the economic incentives created by the system would act to promote the development and use of improved emission control technologies and sales of alternative fueled HDEs. The achievement of emission control technologies and use of alternative fuels could then serve as the technological basis for more stringent emission standards in the future.

To allow manufacturers greater flexibility, the EPA proposed three additional provisions. First, averaging and trading between diesel- and methanol-fueled diesel HDEs would be permitted due to similar emission traits and usage characteristics of diesel HDEs. For the same reason, averaging and trading between gasoline- and methanol-fueled Otto-cycle (the 4-stroke, spark-ignition, gasoline-fueled engine combustion cycle) HDEs would be permitted. Second, averaging and trading of PM emissions among all engine families within urban bus subclasses would be allowed, while a ceiling of EFELs for urban buses is applied. Third, averaging and trading of NO_x emissions between urban bus engines and other subclass engines would be permitted.

Environmental groups had concerns about the environmental consequences of EPA's MPS, and strongly opposed the program. The Natural Resources Defense Council (NRDC) pointed out that the trading and banking system proposed by the EPA would cause increases in emissions from HDEs (NRDC, 1989). Although the two-step compliance process of the MPS can maintain the safety margin (or design cushion) among engines within an engine family, the system will not maintain the safety margin among engine families. If a MPS is applied to engine families, manufacturers will shave the design cushion of engine families, and emission certification rates on average for the industry will be equal to emission standards. The actual emissions under the permit system will, therefore, increase relative to emissions under the current system.

In 1990, EPA adopted a revised MPS to control HDE NO_x and PM emissions (EPA, 1990b; EPA, 1990c). In response to the concerns of possible adverse air quality impacts of the permit system, the EPA established several restrictions on the permit system. First, all trading and banking credits are subject to a 20% one-time discount rate. Second, two programs are established for banking: a transition program for the early stage and a rolling program beginning in the 1994 model year. Under the transition program, only engine families whose emission levels meet the eligibility criteria will be eligible to generate emission reduction credits (ERCs). The eligibility criteria are defined by the EPA in terms of HDE emission characteristics. Under the rolling program, ERCs generated in any given model year can be withdrawn for three succeeding model years. ERCs not used by the end of the third year will be forfeited. Third, cross-subclass averaging and trading of NO_x and PM emissions are not permitted among diesel cycle engines. Fourth, averaging and trading between non-California engines and California engines are not permitted. Fifth, HDEs fueled by CNG are not included in the emission trading program, due to the lack of emission standards and test procedures. The EPA may include CNG-fueled HDEs in the future.

EPA supported a study to estimate cost savings of its early version of the MPS (Sobotka and Company, Inc. [SCI], 1986). In the study, SCI divides HDEs into four subclasses: heavy-duty gasoline engines (HDGE), light-heavy-duty diesel engines (LHDDE), medium-heavy-duty diesel engines (MHDDE), and heavy-duty diesel engines (HDDE). Cost savings of the permit system are estimated for three scenarios: the restricted program--trading and averaging are allowed only within an engine subclass; the partially restricted program--trading and averaging are allowed among three diesel engine subclasses, but not between gasoline HDEs and diesel HDEs; and the unrestricted program--trading and averaging are allowed among the three diesel subclasses and between gasoline HDEs and diesel HDEs.

Assuming actual production-weighted NO_x and PM emissions to be 80% of the 1991 model-year emission standards (80% is used to take into account the emission design cushion [assuming 20%]), SCI estimates cost savings of the MPS for the three scenarios (Table 3.3). The results show substantial control costs can be saved by the MPS. The contribution of permit system components to cost savings is different under the three trading scenarios. Under the restricted and partially restricted program, averaging mainly contributes to cost savings, while under the unrestricted program, both averaging and trading contribute to cost savings. SCI also estimates cost savings of banking as about 2% of total control cost.

Table 3.3. Annual Cost Savings of Emission Averaging and Trading: HDEs (SCI, 1986, 1986 $)

	Control cost (million $)	Savings (million $)	Percentage
Baseline--no averaging or trading	1,009.6	N/A	N/A
Averaging:			
Restricted	886.5	123.1	12.2
Partially restricted	851.4	158.2	15.7
Unrestricted	818.1	191.5	19.0
Averaging and trading:			
Restricted	878.7	130.9	13.0
Partially restricted	842.4	167.2	16.6
unrestricted	710.9	298.7	29.6

EPA's HDE marketable permit system is the first such system to be applied to motor vehicle emission control. The economic benefits of the system will become clear as the program is taken advantage of by manufacturers.

D. CARB's Low-Emission Vehicle Program

California has the worst air quality in the nation, even though it has the most stringent emission regulations for both mobile and stationary sources. Although a 0.25 gpm non-methane hydrocarbon (NMHC) standard has been adopted for automobiles and LDTs for 1993 and later model year vehicles to attain national and state air quality standards (especially the ground level ozone standard), further reductions in mobile source HC emissions will be necessary. In the summer of 1989, following the recommendations of the AB 234 Advisory Board on Air Quality and Fuels, CARB established a low-emission vehicles/clean-fuels program to further reduce mobile source emissions (CARB, 1989a). This program is intended to introduce clean fuels and low-emission vehicles designed to operate on such fuels. In the draft proposal, CARB defines two types of low-emission vehicles: low-emission vehicles (LEVs) and ultra-low-emission vehicles (ULEVs). CARB proposed to require that a certain percentage of new vehicles sold in California would have to be LEVs and ULEVs beginning in the 1997 model year.

In late 1989, CARB refined its initial proposal (CARB, 1989b). To help gradually develop and introduce LEVs, CARB added one more vehicle type: transitional low-emission vehicles (TLEVs), that were between conventional vehicles and LEVs. TLEVs would be required beginning in the 1994 model year. Emission standards and sales requirements for each of the three types of vehicles were established. Also, fuel suppliers would be required to sell a certain percentage of fuels as clean fuels, commensurate with the number of TLEVs, LEVs, and ULEVs.

Vehicle manufacturers strongly opposed the sales requirement of different types of low-emission vehicles due to the difficulty of changing production lines quickly for each type of vehicle. Following the concept of an incentive approach to introduce alternative fuels proposed by the AB 234 Board (California Advisory Board on Air Quality and fuels, 1990), CARB introduced a credit system to fulfill its sales requirements (CARB, 1990a). Manufacturers who sold a greater number of cleaner vehicles could offset their sales requirement of less clean vehicles. Therefore, the initial fixed sales requirement for each type of vehicle became a flexible sales requirement. Also, a new vehicle type --- zero-emission vehicles (ZEVs) was added in the proposal. Based on NMOG emission performance for the four types of vehicles, sales trading ratios among vehicle types were established.

The sales trading ratio between different vehicles established by CARB was debated. For example, CARB established a trading ratio of 2 between ZEVs (basically electric vehicles) and TLEVs. Utility companies argued that a ratio of 5 should be assigned. It was also argued that the trading ratio alone would place severe constraints in manufacturers' options for meeting the requirement of LEVs. CARB then revised its sales credit system to an emission credit system in its final proposal (CARB, 1990b). Under the new credit system that regulates sales-weighted, fleet-average emissions of NMOG, any combination of TLEVs, LEVs, ULEVs, ZEVs, or conventional vehicles could be sold as long as each manufacturer's fleet did not exceed the fleet average standard for NMOG. Emission standards were established for each type of vehicle. Emissions of the vehicles within a vehicle type could not exceed the emission standards for this type. Emission standards for each vehicle type are shown in Table 3.4 below.

Table 3.4. Emission Standards: gpm at 50,000 miles
(Passenger Cars)

Vehicle type	CV	TLEV	LEV	ULEV	ZEV
NMOG	0.25[a]	0.125	0.075	0.040	0.0
CO	3.4	3.4	3.4	1.7	0.0
NO_x	0.4	0.4	0.2	0.2	0.0
HCHO	0.015[b]	0.015	0.015	0.008	0.0

a Emission standard of NMHC.
b This standard is applied only to methanol vehicles.

In addition, CARB established fleet average NMOG emission requirements for light-duty vehicles from the 1994 to the 2003 model years. Manufacturers may certify vehicles to any combination of the conventional (CV) and low-emission vehicle categories (shown in table 3.4 above) to meet the average requirement. A manufacturer whose fleet average NMOG is below the average requirement would earn credits equal to the difference between the standard and its sales-weighted average rate multiplied by its total sales. These credits could be banked internally for the manufacturer's later use or traded to other manufacturers. Trading and averaging between light-duty vehicles with weight less than 3750 lbs and light-duty vehicles with weight greater than 3750 lbs are permitted. Also, manufacturers that fail to achieve the fleet average requirement in any given model year would be required to make up the shortfall in the next model year by lowering their sales-weighted average. To discourage manufacturers from accumulating credits as a means to delay certifying LEVs or ULEVs at the earliest date, different discount rates are applied to manufacturers' emission reduction credits in different consecutive years (Table 3.5).

Table 3.5. Fleet Average NMOG Standard: gpm, Passenger Cars

Model year	Car and LDTs < 3750 lbs	LDT > 3750 lbs
1992	0.390	0.500
1993	0.334	0.428
1994	0.250	0.320
1995	0.231	0.295
1996	0.225	0.287
1997	0.202	0.260
1998	0.157	0.205
1999	0.113	0.150
2000	0.073	0.099
2001	0.070	0.098
2002	0.068	0.095
2003 and after	0.062	0.09

To foster the development of the cleanest vehicle technologies, CARB established sales requirements for ZEVs (currently only battery-power electric vehicles qualify) in model years after 1997, in conjunction with the marketable permit program. A manufacturer who sells more than the sales requirement may earn sales credits. These credits could be used for offsetting the manufacturer's future sales requirement, or they could be traded to other manufacturers.

Vehicle manufacturers support CARB's MPS, since the system gives them flexibility in meeting stringent emission standards (CARB, 1990c). Also, environmental groups support the market concept applied to achieving CARB's stringent emission standards (CARB, 1990c).

CARB has adopted the low-emission vehicle program (CARB, 1990d). The final program contains a banking provision. The banking provision will start to be implemented with 1994 model-year vehicles (the same model year when the low-emission vehicle programs begins to be implemented). The banking provision includes forward- and backward-banking of vehicle emission reduction credits (ERCs).

Forward banking allows manufacturers to bank emission reduction credits earned from the previous model-year vehicles, and to use them to offset emissions of the future model-year vehicles. Discount rates are applied to the banked ERCs. In the first of the year, the ERCs carry the full emission reduction value. In the second year, the value of ERCs is reduced to 50% of their original emission reductions. In the third year, the value is reduced to 25%. In the fourth year and after, the value is reduced to zero.

Backward banking allows manufacturers to use the ERCs earned from future model-year vehicles to offset emissions of the current model-year vehicles. In the 1995 model year, manufacturers can use the ERCs earned from the 1996-1998 model year vehicles to offset emissions of the 1995 model-year vehicles. In the 1996 model year, manufacturers can use the ERCs earned from 1997-1998 model-year vehicles to offset emissions of 1996 model-year vehicles. In 1997 and future year, manufacturers can use the ERCs earned only from the next mode-year vehicles to offset current emissions.

CARB's low-emission vehicle program is a revolutionary approach to emissions control, allowing manufacturers flexibility in meeting vehicle emission regulations. The concepts of averaging, trading, and banking are introduced full scale to regulate emissions of light-duty vehicles. However, some issues with CARB's MPS need to be investigated. First, the program of averaging, trading, and banking is primarily based on NMOG emissions. The use of any combination of vehicle types to meet fleet average NMOG standards could result in an increase in emissions of other pollutants, such as CO and NO_x, relative to their levels under CAC.

Second, the MPS is based on emission levels of five vehicle types: conventional vehicles, TLEVs, LEVs, ULEVs, and ZEVs. Emissions from vehicles within each type are not allowed to exceed the emission limit established for the vehicle type. Thus, the emission design cushion within a vehicle type would be maintained, and possible emission increases from a trading program can be prevented. However, the restricted averaging, trading, and banking among the five vehicle types may reduce the cost savings of the program due to its reduced flexibility. Third, the credits banked for future use could have large emissions impacts in the future. Since the main goal of the low-emission vehicle program is to help California meet the federal and state air quality standards, the emission impact of the marketable system over a period of time should be analyzed.

E. A Description of the Marketable Permit System Used in Our Simulation Model

This section describes the features of the MPS used in our simulation. A complete MPS would include three components: averaging within a manufacturer, emission trading among manufacturers, and emission banking over time. Currently, our simulation includes only the first two components. Later work may incorporate the effects of banking into the simulation. The MPS we employ is designed to mimic very closely the permit system developed by CARB.

Under the MPS envisioned in our simulation, corporate average emission standards for light-duty vehicles are established. Manufacturers are required to meet the average emission standards in the same way that they must currently meet CAFE regulations. An individual vehicle is not subject to emission standards; rather a manufacturer's fleet average emissions is subject to a standard. The fleet average emissions are calculated from the certified emission rates of a manufacturer's engine families weighted by the projected annual sales of the vehicle models within an engine family.

In a general MPS, average emission standards would be established for HC, CO, and NO_x, separately. Manufacturers would be required to meet the average standards for each of the three pollutants. Averaging among pollutants would not be permitted since across-pollutant averaging could intensify the adverse health effects of one pollutant or another. Since CARB's proposal includes only HC trading, we include HC trading in the first round of our simulation work. Later, we plan to incorporate trading among all three pollutants to determine whether the benefits of a MPS increase when all three pollutants can be traded.

To enforce satisfaction of the corporate average vehicle emissions, vehicles would be tested for emission certification in the same way as vehicles are currently tested for emission compliance. Manufacturers must determine the emission levels of each engine family and submit emission test results of each engine family for emission certification. Emission certification of a manufacturer would require two steps for compliance: vehicle models within an engine family must comply with the family emission levels (FELs), and the manufacturer must comply with the average emission standards. The FEL compliance is similar to the current emission standard compliance.

Corporate average emissions can be calculated using two different weighting factors: production volume of each engine family, or sales volume of each engine family. We use sales-weighted emissions because production-weighted emissions may not represent the actual in-use vehicle fleet in a region. Also, sales-weighted emissions can be easily applied to a regional level by using regional sales data. In addition, vehicle sales information is currently collected in the emission compliance process and for the CAFE regulation.

Since vehicles must be certified for emission compliance before sales data on that year is available, projected vehicle sales must be used to calculate corporate average emissions. By the end of each model year, projected sales-weighted emissions would then need to be corrected by the actual sales in the model year. The adjustment of corporate average emissions by actual sales is necessary, because it would prevent the intentional projection of high sales of clean-fuel vehicles. If emissions calculated from projected sales are less than emissions calculated from actual sales, manufacturers would be required to make up the emission difference in the following model year. Otherwise, if emissions calculated from projected sales are higher than emissions calculated from actual emissions, manufacturers would earn emission credits that could be used for averaging emissions in the following model year.

The corporate sales-weighted average emissions will be calculated as the following:

$$CAE_i = \frac{(\sum_{j=1}^{n} E_{ij} * Sales_j)}{\sum_{j=1}^{n} Sales_j}, \quad (3)$$

where:

CAE_i = corporate average emissions for pollutant i (gpm)

E_{ij} = emissions of pollutant i for engine family j (gpm)

$Sales_j$ = sales volume of engine family j (equal to sales of all models covered by the engine family)

i = 1, 2, 3 to represent HC, CO, and NO_x

j = engine family, small, medium, large

n = the total number of engine families within a manufacturer.

Manufacturers can lower their fleet emissions either by lowering emission rates (E_{ij}), by increasing the share of low-emission vehicles ($Sales_j$), or both. A change in E_{ij} comes from changes in emission control technologies employed on the vehicles, while changes in $Sales_j$ results from changes in the vehicle mix. As mentioned in the previous section, emission averaging in CARB's low emission vehicle program is based on five vehicle categories (n=5).

One important difference between the permit system envisioned by CARB and the one envisioned here is that emission averaging can be based on engine families. The number of engine families is much larger than five (for example, the three domestic manufacturers have 25-40 engine families each). In this way, the engine-family-based permit system will likely achieve considerably larger cost savings than CARB's vehicle-category-based permit system. In the simulation work, cost functions are based only on vehicle classes (based on cylinder sizes). As such, the actual simulation results are for a system somewhere between CARB's vehicle categories and the engine families based system we envision.

As an aside, it is worth noting that the permit system could be based on vehicle models. There are over 1000 passenger car and light truck models. Therefore, the use of a vehicle model basis would result in greater averaging flexibility. However, to enforce the model-based program, the number of vehicle emission tests necessitated would increase substantially. It is unclear whether the additional cost savings of a model-based program would outweigh the additional operational and administrative burden. An additional consideration is that actual emissions from the vehicle model-based program may increase over the emissions from the engine family-based program due to the reduced need for a safety margin.

Emission averaging gives vehicle manufacturers the opportunity for reallocating emission control efforts among their engine families. The emission trading component of a MPS provides the opportunity to reallocate emission control efforts among engine families across manufacturers, resulting in greater flexibility in meeting emission standards at the auto industry level. Emission trading would occur in the permit system envisioned in our simulation in the following way. If a manufacturer's fleet emissions are less than the average emission standards, the manufacturer will earn emission reduction credits (ERCs) which are the currency in the market of emission trading. The ERCs earned in a model year are the difference between the average emission standards and the manufacturer's fleet average emissions multiplied by its total vehicle sales in the model year. These earned ERCs can be sold to other manufacturers. Emission reduction credits will be computed as

$$ERC_i = (CAES_i - CAER_i) * Sales \qquad (4)$$

where:

ERC_i = emission reduction credit of pollutant i (gpm-vehicle per year)

$CAES_i$ = corporate average emission standard of pollutant i (gpm per vehicle)

$CAER_i$ = corporate average emission rate of pollutant i (calculated as the above formula, gpm per year)

Sales = total annual vehicle sales (the sum of sales of all engine families)

To effect the trades of ERCs between manufacturers, a formal emission trading market will be established to conduct transactions. Since there are about a dozen major manufacturers in the U.S. light-duty vehicle market, the trading market will be less complex than the stationary emission trading market. The latter could involve thousands of participants. A private agency could emerge to broker the purchase or sale of ERCs. The EPA and CARB would still need to certify the ERCs earned by manufacturers and at the end of a model year, manufacturers will be required to submit to the EPA or CARB information on the ERC transactions for emission compliance.

The ERCs earned by a vehicle manufacturer represent a valuable commodity in the trading market. If a manufacturer's emission control cost of earning ERCs is less than the market price of the ERCs, the manufacturer will control emissions below the applicable standards to earn ERCs. In contrast, if a manufacturer's emission control cost is higher than the market price of ERCs, the manufacturer will control less emissions and buy ERCs to satisfy its requirements for emission control. Emission control cost savings are created by such emission trading, as long as there are differences in emission control costs among manufacturers. Emission control cost differentials should exist, because there are differences in technical expertise, production lines, and plant retooling capabilities for new vehicle production among manufacturers.

F. Summary and Conclusions

A MPS of the sort outlined here has the potential for achieving emission control cost savings relative to the current CAC approach. Emission averaging helps equalize marginal costs of emission control among different engine families within a manufacturer. Emission trading helps equalize marginal control costs among engine families across the automotive industry. The equalization of marginal costs results in reduced costs of emission control. The simulation model outlined in the next chapter is intended to estimate the reductions in costs associated with this MPS.

Chapter IV. Cost and Emissions Data for Estimating Gasoline Vehicle Emission Control Costs.

This section describes the data collection procedure and provides summaries of the data collected for use in estimating cost functions for gasoline powered vehicles. Since the MPS analyzed in our study is based on individual engine families, a cost function for each engine family among manufacturers is needed to estimate the cost of meeting emission standards using a permit system.

Currently, there are about three hundred engine families produced for the U.S. auto market. To establish individual cost functions for these three hundred engine families, much detailed engineering data on emission control strategies, emission performance, and emission control costs for each of the engine families would be needed. Instead of establishing a cost function for each engine family, an alternative is to establish a cost function for a group of vehicles with similar emission control strategies and emission performance. However, by establishing a cost function for a group of engine families and allowing emission averaging and trading among vehicle groups, not among vehicle engine families, the simulation model can estimate emission control cost savings of emission averaging, trading, and banking only among the vehicle groups, not among engine families. Hence, our simulation will tend to underestimate the cost savings of a MPS.

Grouping vehicles could be based on vehicle weight, engine displacement, or number of cylinders. Although these three parameters are closely correlated with each other, we chose the number of cylinders to categorize vehicles. The number of cylinders determines the number of fuel injectors of the multi-point electronic fuel injection system (more vehicles are designed with multi-point fuel injection than with throttle body fuel injection), and the number of catalytic converters in some cases. The fuel injection system is considered as an emission control system here. Based on the number of cylinders, we have grouped vehicles into three classes: small, medium, and large vehicles. Small vehicles include vehicles with 4-cylinder engines, medium vehicles include vehicles with 5- and 6-cylinder engines, and large vehicles include vehicles with 8- and 12-cylinder engines.

A. Data Requirements for Vehicle Emission Control Cost Functions

Emissions of light-duty vehicles are regulated for three pollutants: hydrocarbon (HC), carbon monoxide (CO), and nitrogen oxides (NO_x). The control of these three pollutants are often interrelated. To capture these effects, we estimate multi-variate emission control cost functions, i.e., emission control costs are a function of levels of emissions of HC, CO, and NO_x. We use data on tailpipe emissions and emission control costs for different vehicle models to establish vehicle emission control cost functions.

Vehicles must be certified to be in compliance with emission standards before they can be sold in the U.S. market. Vehicle emission certification is based on engine families, which define a unique combination of engine displacement and a set of emission control systems. One engine family usually includes several vehicle models. Vehicle samples within each engine family are tested through the Federal Test Procedure (FTP) to measure tailpipe emissions. Usually, two vehicle models within an engine family are tested, one represents the high-emission model, another represents the high-sales-volume model. However, the number of vehicles tested for an engine family can vary from one up to six, depending on the reliability of test results and the complication of emission control systems. Tailpipe emissions are presented in grams per mile at 50,000 miles, and compared with applicable emission standards for emission certification.

Emission certification rates for the three pollutants for vehicle engine families certified in California in 1990are employed. As mentioned above, a number of vehicles are tested within one engine family. As a result, we have one data point in our sample for each tested vehicle.

Although there have been studies estimating vehicle emission control costs (for example, Lindgren, 1978), there has been no estimate of emission control costs for individual vehicle models. Regulatory agencies, like the EPA and CARB, estimate the cost of emission control systems for generic vehicle fleets (i.e., passenger cars and LDTs) for assessing the cost of meeting a proposed emission standard. They typically do not differentiate emission control costs by vehicle model.

Our approach to estimating vehicle emission control costs is to identify the emission control systems for individual vehicle models, to estimate costs of these systems, and to aggregate the cost of individual systems together as total emission control costs. To identify emission control systems installed on individual engine families, information in manufacturers' application forms to CARB for vehicle emission certification are used.

During the process of certifying engine families for compliance with emission standards, manufacturers submit to the EPA or CARB an application form for each engine family for emission certification. The application form contains detailed information on vehicle design and technical specifications, vehicle operation parameters for emission tests, vehicle models included in the engine family, emission control systems, and required maintenance of these systems. The information on emission control systems for an engine family is presented in the emission part list in the application form. In the part list, the manufacturer lists emission control parts and their part numbers. Information on emission control systems for individual engine families was obtained from the emission part lists.

The cost of individual emission control systems for each engine family can be estimated through two approaches. The first approach is to identify the difference among different vehicle models in terms of material and labor consumption used in manufacturing the system. By accounting for the material cost, labor cost, and different overhead costs, the total cost of an emission part for a vehicle model can be estimated. Although a previous EPA study has taken this engineering approach to estimate cost of emission control systems for generic vehicle classes, not for individual vehicle models (Lindgren, 1978), this approach needs much detailed understanding of designing and manufacturing emission parts. In order to identify cost difference among manufacturers and among vehicle models, the approach also needs detailed information on each manufacturer's production plans and profits, and the way in which a particular vehicle model is made.

The second approach is to find the price of an emission part for a particular vehicle model, and discount the price to the manufacturing cost of the part by accounting for manufacturer and dealer markup. Since emission parts are manufactured by independent part suppliers, as well as by vehicle manufacturers, the price of a part should be determined relatively competitively, and, therefore, should accurately reflect the cost the a part. This is especially true for non-proprietary parts, the parts which can be made without patents or special technology. Each manufacturer gives its dealers the manufacturer's suggested retail price (MSRP) for major vehicle parts. The approach is to collect MSRPs for emission control systems and discount the MSRPs to the manufacturer level to compute the cost of emission control systems.

B. Determining Emission Control Systems for Engine Families

The information on emission control systems for a particular engine family is presented in two lists on the emission application form: the high-cost part warranty list and the emission part warranty list. In the high-cost warranty list, emission parts whose price is equal to or greater than $300 must be listed. This price limit is applied to 1990 model-year vehicles. The limit is increased to $310 for 1991 model-year vehicles to account for inflation. It is manufacturers who determine which parts are in the high-cost list.

Prior to 1990, CARB had an emission part warranty list that had to be submitted by manufacturers in the application forms. After 1990, CARB abandoned this requirement. However, manufacturers still voluntarily present the emission part warranty list in their application forms. In contrast, prior to 1990, there was no requirement of the emission part warranty list in application forms at the federal level, but after 1990, the EPA requires manufacturers to present the emission part warranty list. There is a general guideline both at the federal level and in California for manufacturers to determine which parts should be included in the emission part warranty list. In general, manufacturers have presented in the part list any vehicle parts that could affect vehicle emissions.

Manufacturers have the right to put into the list some parts which they believe as emission related parts. For example, some manufacturers put the fuel metering system and ignition system on the list, while others do not. In many cases, decisions on which parts to include in estimating vehicle emission control costs had to be made. Emission parts were obtainedfrom the part lists of the application form for each engine family. Choices were discussed with manufacturers' representatives and we have divided the emission parts into six difference groups. Different groups' costs are weighted differently in determining emission control costs. Table 4.1 presents the emission part groups based on discussions with manufacturers' representatives.

Table 4.1. Emission Part Groups
(from the part list of engine family application forms)

Emission Part Group	Emission Control System	Emission Part
Tailpipe emission control	oxygen sensor	oxygen sensor
	catalytic converter	catalytic converter
	PCV valve	PCV valve
	EGR system	EGR valve ;,2 EGR temperature sensor EGR amplifer EGR thermo switch EGR thermo valve EGR frequency valve EGR check valve EGR duty cycle valve EGR pressure reservoir EGR pressure sensor EGR PFE (?) EGR EVR (?) EGR valve position sensor EGR CV generator EGR solenoid
	air injection system	air pump non-return valve air injection valve air injection check valve air injection shutoff valve air injection switch-over valve air injection solenoid valve

		air injection vacuum delay retard valve
	air metering system	air flow meter
		air mass meter
		manifold air pressure sensor
		altitude sensor
		atmospheric pressure sensor
		air temperature switch
		air temperature valve
		air bleed valve
		air control valve
		bypass valve
	miscellaneous	exhaust gas sensor
		dashpot check valve
		frequency solenoid valve
		vacuum switch
Evaporative emissions	Canister system	canister
		purge valve
		air booster valve
		two-way valve
		frequency valve
		switch-over valve
		tank ventilation valve
		thermo sensor
		tank relief rollover valve
Partial tail-pipe emission control	idle speed control	idle control valve
		idle switch
		idle air regulator
	fuel assistant system	coasting fuel cutoff valve
		throttle air control bypass valve
		cold enrichment breaker system
		cold mixture heating system
		auxiliary accessory enrichment system
Electronic control unit		on-board micro-computer
		air temperature sensor
		coolant temperature sensor
		thermo sensor
		thermo valve
		switch valve
		PIP sensor (?)
		throttle body temperature sensor
		crankshaft sensor
		camshaft sensor
		distance sensor
		vacuum switch
Fuel injection system		throttle body
		injector
		throttle position sensor
		fuel injection control unit
Non-emission parts		auxiliary air valve
		air preheat control valve
		ignition control unit
		coolant thermostat
		fuel pressure regulator
		cold start valve
		thermo time switch
		knock control sensor
		reference sensor
		speed sensor
		fuel pump
		distributor
		cold start injector

Note: Some emission parts are a substitute for others. A particular vehicle is incorporated with only some of the emission parts in the table. Different manufacturers may use different names for the same part. If those parts are identified with different names, the most common name in the table is used.

In the above table, emission parts are categorized into six groups: tailpipe emission control, evaporative emission control, partial tailpipe emission control, electronic control unit, fuel injection system, and non-emission parts. The emission parts within the tailpipe emission control group are used solely for controlling tailpipe emissions. All of the cost of the parts in this group are included to estimate vehicle emission control cost. Evaporative emission control parts are used to control vehicle evaporative emissions (currently hot soak and diurnal evaporative emissions). Since evaporative emissions are not included in the first phase of our study, these parts are not included in estimating emission control costs.

Partial emission control parts contribute to emission reduction, fuel economy improvement, vehicle startability, and vehicle driveability. One third of the cost of these parts are accounted for to estimate emission control costs. Since there is no information on how much a part in this group contributes to each of the vehicle attributes: emissions, fuel economy, and performance, the cost of a part is simply divided evenly among the three attributes.

Vehicle electronic control units (ECU) and related sensors are used to control emissions, increase fuel economy, and maintain good vehicle performance. Analagous to our treatment of partial emission control parts, one-third of the cost of ECU system as emission control cost is accounted for.

The fuel injection system reduces emissions by precisely controlling the air/fuel ratio. Fuel injection systems also help increase fuel economy and engine output power. Virtually, all new vehicles are fuel injected. Although fuel injection systems have been used by some European manufacturers since the 1960s for achieving higher power, its extensive use since the early 1980s is primarily due to stringent vehicle emission standards. Without the urgency of meeting emission standards, many manufacturers claim that they would not have introduced fuel injection systems so quickly. For this reason, we include a portion of fuel injection system costs in our estimate. Since the fuel injection system helps reduce emissions, increase fuel economy and power, and maintain vehicle performance, one-fourth of its cost is included in our emission control cost estimates.

Finally, non-emission parts are not included in our calculation, although they are presented by some manufacturers in the emission part list. This is because these parts are needed primarily for other purposes, such as engine protection and vehicle performance maintenance, even though their use helps reduce emissions.

C. Vehicle Dealers Survey of Emission Part Prices

Information on emission parts installed in an engine family was collected, and their part numbers from the emission part list of the application form for a particular engine family. A survey form was created that contained information on the name and the number of emission parts. We contacted vehicle dealers in the Sacramento area and asked them to provide us with the price of each part in our survey. Originally thirteen manufacturers were selected for our study. However, the part numbers from application forms for the Nissan engine families did not match the part numbers of Nissan dealers so Nissan was subsequently dropped. Therefore, twelve manufacturers are included in the study. Table 4.2 presents summary information on the twelve manufacturers.

Table 4.2. Manufacturers Included in This Study

Manufacturer	Number of engine families[1]	Vehicle sales: 1990, U.S.[2]	Numbers of dealers participating in survey[3]
Audi	6	21,093	1
BMW	5	63,349	1
Chrysler	23	1,599,812	2
Ford	38	3,285,516	1
General Motors	44	4,754,026	12[4]
Honda	14	853,760	2
Mazda	18	346,279	6[4]
Mercedes-Benz	7	76,295	2
Mitsubishi	12	139,293	1
Toyota	24	931,589	3
Volkswagen	8	136,283	2
Volvo	5	88,028	2
Total	204	12,295,323	35

1 CARB (1990 summary table). These are the engine families certified in California in 1990.
2 Automotive News Market Databook, 1991. The sales data include passenger cars and LDTs.
3 The number of dealers includes dealers who participated in the first-round and in the second-round survey. The same dealer participated in both surveys for four manufacturers. For some of the European manufacturers, we have contacted manufacturers for prices of some emission parts.
4 The larger numbers of dealers for GM and Mazda is due to the phone survey of dealers for these two manufacturers. We asked prices for about 10-15 parts for each of the dealers via telephone. We conducted phone surveys for these two manufacturers from a large number of dealers because of the time commitment required to complete the entire survey by a single dealer.

For each of the twelve manufacturers, dealers in the Sacramento area to completed our price survey. Two rounds of surveying were necessary to complete our data set. In the first-round survey, the survey forms to included information on emission part names and emission part numbers. Dealers were asked to find the MSRPs for the parts in our survey by using the part numbers provided. Table 4.3 provides an example of the first-round survey format. If the part number that we provided in the survey form matched the part number a dealer had from the manufacturer, the dealer completed the first-round survey form. However, in some cases, our part numbers (which were obtained from manufacturers' application forms) did not match with the numbers dealers obtained from manufacturers. Thus, dealers were unable to find prices for those parts. In some cases, dealers were able to identify the prices based on part names.

Table 4.3. An Example of the First-round Survey Form
Honda: 1990 model-year vehicles (portion of the form)

Part Name	Part Number	Price
PCV valve	17130-PK1-0034	
	17130-PM3-0031	
	17130-PM6-0032	
EGR valve	18710-PK2-S020	
	18710-PM5-L511	
	18710-PM8-A012	
	18710-PR4-A511	
	18710-PT3-A002	
Oxygen sensor	36530-PR4-L021	
	36531-PK1-0141	
	36531-PK2-L012	
	36531-PM5-A013	
	36531-PM5-L012	
	36531-PM5-L021	
	36531-PM8-A013	
	36531-PR4-L021	
	36531-PT2-J020	
	36531-PT3-A021	
	36532-PK2-L012	

In order to obtain the prices for the remaining parts after the first-round survey, a second-round survey form was designed. To do so, we went back to the application forms to determine which engine families used which of the remaining parts. The executive order for an individual engine family was checkedto see which vehicle models were covered by the engine family. Then, in the second-round survey, information on emission part names, vehicle models that used the parts, and specifications of the vehicle models were included. Usually, there were at least several vehicle models covered by one engine family. A popular vehicle model for the concerned engine family was chosen. Table 4.4 is an example of the second-round survey.

Table 4.4. An Example of the Second-round Survey
Honda: 1990 model-year vehicles (portion of the form)

Part name	Vehicle model using the part	Price
Catalytic converter	Prelude 2.0 S, 2.0L, A Civic Sedan LX, 1.5L, A Civic CRX HF, 1.5L, M Accord EX, 2.2L, A Civic CRX DX, 1.5L, M	
Air temperature valve	Prelude 2.0 S, 2.0L, A	
Throttle Body	Accord Sedan EX, 2.2L, M	

Using the information provided in the second-round survey, dealers could find a part number for each part. Since dealers had to go to different sources to find part numbers and part prices, it took much longer to finish the second-round survey than the first-round survey.

Since the second-round survey was more time consuming, many dealers were unwilling to completely finish the survey. In these cases, the survey form for a manufacturer was divided into smaller portions, and dealers were asked to complete one portion. This resulted in more than one dealer participating in the second-round survey for some manufacturers. Since all dealers of a manufacturer obtain the same MSRPs for parts from the manufacturer, the prices that were obtained from different dealers are consistent. Table 4.2 presents the number of dealers who participated in the survey for each of the manufacturers.

In responding to the survey, most dealers give us MSRPs, the prices dealers charge to individual customers. A few dealers gave wholesale prices, the prices dealers charge to mechanical shops. When wholesale prices were provided, dealers were asked the price difference between retail and wholesale, and wholesale prices were converted to retail prices. The surveys were conducted between October 1990 and July 1991.

D. Calculating the Emission Control Costs by Engine Family

Since a unique set of emission parts is used for an engine family, vehicle models within an engine-family have the same emission control systems, and therefore the same emission control costs. Emission parts are categorized into five groups and a portion of the emission part costs from each of the groups is included in computing emission control costs for each engine-family.

The cost analysis is based on emission control costs at the manufacturer level because our simulation model will simulate manufacturers' production behavior. However, the cost of emission parts were obtained at the consumer level from our emission part survey. To discount the cost of emission parts from the consumer level to the manufacturer level we need to consider two markup factors: dealer markup and manufacturer markup.

A 1978 study for the EPA used a factor of 40% for dealer markup, and a profit markup of 20% for parts suppliers and vehicle manufacturers (Lindgren, 1978). However, a 1985 study for the EPA concluded that dealer markup was 5.7% and manufacturer markup 19.2%. (Jack Faucett Associates, 1985). In the 1985 study, the authors estimated dealer markup by considering dealers' interest expense, profit markup, and sales commission, all of which are costs that dealers must recover from sales. In this sense, the estimate was probably the lower bound of dealer markup. They calculated manufacturers' markup by using data from manufacturers' financial reports.

There is a large discrepancy on the dealer markup between the two studies, and there has been a constant dispute on the magnitude of the markup factors for emission control cost estimates. As a result, dealers were asked the price difference between retail prices and dealer costs for emission parts. Although some dealers were reluctant to provide this information, markup information from most of the dealers was collected. Table 4.5 presents the results of the dealer markup factors from the survey.

Table 4.5. Percentage Markups from Dealer Markup Survey

Manufacturer cost	$\frac{\text{(Retail-wholesale)*100}}{\text{Retail}}$	$\frac{\text{(Retail-dealer)*100}}{\text{Retail}}$
Audi	10-15	35-40
BMW	15	38
Chrysler	25	40
Ford	20	40
GM	20	40
Honda	20	40
Mazda	20	60
Mercedes-Benz	25	38
Mitsubishi	25	N/A
Toyota	20	40-65
Volvo	20	40
Volkswagen	15	35-40

Note: The difference between retail price and dealer cost varies among emission parts. The presented results are for emission parts on average.

Comparing our survey results with the two EPA studies, a dealer markup factor of 40% was used to discount emission part prices from retail prices to dealer costs. To discount part prices from dealer costs to manufacturer cost, a manufacturer markup factor of 20% was used here, which is also the number used in the two EPA studies.

Emission part prices after the two steps of discounting represent an estimate of the manufacturing costs of the emission parts. To fully account for the cost of an emission part for estimating emission control cost, the cost of assembling an emission part into a vehicle must be considered. This cost consists of two components: vehicle assembling for an emission part and necessary modifications of engine and other major vehicle components to incorporate the emission part into a vehicle. The 1978 study for the EPA cited above estimated the vehicle assembling and engine modification costs, as well as manufacturing costs of major emission parts. Using the cost information in that study, vehicle assembling and engine modification cost are calculatedas a percentage of total emission part cost for some individual emission control systems. Table 4.6 contains the calculated results.

Table 4.6. Percentage of Vehicle Assembling and Engine Modification Cost as Total Cost for Emission control Systems (Based on Lindgren, 1978)

Emission part	Cost of vehicle assembling and engine modification (% of total cost)
Valve and orifice	25
Air injection system	10
EGR system	18
Oxygen sensor	15
Catalytic converter	5

The percentage cost of vehicle assembling and engine modification for the parts in Table 4.6 are used to add the cost of vehicle assembling and engine modification to the emission part cost estimated above. The EPA's study had neither information on electronic control units and related sensors, nor information on vehicle air/fuel system (i.e., fuel injection systems). The percentage cost of assembling and engine modification is assumed to be 15% for these parts.

In summary, to calculate emission control costs at the manufacturer level for individual engine families, we use information on emission control systems installed for each engine family and the prices of emission parts from our survey, discount emission part prices by the dealer markup and the manufacturer markup, and include the cost of vehicle assembling and engine modification for emission parts.

In computing the emission control costs per vehicle, the costs of individual components in the vehicle are summed. This will not be accurate if our mark-up figures are incorrect. In particular, some have suggested that the sum of these costs may be too large, biasing our estimates of current emission control costs upwards. This concern that the sum of the parts may exceed the total actual sum could be addressed partially by performing the same summation procedure over all parts of a vehicle. This would provide an estimate of the total cost of producing the vehicle which could be used to judge the reasonableness of the procedure. This would be a major effort on its own, but may be performed in the future as a way of calibrating the data.

E. Summaries of the Emission Control Cost Data

Table 4.7 contains summary statistics on the data collected in the survey of vehicle dealers. The first four rows of the table contain information on variables that describe the engine families included in our study. The means, standard deviations, and the minimum and maximum of these variables in our sample are provided in columns two through five. The final five rows in the table provide summary statistics for the cost data collected from dealers.

Direct tailpipe emissions control costs (DCC) are the costs of emissions control counting only those parts that directly relate to emission control. The average over our engine families is about $640. The following three rows report the costs of parts that can be attributed to emissions control to some degree. Partial tailpipe emissions (PCC) are those parts that are installed for emissions control partially, but also serve other purposes. Computer system costs (CSC) and fuel injection costs (FIC) are also reported and included, since some portion of their costs can be reasonably attributed to emissions control.

The final row in the table reports a measure for total costs. As described above, total costs of emissions control are defined as DCC + .33*PCC + .33*CSC + .25*FIC. That is, one-third of the partial emissions control costs, one-third of the computer system costs, and one-fourth of the cost of the fuel injection system are attributed to emissions control. This is certainly not the only way to attribute these costs, but it seems to be a reasonable allocation. Using this definition for total costs, our survey results indicate that manufacturers are spending nearly $900 on average per vehicle surveyed.

Tables 4.8 and 4.9 report means on the same set of variables broken down by manufacturer, geographic region of production, and vehicle class (cylinder size). These tables graphically illustrate the wide dispersion in control costs between both manufacturers and vehicle classes. For example, the total costs of emission control varies from a low of about $470 for Chrysler vehicles to a high of over $2700 for Mercedes-Benz vehicles. Likewise, small cylinder vehicles have emission control costs on the order of $850 where large cylinder vehicles have costs of over $1025. The breakdown of costs by geographic region in table 4.9 also indicates some striking results: Japanese companies spend twice as much as American producers on emission control and European companies spend nearly three times as much as their American counterparts.

These results indicate that there are large differences between vehicle manufacturers in the costs of meeting current emission standards. These large cost differences suggest that a MPS may generate substantial cost savings.

F. Emission Rates of Tested Vehicle Models

Vehicle models within an engine family are tested through the FTP for certifying the engine family for meeting emission requirements. The measured emissions of HC, CO, and NO_x from each of the tested vehicle models are adjusted to emissions at 50,000 miles by applying emission deterioration factors for the three pollutants applicable to the engine family. The highest emissions for a particular pollutant among the tested vehicles is chosen as the emission rate for the engine family. It is the engine-family emission rates that are used to determine whether the engine family meets emission standards, so emission rates of an engine-family may be from different tested vehicle models.

Emission rates of individual tested vehicle models within an engine family are used, rather than emission rates of the engine family. In the database, a set of emission rates for HC, CO, and NO_x is from one particular vehicle model. Therefore, within an engine family, we may have several data points for emissions, but only one data point for emission control costs (recall that we estimate emission control cost for individual engine families). Although there is no difference in emission control costs among these tested models, there are differences in emissions among them. The emission differences could be due to vehicle weight, fuel economy, and test errors of individual FTP tests. To account for these effects, we include fuel economy in our emission control cost functions.

As a result of these multiple tests, we have 204 engine families (Table 4.2), but we have 393 tested vehicle samples. Among the 204 engine families, we have excluded several engine families because they use different engine technologies from the majority of the engine families. We have excluded four carbureted engine families (one from GM, two from Honda, and one from Toyota) and two engine families with rotary engines from Mazda because we do not have enough information on the full emission control costs of these engine families due to their different control strategies. In total, we have 198 engine families and 382 vehicle samples in our study.

Table 4.10 reports summary statistics for the emissions certification data. The means, standard deviations, minimums, and maximums for the 1990 test results for HC, CO, and NO_x are provided. Tables 4.11 and 4.12 present the means broken down by manufacturer, geographic region, and vehicle class. Although there is not as much variation in the emissions data across manufacturers and vehicle classes as was exhibited in the cost data, there is still a fair amount of variation. For example, the average CO emissions for Chrysler are over twice the average emissions for BMW or Toyota. Differences in NO_x emissions between manufacturers is even more pronounced with GM and Chrysler producing nearly four times the emissions of Mercedes Benz. These differences in certification emission rates may reflect the AB965 bill that allows high emissions for certain engine families and the 0.7 gpm NO_x standard applied to some 1990 engine families.

Table 4.7. Gasoline Vehicle Survey Data: Summary Statistics

Variable	Mean[1]	Std Dev	Minimum	Maximum
Number of Cylinders	5.20	1.44	4.0	12.0
Cubic Inch Displacement	173.72	65.84	81.0	454.0
Miles Per Gallon (city)	21.18	4.45	10.5	47.6
Vehicle weight	3,576[2]	637.5	2125	6,000
Direct emissions control costs (DCC)	637.41	382.96	173.91	3,054
Partial emissions control costs (PCC)	56.19	121.03	0	928.44
Computer System Costs (CSC)	314.20	205.93	81.66	2,510
Fuel injection costs (FIC)	546.99	309.11	0	1,753
Total Costs (= DCC + PCC/3 + CSC/3 + FI/4)	897.63	472.78	308.37	3,338

[1] There are 387 observations used in these computations.

[2] There are missing values on six observations for WEIGHT so 381 observations are used in the summary statistics.

Table 4.8. Gasoline Vehicle Survey Data: Means by Manufacturer

Variable	Manufacturer											
	Audi	BMW	Chrysler	Ford	GM	Honda	Mazda	Mercedes Benz	Mitsubishi	Toyota	Volvo	VW
Number of Cylinders	4.9	6.25	5.38	5.55	6.03	4.18	4.44	6.67	4.48	5.15	4.40	4.00
MPG	19.97	16.70	19.21	21.12	19.64	26.02	22.95	17.83	22.18	21.68	19.61	22.99
Vehicle Weight	3,473	3,750	3,923	3,594	3,752	2,989	3,336	4,000	3,365	3,676	3,583	3,331
Direct Emissions Control Costs	809.73	1,322.16	325.31	459.83	390.56	689.70	887.87	2,330.82	621.18	755.15	873.02	726.30
Partial Emissions Control Costs	479.35	147.29	0	38.99	0	59.73	57.46	117.16	0	80.67	92.35	53.09
Computer Systems Costs	592.93	575.02	226.34	144.39	148.14	338.20	502.94	253.25	470.85	536.80	303.29	390.80
Fuel Injection Costs	1,098.90	505.32	266.16	246.45	509.19	350.34	890.18	983.17	719.61	574.28	1,006.34	920.19
Total Costs (DCC + PCC/3 + CSC/3 + FI/4)	1,441.89	1,689.26	467.30	582.57	567.26	909.93	1,297.22	2,700.08	958.04	1,104.55	1,256.48	1,104.31
Number of Observations	14	8	39	72	74	33	32	9	25	47	15	19

Table 4.9. Gasoline Vehicle Survey Data: Means by Geographic Region and Cylinder Size

Variable	Geographic Region			Cylinder Size		
	American	European	Japanese	4	5 & 6	8 & 12
Number of Cylinders	5.71	4.94	4.63	4.0	5.93	8.08
MPG	20.13	20.07	23.11	24.03	18.69	16.23
Vehicle Weight	3,728	3,564	3,375	3,201	3,856	4,330
Direct Emissions Control Costs	403.78	1,073.63	745.94	584.84	665.51	775.56
Partial Emissions Control Costs	15.18	174.43	55.48	45.01	77.97	43.22
Computer Systems Costs	163.17	417.77	469.02	333.62	311.44	242.77
Fuel Injection Costs	355.70	936.22	620.65	532.10	540.42	625.10
Total Costs (DCC + PCC/3 + CSC/3 + FI/4)	552.15	1,505.08	1,075.94	844.07	930.42	1,027.16
Number of Observations	185	65	137	203	134	50

Table 4.10. Gasoline Vehicle Emissions Certification Data[1]: Summary Statistics

Pollutant	Mean[2]	Std Dev	Minimum	Maximum
HC	0.20	0.08	0.07	0.68
CO	2.21	1.22	0.24	7.80
NO_x	0.28	0.22	0	1.70

[1] Source: California Air Resources Board Certification Data.

[2] There are 387 observations used in these computations.

Table 4.11. Gasoline Vehicle Emissions Certification Data: Means by Manufacturer

	Manufacturer											
Pollutant	Audi	BMW	Chrys	Ford	GM	Honda	Mazda	Mercedes Benz	Mitsu	Toyo	Volvo	VW
HC	0.24	0.23	0.26	0.17	0.22	0.18	0.18	0.18	0.23	0.17	0.26	0.22
CO	2.01	1.44	3.01	2.19	2.75	2.09	2.03	1.58	1.84	1.41	2.11	2.37
NO_x	0.18	0.15	0.44	0.28	0.49	0.21	0.19	0.09	0.21	0.26	0.21	0.21
Number of Observations	14	8	39	72	74	33	32	9	25	47	15	19

Table 4.12. Gasoline Vehicle Emissions Certification Data: Means by Geographic Region and Cylinder Size

	Region			Cylinder Size		
Pollutant	American	European	Japanese	4	5 & 6	8 & 12
HC	0.21	0.23	0.18	0.19	0.21	0.24
CO	2.59	2.01	1.80	2.24	2.22	2.05
NO_x	0.36	0.18	0.22	0.23	0.30	0.46
Number of Observations	185	65	137	203	134	50

Chapter V. Emission Control Cost Functions for Gasoline Powered Vehicles

This chapter describes the procedures employed for estimating emission control cost functions for gasoline powered vehicles. A number of important choices concerning functional form and the selection and definition of variables was made in the construction of these functions and these choices are discussed.

A. Issues in the Construction of Cost Functions

Economic theory tells us that cost functions for emission control should be downward sloping in emissions; that is, when emission levels rise, the total costs of emission control fall since less emissions are being controlled. In addition, if the marginal costs of emission control rise with an increase in the amount of emissions controlled, the total cost function is decreasing at a decreasing rate.[3] Beyond these restrictions on the shape of the cost function, there is little theoretical basis for making choices about the specific functional form.

In general, a cost function for emissions control of HC, NO_x, and CO can be written

$$C_{ij}=C_{ij}(HC_{ij},NO_{x_{ij}},CO_{ij},X_{ij}), \quad i=1,\ldots,M, \quad j=1,\ldots,K, \tag{5}$$

where C_{ij} indicates the costs for engine class i for manufacturer j, X_{ij} is a vector of additional variables that might explain emissions control costs, M is the number of engine classes, and K is the number of manufacturers.

There are several issues regarding how to estimate cost functions for use in a simulation of a permit system. First, there must be different cost functions for different vehicle manufacturers and classes of vehicles within a manufacturer in order for emission trading and averaging to take place. Ideally, separate cost functions for each manufacturer and each engine family

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[3] Put simply using calculus, we require that the first derivative of total cost with respect to emissions is negative and the second derivative is positive.

would be employed. However, this is impossible since the data set provides only a few observations on each engine family. Hence, grouping of engine families together is necessary.

The problem is then how to estimate separate functions with a limited number of observations. To accomplish this, the data was divided into three subsets either by cylinder size (small, medium, or large) or by geographic region of the manufacturer (American, European, or Japanese). Separate cost functions for each of these three subclasses were estimated with a dummy variable to differentiate among the other category. For example, for the set of cost functions estimated separately by geographic region, two dummy variables were included to separate out the effects of cylinder size. Likewise, for the set of cost functions estimated separately by cylinder size, two dummy variables were included to differentiate among the manufacturers. In both cases, a total of nine cost functions are constructed: three cylinder sizes by three geographic regions.

An alternate possibility would be to have estimated separate cost functions for each of the 12 manufacturers in the data and within each manufacturer, a separate function by cylinder size of the vehicle. Although separate cost functions for each cylinder size were estimated with dummy variables for each manufacturer, separate cost functions for each manufacturer could not be estimated separately due to the limited degrees of freedom in many of the subgroups. This limits the ability to do sensitivity analysis. Further, the simulation results based on these were quite similar to the results based on the nine cost functions.[4] Since the focus of this work is on the sensitivity of results to the cost function specification and since the results were so similar between the two approaches, aggregation into nine functions is employed.

A second issue concerns the choice of functional form for the emission control cost functions. Theoretically, the partial derivative of the cost

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[4] Results of the simulations with these functions yielded estimates of cost savings within 1-2% of the more aggregate functions used in the remainder of the study.

function with respect to E_{ij} should be negative and the second derivative is positive (if the marginal cost of abatement increases at an increasing rate). However, beyond these signs, there is little to guide us regarding the shape of the functions. One of the purposes of this work is to examine the sensitivity of the cost savings estimates to assumptions about functional form. Two simple functions were chosen for this purpose, a doublelog form where both the total costs and pollution variables are logged, and a semilog form where only the total costs are logged. As long as the coefficient on HC emissions is negative, these functions imply rising marginal abatement costs with increased abatement.

Finally, the choice of variables to be included in the cost functions must be addressed. There are three pollution variables available, HC, CO, and NO_x. Although they should all affect total costs of emission control, they are quite collinear, hence precise estimates of their coefficients are difficult to obtain. To deal with this problem, cost functions were estimated two ways: first with just HC and then with all three pollution variables. Both sets of cost functions are used in the simulation and it turns out that both sets have interesting interpretations regarding what the cost savings associated with those functions represent.

The second decision regarding variable inclusion is the choice of other independet variables. We have included only the MPG variable. This variable was included due to the type of data we are using to estimate the functions. Recall from chapter IV that the data we have on emission control costs come from surveys of dealers who provided us with cost data based on engine families. Our data on emissions come from CARB's certification data. As discussed in chapter IV, there is often more than one vehicle in each engine family used in the certification procedure. In particular, the vehicle that is likely to have the highest emissions is tested as is the vehicle likely to enjoy the highest level of sales. Each of these vehicles is tested for each of the three criteria pollutants, and the <u>highest</u> emissions for each of the pollutants from two tested vehicles is used as the emission level for that engine family. In other words, the certified emission level for each pollutant for a particular engine family can come from different vehicles. For example, the HC and CO emission levels may come from the high emission vehicle and the NO_x emission level may come from the high sales volume vehicle.

As a result of this mixing of emissions levels between two vehicles, rather than use the single set of certified emission levels assigned to each engine family, we have chosen to use the test results for each tested vehicle. This gives us more than one set of emissions data for many engine families. However, we have only one emission control cost estimate for each engine family. By assigning this emission control cost estimate to various sets of emission test results, we have a data base of 386 observations. However, this raises the important question of why the costs of emission control are the same for different sets of emission levels.

Since vehicles in the same engine family contain the same emission control technologies, we assume that the reason for the emission levels to differ between two vehicles in the same engine family is due the weight of the vehicle, or other vehicle specifications such as engine displacement. A proxy for these effects is the fuel economy of a vehicle so we include the MPG variable to capture the effects of these variables on the costs of emission control.

We expect the signs of the coefficients to be negative for the pollution variables. The sign on the MPG variable requires additional explanation. Essentially, a negative sign on this coefficient suggests that as fuel economy in an engine family increases, the cost of emission control falls. If technologies that improve fuel economy also tend to reduce vehicle emissions, this coefficient will have a negative sign. If not, the sign will be positive. This is a testable hypothesis that regression results can be used to examine.

B. Cost Function Estimates

Results for all of the estimated cost functions are reported in Tables 5.1 and 5.2. Table 5.1 contains the results for the cost functions estimated by geographic region and Table 5.2 contains the results by cylinder size. The t-statistics for the HC coefficient are reported in parentheses under the coefficient estimate. Significance at the 10% level of all other coefficients are denoted by an asterisk. The HC coefficients are all of the correct sign and most are significant.

The variables "MED" and "LARGE" in Table 5.1 are dummy variables for cylinder sizes, taking on values of "1" if the cylinder size fits in the category, and "0" otherwise. Likewise, the variables "EURO" and "JAPN" are dummy variables for the manufacturer groups in Table 5.2. The dummy variables in each set of equations are significant.

When CO and NO_x are included in the functions, they are of the expected sign (negative) roughly two thirds of the time and when they are positive, they are rarely significant. The effects of multicollinearity between the three pollution variables are also apparent in the effect on the t-statistic for the HC coefficient[5]. When CO and NO_x are omitted from the equation, the t-statistic for HC is generally higher than when they are included.

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[5] The correlation coefficient between HC and CO is 0.47 and between HC and NO_x is 0.45.

Table 5.1: Cost Function Estimates

Based on Geographic Divisions[1]

	DOUBLELOG			SEMILOG			DOUBLELOG			SEMILOG		
	JAPN	AMER	EURO	JAPN	AMER	EURO	JAPN	AMER	EURO	JAPN	AMER	EURO
INT	7.00*	6.01*	7.36*	7.19*	6.37*	7.96*	6.94*	6.07*	8.02*	7.21*	6.31*	8.35*
HC	-.06 (-1.32)	-.15 (-3.94)	-.24 (-2.34)	-.29 (-1.10)	-.52 (-3.00)	-1.11 (-2.37)	-.08 (-1.49)	-.16 (-3.42)	-.01 (-0.10)	-.27 (-0.90)	-.67 (-3.27)	-.42 (-0.81)
CO							.04	-.03	-.27*	.01	-.01	-.08*
NOx							-.01	.04	-.03*	-.17	.15*	-.57*
MPG	-.01*	-.01*	-.03*	-.01*	-.01*	-.03*	-.01*	-.01*	-.04*	-.01*	-.01*	-.04*
MED	.14*	.26*	.21*	.13*	.26*	.21*	.14*	.25*	.16*	.14*	.26*	.14*
LARGE	.36*	.54*	.70*	.35*	.53*	.71*	.39*	.51*	.60*	.36*	.52*	.55*
R^2	.29	.59	.55	.28	.57	.55	.28	.59	.62	.28	.58	.61

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1. The cost functions were constructed by dividing the data into three subgroups and estimating separate functions for each group using OLS. The three groups were American manufacturers (AMER), European manufacturers (EURO), and Japanese manufacturers (JAPN). Asterisks indicate significance of the coefficient at the 10% level; t-statistics for the HC coefficient are provided in parentheses.

Table 5.2: Cost Function Estimates Based on Cylinder Size Divisions[1]

	DOUBLELOG			SEMILOG			DOUBLELOG			SEMILOG		
	SMALL	MEDIUM	LARGE	SMALL	MEDIUM	LARGE	SMALL	MEDIUM	LARGE	SMALL	MEDIUM	LARGE
INT	6.06*	6.48*	6.15*	6.50*	6.66*	6.55*	6.26*	6.35*	6.45*	6.45*	6.47*	6.34*
HC	-0.16 (-4.89)	-0.08 (-1.42)	-0.15 -(1.81)	-0.83 (-5.03)	-0.20 (-0.79)	-0.68 (-1.66)	-0.10 (-2.51)	-0.11 (-1.65)	-0.12 (-1.47)	-0.52 (-2.37)	-0.45 (-1.48)	-0.72 -1.78)
CO							-0.07*	0.09*	-0.11*	-0.02*	0.04*	-0.05*
NOx							-.001	-0.03	0.06	0.001	0.04	-0.36*
MPG	-0.01*	-0.02	0.01	-.01*	-0.02	0.01	-.015*	-.02	.004	-.01*	-.01	0.02
EURO	1.06*	1.07*	1.36*	1.06*	1.07*	1.37*	1.03*	1.08*	1.45*	1.03*	1.11*	1.50*
JAPN	0.90*	0.76*	0.62*	0.89*	0.75*	0.62*	0.87*	0.79*	0.62*	0.87*	0.80*	0.64*
R^2	0.91	0.78	0.82	0.91	0.78	0.82	0.91	0.79	0.84	0.91	0.78	0.684

[1] The cost functions were estimated by dividing the data into three groups and applying OLS to each group separately. The three groups were small cylinder vehicles (SMALL), medium cylinder vehicles (MEDIUM), and large cylinder vehicles (LARGE). Asterisks indicate significance of the coefficient at the 10% level; t-statistics for the HC coefficient are provided in parentheses.

From the tables, 9 cost functions (one for each cylinder size for each manufacturer) are estimated for each combination of the disaggregation approaches, functional forms, and pollution variables choice. The cost functions based on Table 5.1 have slopes and intercepts that differ by manufacturer and intercepts that further differ by cylinder size. In contrast, the cost functions from Table 5.2 have differing slopes and intercepts by cylinder and intercepts that further differ by manufacturer.

The procedures described for disaggregating the cost functions, choosing functional form, and variable selection have generated eight sets of cost functions that can be used in the simulation of cost savings from a permit system. In addition, several assumptions regarding limits on trading in the simulation will provide additional sensitivity analysis.

C. Summary and Conclusions

The statistical analysis reported in this chapter indicate that emission control costs do vary inversely with emission levels as hypothesized. Additionally, the data indicate that these relationships differ significantly across both manufacturers and vehicle classes.

Although a number of different functions differentiating costs between manufacturers and vehicle classes could be identified, the ones generated here appear to be reasonable first attempts. While it will be important to do additional sensitivity analysis to explore the robustness of these results, these functions can provide useful starting points for examining the potential cost savings from a marketable permit system for vehicle emissions.

CHAPTER VI. Alternative Fueled-Vehicles: Data and Costs

A. Motivation

For a variety of reasons, interest in alternative transportation fuels is accelerating. Primary among these reasons are the negative impacts which the use of petroleum has on the environment, energy security, and global warming. Another concern is the depletion of low-cost supplies of oil. These problems will not subside as long as petroleum remains the world's primary transportation fuel (Sperling and DeLuchi).

In recent years, a number of alternative transportation fuels have been investigated and promoted by scholars and government agencies. Fuels of interest include methanol, compressed and liquefied natural gas (CNG and LNG), gaseous and liquefied hydrogen, and electricity from batteries (Ibid; DeLuchi et al., 1988; Sperling, 1988; U.S. Department of Energy (DOE), 1988). All of these fuels have advantages and disadvantages in terms of their impact on air pollution, energy security, transportation costs, and the greenhouse effect.

In the United States, emphasis has shifted away from energy security concerns and towards interest in the air pollution reductions that might result from the use of alternative fuels. The 1990 CAAA recognizes the potential role of alternative-fueled vehicles (AFVs) in meeting strict new emissions standards for carbon monoxide (CO), nitrogen oxides (NO_x), and non-methane organic gasses (NMOG); new standards have been promulgated which limit AFV emissions of these pollutants (PL 101-549). Furthermore, the CAAA requires that regulations be issued which will require the sale of 150,000 clean-fueled vehicles in California in model-years 1996 to 1998, increasing to 300,000 in 1999 and thereafter. California is also required to revise its State Implementation Plan (SIP) to ensure that sufficient amounts of clean fuels are produced and distributed.

In California, it is expected that AFVs will play an important role in helping manufacturers to meet future emissions standards adopted by the California Air Resources Board (CARB(2), 1990). In fact, CARB expects that, "To meet ultra-low-emission vehicle (ULEV) standards, light-duty vehicles would be expected to be powered by a cleaner-burning fuel...". Regulations for 2002 are based on the assumption that at least 10% of the light-duty vehicles sold in California will meet ULEV emission standards. Also, the introduction of electric vehicles (EVs) is guaranteed by CARB's mandate that zero emission vehicles (ZEVs) comprise at least 2% of large volume manufacturers' vehicle sales in California, beginning in 1998.

The non-gasoline fuels that have the potential for widespread use in California include CNG, electricity, methanol, and LPG. The success or failure of any of these fuels will depend on AFV emissions, cost, performance, and the relative price of gasoline and gasoline-fueled vehicles. More stringent emissions standards will make AFVs more economical, while advances in reformulated gasoline may tend to make AFVs less attractive.

This chapter documents work completed towards the development of plausible estimates of the emissions and production costs associated with five types of AFV. Also in progress is research that will estimate the lifecycle operation and maintenance costs, the effect of AFVs on Corporate Average Fuel Efficiency (CAFE), and consumer willingness to pay for AFVs. These estimates will be utilized as inputs to the mathematical programming models developed through this project. The objectives of model simulations include the following: 1) estimate the amount of money that manufacturers will save from introducing AFVs; 2) estimate the break-even lifecycle costs which would allow AFVs to compete with gasoline vehicles; and 3) examine how different policies for the trading of emissions credits will impact the rate of AFV penetration into California's motor-vehicle market.

B. AFVs Considered in This Analysis

1) Dual-fuel CNG: Mass produced dual-fuel CNG vehicles will be analyzed. Dual-fuel CNG vehicles are designed to solve the problem of CNG refueling facilities being unavailable away from either the home or business. Dual-fuel vehicles will also have a longer driving range than dedicated CNG vehicles. One disadvantage of dual-fuel vehicles is that the engine is compromised to

run sub-optimally on either one or both of the fuels. For example, an optimized CNG engine will have a higher compression ratio than an optimized gasoline engine, making simultaneous optimization of a dual-fuel engine impossible. Dual-fuel CNG vehicles will not reach as low a level of emissions as dedicated CNG vehicles. The problem of fuel storage space, caused by CNG's low volumetric energy content, is exacerbated by the need to carry both gasoline and CNG on board;

2) Dedicated CNG: Dedicated CNG vehicles show great promise for reduction of mobile-source emissions, especially CO. If automotive engineers are successful in developing maximum-lean-burn engines, significant reductions in the three primary regulated pollutants --HC, NO_x, and CO-- can be expected (Weaver). Another important advantage of CNG is its fuel efficiency; CNG vehicles are likely to have lower fuel costs per mile than gasoline or methanol vehicles (Sperling and DeLuchi, Hay). The biggest barrier to the introduction of dedicated CNG vehicles is the high cost of developing a refueling infrastructure. The cost of equipping a retail gas station to service 100 CNG vehicles a day is estimated to be in the neighborhood of $320,000 (Singh). Many believe that dedicated CNG vehicles will therefore be introduced as company fleets, especially for heavy-duty and mass-transit applications, since this will make centralized fueling economical, and take advantage of CNG's low particulate emissions (Sauve');

3) Electric Vehicles: CARB requires that, beginning in 1998, at least 2% of all vehicles sold by large-scale manufacturers in California must be certified as ZEVs. The mandated percentage will increase to 10% by 2003. At this time, EVs are the only technology clean enough to be classified as ZEVs. Currently, EV batteries are heavy and expensive, limiting the range and affordability of EVs. Also, lengthy recharging time limits potential EV applications. The market penetration of EVs mainly depends on advances in battery and EV technologies. Several new battery and battery-charging technologies are now under development (DeLuchi et al., 1989). For example, General Motors (GM) has recently developed the prototype electric sub-compact

Impact with vastly improved performance characteristics using current battery technology (GM, 1/3/90). In this analysis, the lead/acid and sodium-sulphur battery technologies considered are:

4) Flexible Fuel Methanol (FFV, M85): A number of government agencies believe that methanol is the fuel most likely to supplant gasoline (Alson). The advantages and disadvantages of a methanol FFV are similar to those given for the dual-fuel CNG vehicle, above. One important difference is that it is widely expected that the fuel economy of methanol will be worse than that of gasoline (Acurex(IV), SRI). Whereas owners of dual-fuel CNG vehicles are likely to run their automobiles on CNG whenever possible, owners of methanol FFVs will have a cost incentive to fill their tanks with gasoline. This means that some government intervention may be needed to guarantee that FFVs are operated on the cleaner burning methanol blends;

5) Dedicated methanol: Methanol vehicles, with engines built or modified to run solely on M85 (85% methanol blended with 15% unleaded gasoline), are included in this analysis. At this time, two technological problems preventing the use of M100 (100% methanol) have yet to be resolved. The first of these is difficulty in cold starting an engine that burns M100. Starting difficulties have been experienced at temperatures as high as 55^{0}F, even with the most advanced prototype vehicles (Piotrowski(1)). The second problem is that M100 produces an invisible flame that would endanger fire fighters and any others who are exposed to methanol fires. An important advantage of using M100 is its low volatility. Evaporative emissions from a vehicle burning M100 are close to zero, whereas vehicles burning M85 have approximately the same mass as evaporative emissions from gasoline vehicles. Prototype M100 vehicles, with optimized engines, have also obtained significantly lower exhaust emissions than those burning M85 (Piotrowski(2)).

Notably absent from this analysis are retrofit (i.e., modified gasoline vehicles) methanol and CNG vehicles. Retro-fit vehicles have, in general, been characterized by high costs of conversion and poor performance characteristics.

C. Theoretic Derivation Of AFV Emissions Cost Functions

Manufacturers will choose to produce AFVs when doing so is a cost-effective way of meeting fleet emissions standards. That is, when the cost of producing AFVs to obtain lower fleet emissions is less than the cost of further reducing the emissions of gasoline vehicles. Conceptually, the costs of emission control for AFVs is straightforward, and its determination mimics the determination of emission control costs for gasoline powered vehicles.

Suppose that the cost of producing a gasoline vehicle with no emission control is C_G^P. Then the cost of producing a gasoline vehicle with emission control is $C_G^P+C_G^E$, where C_G^E is the cost of producing and installing emission control components. In this case, the cost of the emission reductions achieved is just C_G^E. This assumes that emissions control costs are separable from other production costs of the vehicle.

Similarly, the total cost of producing an AFV can be determined and compared with the cost of producing a gasoline vehicle with no emission controls. The difference between them represents the costs of emission control associated with the AFV, assuming that AFVs are produced solely to meet emissions requirements. The analysis also assumes initially that the AFV generates the same gross revenue for the manufacturer as the gasoline vehicle).

Formally, let the cost of producing an AFV be written C_A^T, where these costs include both production costs and the costs of any additional emission control systems (e.g., a heated catalytic converter installed on a methanol vehicle or an exhaust gas recirculation (EGR) system for a compressed natural gas vehicle). This AFV will produce less emissions per mile than the baseline gasoline vehicle, but will likely cost more to manufacture. One component of the cost of the attendant emissions reductions is the difference in production costs between the AFV and gasoline vehicle, $C_A^T-C_G^P$.

There are two additional costs that will be considered by manufacturers when deciding whether or not to produce AFVs. First, the production of AFVs by manufacturers provides benefits from the Corporate Average Fuel Economy

(CAFE) credits that they earn.[6] Estimates of these benefits are in the neighborhood of a few hundred dollars per vehicle, depending on the manufacturer (Sobey). These benefits are gains to producers from the production of AFVs and therefore must be included in the analysis.

Second, consumer response to the performance characteristics of AFVs is not well understood, but it is expected that differences in performance and the unfamiliar character of AFVs will make consumers less willing to purchase these vehicles. If this is the case, manufacturers will not be able to charge customers the full production cost of the AFV. In effect, they will have to reduce the gross profit margin per vehicle by reducing the vehicle price in order to entice customers to purchase these vehicles. This change in gross profit margin is an additional component of the cost of producing AFVs. When these two additional components are added to the AFV production costs, the cost of emissions control associated with an AFV is given by the following equation:

$$C_A^E = (C_A^T - C_G^P) - \textit{CAFE credit benefit} + \textit{gross profit margin change}$$

These three components of emission control costs, the difference in production costs, the cafe credit benefit, and the change in gross profit margin per vehicle, will be estimated for each of the five types of AFVs included in this study: dedicated and dual-fueled methanol and compressed natural gas (CNG), and electric vehicles.

There are a number of authors and vehicle manufacturers that have estimated the relative production costs of methanol, CNG, and electric vehicles (DeLuchi et al., 1989; SRI; Acurex(v.IV)). One uncertainty in making such estimates is that unit costs will depend on the total quantity of vehicles produced (i.e., economies of scale). Also, there are little data on the incremental cost of adding emissions control systems to AFVs.

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[6] AFVs are given very high mile-per-gallon ratings by EPA. Therefore, sale of an AFV relaxes the CAFE constraint on a manufacturer, allowing a greater percentage of low mpg gasoline vehicles to be sold. These larger cars generally bring the manufacturer a higher per-unit profit than the smaller models. Also, production of AFVs will reduce the amount of fines an auto manufacturer must pay for not meeting CAFE standards.

The CAFE credit benefit is less readily available and will differ between manufacturers. For manufacturers with fleets that already meet the CAFE standard, this benefit is relatively small. However, for manufacturers with relatively low fuel economy, this benefit may be sizable. A review of literature and data on this subject is underway in order to more accurately estimate the CAFE benefits generated by AFVs.

Of the three cost components, the change in gross profit margin is the most difficult to estimate precisely. This issue boils down to projecting the price that consumers will be willing to pay for an AFV. One important determinant of consumers' willingness to purchase and accept AFVs will be the discounted life-cycle costs of AFVs and gasoline vehicles. Included in life-cycle costs are vehicle price, interest payments, fuel expenditures, and maintenance costs. DeLuchi's (et al., 1988) work on life-cycle costs of methanol and CNG vehicles is being updated and refined. Similar estimates made for EVs are also being analyzed (Jet Propulsion Laboratory; DeLuchi et al., 1989; Humphreys and Brown). Life-cycle operating costs are very sensitive to the price of the alternative fuel.

The other key determinant of willingness to pay will be AFVs' relative performance and attributes. For example, consumers' response to reduced driving range and loss of storage due to the lower volumetric energy density of CNG and batteries will be an important determinant of these AFVs' market price. Sperling (1991) has work in progress which will estimate the values of performance attributes. Another option being considered is to leave the value of AFV performance attributes as a residual. That is, model simulations will estimate how much consumers will have to value an AFV in order for it to be profitable to produce the AFV.

Finally, estimates of AFV emissions of HC, NO_x, and CO must be generated for use in the model. A number of studies have provided such estimates for both current and projected vehicles. These sources are summarized in Appendix I. Often emissions data are presented together with emissions from a similar gasoline-fueled vehicle. This is useful, because the automobiles evaluated are not standardized across studies.

D. Empirical Development of AFV Emission Cost Functions

Data relating the emissions and costs of alternative-fueled vehicles (AFVs) are found in articles that generally report the results of emissions tests on some particular vehicle(s). The vehicles are not standardized across articles, which makes statistical analysis of these data problematic. However, often emissions of the vehicle when running on the alternative fuel are compared to emissions from a like vehicle running on gasoline. Therefore, data are comparable insofar that percent changes in emissions for alternative fuels versus gasoline are reported.

The gasoline-fueled vehicle against which AFV emissions are compared usually utilize current in-use emissions control technology. Since the data were generated over the period from 1981-1991, the baseline gasoline vehicle is somewhat of a moving target. However, emission control technologies during this period of time and across manufacturers have been stable enough to allow some conclusions about the emissions of AFVs relative to similar gasoline vehicles.

The form of the CNG and methanol vehicle emissions data suggest that the 1998 AFV emission cost function might be derived from the gasoline-fueled vehicle cost function. The AFV data can be related to gasoline data in at least two ways. First, for an automobile with equal emissions-control-technology expenditure, the AFV will obtain a certain percentage of emissions reductions compared to a like gasoline vehicle. Alternatively, one could estimate the relative (i.e., reduced) level of emissions control expenditure necessary for an AFV to obtain the same emissions levels as a like gasoline vehicle. It is also hypothesized that the marginal cost of obtaining emissions reductions from AFVs is lower than the marginal cost of reducing emissions of gasoline vehicles, at any given level of emissions. These assertions do not completely characterize AFV emission cost functions, but they do represent a first step in relating AFV costs and emissions to gasoline vehicle costs and emissions.

Currently, techniques for deriving AFV emission cost functions from estimated gasoline-vehicle emission cost functions are being explored, with the above hypotheses used as guiding principles, and in consideration of the data presented in the next section.

An alternative and more direct method of deriving these cost functions, utilized by CARB (1990(2)), is to anticipate what AFV emissions control technologies are likely to be used in AFVs, their attendant effect on emissions, and the costs of each technology. This method can be used to directly develop a step-function for the cost of emissions, or one could attempt to fit a continuous function through the data points obtained in this manner. EPA is currently doing research relating to this issue (DeLuchi, 1991).

CARB provides estimates of the minimum costs and the minimum emissions reductions for 3 methanol-vehicle technologies and 2 CNG technologies. Other articles generally report the emissions control equipment utilized by the vehicle tested, but do not estimate the costs of this equipment. A list of emissions control systems that are likely to be installed on methanol and CNG vehicles is given in Table 6.1.

TABLE 6.1
AFV EMISSION CONTROL SYSTEMS

PART		TARGET	APPLICATION
3-wy CC	(1)	HC, CO, NOx	CNG, METHANOL
Air Pump	(1)	HC, CO	CNG, METHANOL
EGR	(1)	NOx	CNG, METHANOL
Fuel injection	(2)	HC, CO	CNG, METHANOL
Lean-burn design (sensors, valves)	(2)	HC, CO	CNG, METHANOL
Closed-loop A/F control	(2)	HC, CO, NOx	CNG, METHANOL
Pre-heated CC	(3)	HC, CO	METHANOL
Fuel prep. sys.	(3)	HC, CO	METHANOL
Evap. Controls	(4)	HC	FFVs (M85)

1 = Standard emissions control parts in use since at least 1981.
2 = Fuel system parts designed to reduce unburned fuel over wide range of engine operation.
3 = Parts designed to reduce cold-start emissions.
4 = Evaporative emission control parts.

For preliminary simulations, AFV costs and emissions will be modeled as a fixed proportion. That is, each of the five types of AFVs have a single cost and single level of associated emissions in the simulation. In the next stage of the project, emissions cost functions for AFVs will be derived by one of the methods outlined above.

E. A Brief Discussion Of Proposed Emission Standards

Emissions of NO_x and CO from methanol and CNG vehicles are essentially chemically equivalent to NO_x and CO emissions from gasoline vehicles. Therefore, identical standards for these pollutants can be applied to methanol, CNG, and gasoline vehicles. However, the composition of hydrocarbons emitted by methanol-fueled vehicles are very different than HCs emitted by gasoline vehicles. CARB has proposed that all HC emissions be regulated on the basis of ozone-forming-potential. CARB's standards will require exhaust emissions to be measured somewhat differently than they have in the past (see Endnote). The data presented in this paper follows the traditional methodology of directly comparing gasoline vehicle non-methane hydrocarbon (NMHC) emissions to CNG vehicle NMHC, and to organic-equivalent hydrocarbon emissions (OMHCE) from methanol-fueled vehicles. These data will be adjusted to reflect ozone-forming-potential (CARB (2)) before final estimates of emissions cost functions are made.

Electric vehicles are currently designated as ZEVs by CARB. If the emissions from power plants caused by the use of electric vehicles need to be accounted for, estimates of emissions per mile will have to be made for EVs. The emissions of EVs generated from power plants have been explored in some detail by Wang et al. (1990). In our analysis, we will establish two cases of dealing with EV emissions. The first case assumes that EVs are zero-emission vehicles. The second case will estimate the emission reductions of EVs when accounting for power plant emissions attributable to EVs.

Evaporative emissions of HCs are not included in CARB's emissions credits trading program. CARB believes that, "...vehicle/fuel systems that comply with the new evaporative test procedures should have nearly zero evaporative emissions..." (CARB(1)). Currently, however, this is not the case; for example, evaporative emissions for 1986 model year gasoline vehicles were estimated to compose between 37.5% to 70.5% of the total 1986 vehicle HC emissions (Alson et al.). Conversely, dedicated CNG vehicles emit virtually zero evaporative HCs. If manufacturers find it costly to achieve similar low evaporative emissions from gasoline vehicles, it may be appropriate to include evaporative emissions in the emissions trading market. Future model simulations will explore the implications of this possibility for the cost effectiveness of AFVs.

F. Data

A majority of the articles reviewed and summarized in Appendix I are reports of emission tests of some AFV(s). Collection of additional data is ongoing. Fortunately, most of the articles compare AFV emissions to some similar gasoline vehicle. Table 6.2 groups these articles for methanol and CNG vehicles, and lists the change in emissions relative to the reference gasoline vehicle. Dual- and flexible-fuel vehicle emissions are generally referenced against the same vehicle operating on gasoline. Dedicated AFVs are generally compared to a gasoline vehicle of similar weight and power. More detailed data from the sources listed in Table 6.2 are found in Appendix I.

There is some duplication and overlap in these data. Most significant is the paper by DeLuchi et al. (1988), which represents the most comprehensive collection to date of methanol and CNG vehicle emission data. Relying largely on the work of DeLuchi et al. (1988), who considered both data and theoretical expectations, it is concluded that AFV emissions are likely to compare to gasoline-vehicle emissions in the following ways:

1) CO: Methanol vehicles burning M85 will have approximately the same level of CO emissions as gasoline vehicles. Lean-burn methanol vehicles burning M100 will have moderately lower CO emissions. Both of these results are contingent on technology developing which will eliminate methanol's cold-start problem. Dedicated CNG vehicles, which can be operated at very lean air-fuel ratios, have the potential to virtually eliminate CO emissions. Dual-fuel CNG vehicles are likely to greatly reduce CO emissions, but not to the same extent as an optimized vehicle will.

2) NO_x: Theory indicates that NO_x emissions from CNG and methanol vehicles will likely be close to gasoline-vehicle levels. However, data indicate that NO_x control may be a problem with these fuels, especially CNG (Weaver);

3) HC: Both CNG- and methanol-fueled vehicles are expected to emit lower quantities of reactive HCs than gasoline vehicles.

Estimates of AFV production costs are few, but they are generally close in magnitude. The values listed in the last column of Table 6.2 are estimates of the additional expenditure necessary to produce an AFV versus a similar size gasoline vehicle. These figures assume large production runs of approximately 100,000 vehicles or more. Also, no allocation is made of the fixed costs necessary to bring AFVs into production. Fixed costs include research and development, and the tooling necessary to begin mass production. Although fixed costs are important, they should not impact the relative efficacy of emission control policies, given that these policies require the same level of emissions control. It is this latter issue, the relative efficiency of various policies, which is the focus of the programming model.

TABLE 6.2: EMISSIONS AND PROJECTED COST DATA FOR AFVs

PERCENT CHANGE IN EXHAUST EMISSIONS vs. SIMILAR GASOLINE VEHICLE
ADDITIONAL PRODUCTION COST OF AFV vs. GASOLINE VEHICLE

FFVs (M85) :	CO	NOx	OMHCE	COST
Prakash :	+66%	-17%	+44%	---
DeLuchi[2] :	+33%	-21%	-18%	---
EPA(2) :	---	---	---	+$150[2]
SRI :	---	---	---	+$260
Singh :	---	---	---	+$275[2]
CARB :	---	---	---	+$200

DEDICATED M85:	CO	NOx	OMHCE	COST
DeLuchi[2] :	-9%	-19%	-5%	$0
EPA(2) :	---	---	---	$0
Piotrowski et al. (1):	+33%	+51%	-66%	---
Blair :	+3%	+347%	-28%	---
Piotrowski & Murrell :	+5%	+19%	-48%	---
Yee et al. :	+32%	-33%	+57%	---
Nichols :	-20%	-56%	-43%	---

DEDICATED M100:	CO	NOx	OMHCE	COST
Piotrowski(1):	-21%	+114%	-55%	---
Piotrowski(2):	-27%	+21%	-57%	---
Piotrowski & Murrell :	+58%	-22%	-43%	---

[1] Projected in-use emissions relative to gasoline.

[2] When a range or multiple values are given, the mean is reported.

Percent changes are calculated as follows:
[% change = (AFV emissions/gas vehicle emissions)-1]

TABLE 6.2(continued): EMISSIONS AND COST DATA FOR AFVs

PERCENT CHANGE IN EXHAUST EMISSIONS vs. SIMILAR GASOLINE VEHICLE
ADDITIONAL PRODUCTION COST OF AFV vs. GASOLINE VEHICLE

DUAL-FUEL CNG VEHICLES

DUAL-FUEL CNG:	CO	NOx	NMHC	COST
CARB :	---	---	---	+$1,000
Prakash :	-28%	+379%	-72%	---
EPA(1) :	-89%	+46%	-16%	+$1,600
EPA(1) :	---	---	-42%[1]	---
Bruetsch :	+25%	+83%	-54%	---
DeLuchi :	-88%	-13%	-53%	---

DEDICATED CNG VEHICLES

DEDICATED CNG:	CO	NOx	NMHC	COST
EPA(1) :	-99%	+77%	-30%	+$900
EPA(1) :	---	---	-86%[1]	
ADAMS :	-99%	+73%	-54%	
Singh :	---	---	---	+$800
DeLuchi :	---	---	---	+$450[2]

[1] Projected in-use emissions relative to gasoline.

[2] When a range or multiple values are given, the mean is reported.

Percent changes are calculated as follows:
[% change = (AFV emissions/gas vehicle emissions)-1]

The additional cost of producing methanol vehicles should be close to zero for dedicated vehicles and in the range of $150 to $300 for FFVs. CNG vehicles are expected to cost an additional $1,000 to $1,600 for dual-fuel vehicles, and between $450 and $900 extra for dedicated vehicles.

Table 6.3 gives a partial summary of the data for electric vehicles. Included are the type of battery used, the range of the vehicle, and the projected vehicle cost, to the consumer, of EVs.

Table 6.3

Estimates Of Electrical Vehicles Market Price (1987 dollars)

Study	Battery Type	Range(miles)	Cost
DeLuchi,et al.('89)	Sodium/Sulfur	150	$15,651
DOE	Lead/Acid	44	11,588
DOE	Nickel/Iron	90	15,219
DOE	Sodium/Sulfur	207	17,210
Harvey and Gyamfi	Lead/Acid	100	14,801
Harvey and Gyamfi	Nickel/Iron	100	15,827
Harvey and Gyamfi	Sodium/Sulfur	100	15,182
Harvey and Gyamfi	Lead/Acid	150	18,908
Harvey and Gyamfi	Nickel/Iron	150	19,171
Harvey and Gyamfi	Sodium/Sulfur	150	17,567

Note: For studies which give a range of estimates, the mean is reported.

G. Model Calibration: Point Estimates of AFV Costs and Emissions

At the time of this writing, the mathematical programming model is being calibrated with estimates of 1990 gasoline emissions control costs. Estimates of the potential emission reductions from AFVs are being used to calculate break-even costs for AFVs (i.e., the production cost at which a manufacturer would choose to produce AFVs). Estimates of the CAFE benefit, production cost, and market price for AFVs will be introduced into the model in upcoming simulations.

Table 6.4 summarizes the AFV emissions and cost estimates utilized in the initial simulations. These data reflect current AFV technologies, although costs assume mass production. The values in Table 6.4 were selected based on scrutiny of the data presented in this report, especially DeLuchi et al. (1988) and Sperling and DeLuchi.

TABLE 6.4
AFV PRODUCTION COST AND EMISSIONS DATA USED FOR 1990 MODEL CALIBRATION

VEHICLE :	CO(%)	NOx(%)	HC(%)	COST
FFV (M85):	2.09(0)	.26(0)	.18(-10)	+$250
DED. M85:	2.09(0)	.26(0)	.10(-50)	0
DUAL CNG :	1.59(-25)	.26(0)	.14(-30)	+$1,300
DED. CNG:	1.04(-50)	.26(0)	.08(-60)	+$700
'90 FLEET:	2.09	.26	.20	

Emissions given in gm/mi: NMHC for gasoline and CNG vehicles. OMHCE for methanol vehicles.
Quantities in parenthesis express AFV emissions relative to the average 1990 fleet emissions in California for 1900. [% change = (AFV emissions/gas vehicle emissions)-1]
Cost figures are the estimated increase in costs for production of an AFV vs. a gasoline vehicle, assuming AFV production runs of approximately 100,000 vehicles.

ENDNOTE: To determine ozone-forming-potential (measured in grams of ozone per gram of NMOG) of a vehicle-fuel combination, the following two components must be measured: 1) non-methane organic gasses (NMOG) "...consist of the full, unadjusted mass of all measurable non-oxygenated hydrocarbons (except methane) containing 12 or fewer carbon atoms, and all ketones, aldehydes, alcohols, and ethers containing 5 or fewer carbon atoms" (CARB(2)) (NMOG is measured in gm/mi); and 2) the maximum incremental reactivity of the NMOG from each motor vehicle fuel, which is a measure of the ozone-forming-potential of a vehicle-fuel combination's NMOG (in gm-Ozone/gm-NMOG).

Gasoline vehicle HC emissions have traditionally been measured as non-methane hydrocarbons (NMHCs). Alcohol-fueled vehicles' HC emissions have generally been expressed in terms of organic material hydrocarbon equivalent (OMHCE). "In the case of hydrocarbon fuels, such as gasoline and CNG, NMOG is almost the same as NMHC. Aldehydes and alcohols comprise a significant portion of the NMOG emissions from alcohol-fueled vehicles" (Klausmeier and Draves). Comparing OMHCE to NMHC directly assumes that the ozone reactivity of a vehicle's exhaust depends largely on the amount of carbon present.

CARB's proposed regulations are more robust in that they "consider the individual reactivities of all measurable hydrocarbon species in an exhaust sample, both oxygenated and non-oxygenated." (CARB(2)). The full mass of all non-methane reactive gasses are to be taken into account, with each compound weighted by its relative reactivity.

The bottom line to all this is that, to precisely model the proposed emissions standards, previous OMHCE and NMHC emissions data for AFVs need to be adjusted according to the NMOG and reactivity measures being developed by CARB. For the time being, these relatively minor adjustments are ignored; NMHC from CNG vehicles and OMHCE from methanol fueled vehicles are compared directly to gasoline-vehicle NMHC.

CHAPTER VI. APPENDIX I: BRIEF SUMMARIES OF DATA SOURCES

AUTHOR: Adams, Tim G. (Ford Motor Co.)

TITLE: The Development of Ford's Natural Gas Powered Ranger (1985)

VEHICLE: 1984 Ford Ranger Truck.
CYLINDERS: 4
DISPLACEMENT: 2.3 liter
MILEAGE: low
FUELS: CNG dedicated

EMISSIONS CONTROLS: standard Ranger equipment?

TEST PROCEDURE: FTP-75

TEST RESULTS: Exhaust Emissions, gm/mi

	CO(%)	NOx(%)	NMHC(%)
CNG :	.03(-99)	1.9(+73)	.14(-54)
Gas :	3.2	1.1	.31

COST DATA: Retro-fit cost = Gas + $1,500
Dedicated, mass production cost = Gas + $750

AUTHOR: Alson, Jeffrey A., Jonathan M. Adler, and Thomas M. Baines

TITLE: Motor Vehicle Emission Characteristics and Air Quality Impacts of Methanol and Compressed Natural Gas. Chapter 8 in Sperling, Daniel, editor (1989).

VEHICLE: Data extracted from EPA's Methanol vehicle data base. Statistical summary of 40 cars which met EPA's standards for methanol vehicles.

MILEAGE: average of 10,000 for methanol vehicles
CNG vehicle mileage not provided
FUELS: various

EMISSIONS CONTROLS: Current Technology = vehicles which use engines very similar to those used in today's gasoline cars.

TEST PROCEDURE: FTP

TEST RESULTS: Exhaust Only, gm/mi

	CO(%)	NOx(%)	HC	Methanol	HCHO
avg. Methanol:	1.7(-87,+42)	.61(-53,+13)		.47	.035
avg. dual CNG:	.52(-96,-57)	.97(-25,+80)	.23(0,-77)		
avg. Gas(new):	1.2	.54	.23		
avg. Gas(50k):	13.0	1.3	1.0		

NOTES ON HC MEASURE: NMHC for CNG.
For methanol vehicle emissions: Meth. + HCHO < OMHCE.

AUTHOR: Blair, David (EPA)

TITLE: Evaluation of M85-Fueled 1987 Turbo Buick Regals (1987)

VEHICLES: Two 1987 Turbo-charged Buick Regals.

CYLINDERS: 6
DISPLACEMENT: 231 ci
MILEAGE: 445, 780
WEIGHT: 3,625 lbs
FUELS: M85

EMISSIONS CONTROLS: 3-way catalytic converter, closed loop A/F ratio control.

TEST PROCEDURE: FTP

TEST RESULTS: Exhaust Only, gm/mi

	CO(%)	NOx(%)	HC(%)	HCHO(%)
CAR 1 :	2.81(+6)	1.12(+339)	.159(-35.1)	32.54
CAR 2 :	4.95(+1.87)	1.18(+356)	.192(-21.6)	33.59
GASOLINE :	2.1 - 3.2	.18 - .48	.18 - .31	

Percent changes measured against mean gasoline vehicle emissions.

NOTES ON HC MEASURE: FID test results adjusted by xx/.85 to account for undetected methanol.

AUTHOR: Bruetsch, Robert I. (EPA)

TITLE: Emissions, Fuel Economy and Performance of Light Duty Compressed Natural Gas and Dual-Fueled Vehicles (1988)

VEHICLES

	1984 GM Delta	1987 Crown Victoria	1987 Celebrity	1984 Ranger
CYLINDERS:	8	8	6	4
DISPLCEMNT:	307 ci	302 ci	173 ci	140 ci
FUELS:	DUAL	DUAL	DUAL	DEDICATED
WEIGHT:	4000 lbs	4,250 lbs	3,250 lbs	3,000 lbs
EMS CNTRLS:	A,B,C,D	A,B,C,D	A,D	A,B,C

A= Exhaust gas recirculation
B= Air pump
C= Oxidation catalyst
D= Three-way catalyst with closed loop

TEST PROCEDURE: FTP

TEST RESULTS: Exhaust Emissions Only

	CO(%)	NOx(%)	NMHC(%)	HCHO mg/m
DELTA :	1.69(-83)	1.18(+195)	.082(-74)	4.82
CROWN VIC :	2.40(+78)	.79(-26)	.167(-29)	4.91
CELEBRITY :	1.28(+13)	1.41(+135)	.089(-72)	3.47
avg. DUAL :	+25%	+83%	-54%	
RANGER :	.04	1.98	.057	4.66

NOTES ON HC MEASURE: FID correction factor of 1/1.11. Some difficulty encountered in measuring Methane and NMHC.

AUTHOR: California Air Resources Board

TITLE: Proposed Regulations for Low-Emission Vehicles and Clean Fuels: Technical Support Document, August 13, 1990

VEHICLE: Projected costs and emissions of the following:
TLEV = Transitional low emission vehicle
LEV = Low emission vehicle
ULEV = Ultra low emission vehicle

EMISSIONS CONTROLS AND COSTS: Projected vehicle costs, over standard gasoline vehicle:

TLEV: +$1,000 for CNG dual-fuel with underfloor catalyst. "Slightly less" for dedicated CNG.

+$200 for methanol with improved close-coupled catalyst.

+$70 for gasoline vehicle with smaller engine, dual oxygen sensors, improved fuel preparation system, and close coupled CC ($70=cost of fuel prep. system only).

LEV: +$1,200 for dual-fuel CNG with fuel injection.

+$270 for methanol with heated fuel preparation and close-coupled catalyst.

+$170 for gasoline with heated catalyst and air pump.

ULEV: +$1,200 for dual-fuel CNG with fuel injection.

+$370 for methanol vehicle with same equip. as LEV.

+$170 for gasoline with heated catalyst and air pump, burning reformulated gasoline.

TEST PROCEDURE: Proposed California procedure.

TEST RESULTS: Vehicles are projected to meet the following standards, in gm/mi:

	CO	NOx(%)	NMOG
TLEV :	3.4	.4	.125
LEV :	3.4	.2	.075
ULEV :	1.7	.2	.04

NMOG in gm/mi assuming reactivity of gasoline.

OTHER: CARB seems to indicate that heated fuel preparation will be utilized by gasoline-fueled TLEVs but not by gasoline-fueled LEVs.

AUTHOR: Deluchi, Mark A., Robert A. Johnston, and Daniel Sperling

TITLE: Methanol versus Natural Gas Vehicles: A Comparison of Resource Supply, Performance, Emissions, Fuel Storage, Safety, Costs, and Transitions (1988)

VEHICLE: Summary and analysis of other studies.

CYLINDERS: various
DISPLACEMENT: various
MILEAGE: New
FUELS: Dedicated CNG, Dedicated M85-M95

EMISSIONS CONTROLS: Methanol: catalytic converter.
CNG: various.

TEST PROCEDURE: FTP, EPA-CVS.

TEST RESULTS: Exhaust Only, gm/mi

	CO(%)	NOx(%)	HC(%)
CNG Ranger :	.03(-99)	1.9(+73)	.14(-50)
CNG Ford V6 :	.95	2.57	.19 ⊙
avg. of 9 dual CNG :	.75(-88)	.94(-13)	.17(-53)
avg. of 3 ded. meth. :	1.92(-9)	.48(-19)	.23(-5)
avg. of 4 dual meth. :	1.92(+33)	.50(-21)	.20(-18)

Reference gasoline vehicles not standardized. See reference for further explanation.

NOTES ON HC MEASURE: OMHCE for methanol. NMHC for CNG.

COST DATA: Dedicated Methanol: Same as gasoline vehicle.
Dedicated CNG: Gasoline vehicle +$750.

AUTHOR: Nichols, Roberta J., John Lapetz, Carol Smith, and Wallace D. Tallent (Ford)

TITLE: Ford's Development of a Methanol-Fueled Escort (1982)

VEHICLE: 40 dedicated Ford Escorts

CYLINDERS: 4
DISPLACEMENT: 1.6 liter
MILEAGE: 3,000
FUELS: 94.5% methanol, 5.5% isopentane

EMISSIONS CONTROLS: 3-way catalyst, "...in reality it is being used primarily as an oxidation catalyst because the air-fuel (A/F) ratio is not being controlled at stoichiometry."

TEST PROCEDURE: Constant Volume Sample-75

TEST RESULTS: Exhaust Only, gm/mi

	CO(%)	NOx(%)	NMHC(%)	Methanol	HCHO
Baseline:	4.77(-20)	.41(-56)	.24(-43)	.30	.0084
w/o Air :	27.99(+370)	.37(-60)	.51(+42)	.78	.0146
w/o EGR :	4.43(-26)	1.13(+21)	.38(+6)	.15	.0308
w/o both:	23.50(+294)	.74(-20)	.51(+42)	.83	.0826
Gas:	5.95	.93	.36		

NOTES ON HC MEASURE: Methanol NMHC underestimated due to use of FID. As indicated by Methanol > NMHC, where methanol mass should be included in NMHC.

AUTHOR: Piotrowski, David K. (EPA)

TITLE: Recent Results From Prototype Vehicle Technology Evaluation Using M100 Neat Methanol Fuel (1990)

VEHICLES:	Prototype Toyota Corolla	Prototype Nissan Sentra
CYLINDERS:	4	4
DISPLACEMENT:	1.6 liter	1.8 liter
MILEAGE:	New	New
WEIGHT:	2,750 lbs	2,250 lbs
FUELS:	M100	M100

EMISSIONS CONTROLS: Toyota: Sequential port fuel injection. EGR system (not on original lean-burn Toyota Carina). Catalytic Converters: .71 liter Pt:Rh (manifold close coupled). .51 liter Pd (underfloor) catalyst to control HCHO. Four valves per cylinder. Lean-burn system, including sensor and swirl control valve.

Nissan: Ultra lean-burn design similar to Toyota with closed-loop control. Electronic port fuel injection. 1.7 liter Pt:Rh CC. Four valves/cylinder.

TEST PROCEDURE: FTP

TEST RESULTS: Exhaust only, gm/mi

	CO(%)	NOx(%)	HC(%)	HCHO mg/mi
Corolla :	1.61(+58)	.49(-22)	.12(-43)	9.0
Sentra :	.45	.56	.20	28.9
Tercel :	1.02	.63	.21	

Tercel = emissions from similar size gasoline-fueled Tercel. Percent
changes of Corolla based on Tercel emissions.
No emissions for gasoline-fueled Sentra given.

NOTES ON HC MEASURE: OMHCE

COST DATA: None.

OTHER NOTES: Primary differences between these vehicles are engine size, and the Toyota's extra catalyst.

AUTHOR: Piotrowski, Gregory K. and J. Dillard Murrell

TITLE: Phase I Testing of Toyota Lean Combustion System (Methanol), US EPA (Jan. 1987).

VEHICLE: 1986 Toyota Carina.
CYLINDERS: 4
DISPLACEMENT: 1587 cc
MILEAGE: ?
WEIGHT: 2250
FUELS: M85, M100

EMISSIONS CONTROLS: Lean mixture sensor to control A/F ratio.
Swirl Control valve upstream of the intake valve to limit torque fluctuation during lean operation.
Sequential fuel injection.
Catalyst, close-coupled to exhaust manifold.

TEST PROCEDURE: FTP

TEST RESULTS: Exhaust Only, gm/mi

	CO(%)	NOx(%)	HC(%)	ALDEHYDES
M85 :	1.07(+5)	.75(+19)	.11(-48)	7.3
M100 :	.74(-27)	.76(+21)	.09(-57)	11.3
Tercel :	1.02	.63	.21	

Tercel = emissions from similar size gasoline-fueled Tercel.

NOTES ON HC MEASURE: EPA methodology, where "...the results shown here were computed with a FID response factor of .75 and an assumed HC ppm to CH_3OH ppm factor of xx/.85, where xx is the fraction of methanol in a methanol gas blend."

COST DATA: None.

AUTHOR: Piotrowski, Gregory K. (EPA)

TITLE: Evaluation of a Toyota LCS-M Carina: Phase II (1987)

VEHICLE: 1986 Toyota Carina.

CYLINDERS: 4
DISPLACEMENT: 1587cc
MILEAGE: ?
WEIGHT: 2,625 lbs
FUELS: M100

EMISSIONS CONTROLS: Lean burn design. Includes special fuel mixture sensor, swirl control valve, and sequential-port fuel injection. Underfloor catalytic converter for some tests.

TEST PROCEDURE: FTP

TEST RESULTS: Exhaust Only? gm/mi

	CO(%)	NOx(%)	HC(%)	ALDEHYDES mg/m
Test 1 :	.93(-10)	1.25(+98)	.10(-52)	12.1
Test 2 :	.69(-32)	1.45(+130)	.09(-57)	5.2
Baseline :	5.65	?	7.45	447
Tercel :	1.02	.63	.21	

TEST 2 = with underfloor catalyst
BASELINE = engine-out emissions
Tercel = emissions from similar size gasoline-fueled Tercel.

NOTES ON HC MEASURE: OMHCE

COST DATA: None.

AUTHOR: Piotrowski, G.K., Robert Heavenrich, Robert I. Bruetsch, and Jensen P. Cheng (EPA)

TITLE: Interim Report on The Evaluation of a Methanol Fueled Crown Victoria (1987)

VEHICLE: 1986 Crown Victoria.

CYLINDERS: 6
DISPLACEMENT: 302 ci
MILEAGE: 3,500
WEIGHT: 4,000 lbs
FUELS: M85

EMISSIONS CONTROLS: Stoichiometric, fuel injected.

TEST PROCEDURE: FTP

TEST RESULTS: Exhaust Emissions Only, gm/mi

	CO(%)	NOx(%)	HC(%)	HCHO mg/mi
avg. of 8 :	.32(+33)	.68(+51)	.048(-66)	31.21
Certified :	.24	.45	.140	

Certified = Certification data for the Ford Thunderbird (3875 lbs).

NOTES ON HC MEASURE: EPA methodology, where the HC to CH_3OH is assumed to be xx/.85, and xx = the fraction of methanol in the fuel blend.

AUTHOR: Prakash, Chandra B. (Environment Canada)

TITLE: Emission Performance of Four Identical Passenger Cars Running on Gasoline, M85, CNG and LPG (1991)

VEHICLES: Ford Taurus', 1988 FFV (M85 or Gasoline), 1990 dual-fuel CNG, and 1990 Gasoline.

CYLINDERS: 6
DISPLACEMENT: 3 liters
MILEAGE: 7,560(Gas), 25,901(FFV), 8,050(CNG)
WEIGHT: 3,500 lbs, 3,750 lbs (CNG)
FUELS: Gasoline, M85, CNG

EMISSIONS CONTROLS: 3-way closed loop catalytic converter.

TEST PROCEDURE: Urban Dynamometer Driving Schedule (UDDS).

TEST RESULTS: Exhaust Gasses only, gm/mi

	CO(%)	NOx(%)	HC(%)	HCHO(%)
CNG :	1.11(-28)	2.54(+379)	.05(-72)	11.91(+156)
M85 :	2.58(+66)	.44(-17)	.26(+44)	50.65(+987)
Gas :	1.55	.53	.18	4.66

NOTES ON HC MEASURE: NMHC. OMHCE for M85. High HCHO levels for M85 vehicle attributed to malfunction of vehicle.

COST DATA: None.

AUTHOR: U.S. EPA, Office of Mobile Sources

TITLE: Analysis of the Economic and Environmental Effects of Compressed Natural Gas as a Vehicle Fuel: Volume I, Passenger Cars and Light Trucks. (April, 1990)

VEHICLES: Dual-fuel: '84 Delta 88, '87 Crown Victoria
'87 Celebrity, '83 LTD, '85 GMC pickup.
Dedicated: Ford Ranger.

EMISSIONS CONTROLS: Stock?

TEST PROCEDURE: FTP

TEST RESULTS: Exhaust Only, gm/mi

	CO(%)	NOx(%)	NMHC(%)
avg. Dual :	.52(-89)	.97(+46)	.234(-16)
avg. Gas :	4.56	.67	.278
CNG Ranger :	.035(-99)	1.95(+77)	.14(-30)
Gas Ranger :	3.2	1.1	.20

TEST RESULTS: Projected In-Use VOC Emissions

	HC(%)
FFVs M85 :	.53(-44)
Dedctd M100:	.19(-80)
Dual CNG :	.50-.61(-42)
Dedctd CNG :	.07-.19(-86)
Gasoline :	.95

NOTES ON HC MEASURE: Given in Gasoline VOC-equivalent. Adjusted for reactivity and includes HCHO.

COSTS: Dual Fuel CNG = Gasoline car + $1,600.
Dedicated CNG = Gasoline car + $900.

AUTHOR: Yee, Gene, Brian Woodward, and Ronald Yuille

TITLE: Conversion of 1984 Buick Turbo Regal to Use Methanol (M-85) as a Motor Fuel (1986)

VEHICLE: Four 1984 Buick Turbo Regals

CYLINDERS: 6
DISPLACEMENT: 231 ci
MILEAGE: Near new
WEIGHT: 3525 lbs
FUELS: 94.5% methane + 5.5% isopentane

EMISSIONS CONTROLS: Same as stock?

TEST PROCEDURE: FTP

TEST RESULTS: Exhaust Only, gm/mi

	CO(%)	NOx(%)	HC(%)
avg. Meth. :	.384(+32)	2.32(-33)	.69(+57)
avg. Gas :	.29	3.47	.44

NOTES ON HC MEASURE: "The calculations for emissions and fuel economy were changed to reflect the difference in fuel properties..."

OTHER DATA: Acceleration from 0-60 improved 7%
Fuel economy (energy based) improved 21%
Primary emphasis on performance. Emissions indicate relatively rich A/F ratio.

Chapter VII. Cost Savings from Emissions Trading for Conventional Vehicles and the Emission Benefits from AFVs

Before marketable permits can be empirically assessed for AFVs, it is useful to examine the potential cost savings to automobile manufacturers of a MPS for conventional vehicles. The form of such a system was described in Chapter III. This chapter describes the optimization model used to estimate cost savings from a MPS for conventional vehicles and the results of those simulations. In addition, results are presented for the value of AFVs to automobile manufacturers in a MPS such as CARB's Low-Emission Vehicle Program. The results presented here are preliminary and may change with further analysis.

The cost savings from a MPS specifically designed for conventional vehicles and AFVs is the subject of current research. Results of that ongoing work will be contained in a future report.

A. Marketable Permits for Gasoline Vehicles

There are two ways a manufacturer can reduce emissions from its fleet: reducing emissions per vehicle and/or selling a higher percentage of low emitting vehicles. The first simulation model examined is one where manufacturers produce the same mix of vehicles as they currently do, but average and trade the amount of HC emitted per vehicle in their fleet. No allowance for changing vehicle sales is considered. The solution to this problem could be considered a lower bound on the cost savings estimate from a trading system. The solution to the following problem characterizes this outcome,

$$\begin{aligned} \underset{HC_{ij}}{Min} \quad & \sum_{i=1}^{n}\sum_{j=1}^{k} C_{i,j}(HC_{ij}, CO_{ij}, NO_{x_{ij}}, X_{ij})\, \overline{V}_{ij} \\ s.t. \quad & \sum_{i=1}^{n}\sum_{j=1}^{k} HC_{ij}\overline{V}_{ij} \le \overline{HC}, \end{aligned} \tag{6}$$

where $\overline{HC}$ and $\overline{V}_{ij}$ are the fleetwide sales-weighted emission standard and the current sales of vehicles in class i for manufacturer j, respectively, and HC_{ij} are the HC emission from vehicle class i for firm j. (Recall that CO and NO_x do not enter some of the cost functions; they are included in (6) for completeness).

In implementing a trading scheme, there is an important issue regarding the safety margin. Manufacturers currently produce vehicles that more than meet the standards in order to create a margin of safety to account for uncertainty in actual in-use emissions. Under current law, if when in-use vehicles are tested during the useful lifetime of the vehicle (currently 50,000 miles), they are found to be noncompliant, manufacturers could be faced with costly recalls. The safety margins create a buffer against this possibility. If firms must only meet the standards on average over a fleet rather than for each vehicle, manufacturers will likely shave the safety margin on each of its vehicles resulting in larger emissions under a trading system than under CAC. To avoid this problem, current emission certification levels will be used as the standard ($\overline{HC}$) in the simulations, rather than the current standards. In this way, the solution to (6) will achieve the same emission levels as CAC.

Since manufacturers can also be expected to adjust their fleet makeup in response to a trading system, a second simulation model is employed that allows trading in both emissions per vehicle and the number of vehicles produced by each manufacturer in each vehicle class. This trading equilibrium can be characterized by the solution to the following problem:

$$\begin{aligned} \underset{HC_{ij},\,V_{ij}}{Min} \quad & \sum_{i=1}^{n}\sum_{j=1}^{k} C_{ij}(HC_{ij}, CO_{ij}, NO_{x_{ij}}, X_{ij})\, V_{ij} \\ s.t. \quad & \sum_{i=1}^{n}\sum_{j=1}^{k} HC_{ij}V_{ij} \le \overline{HC} \\ & \sum_{i=1}^{n}\sum_{j=1}^{k} V_{i,j} = \overline{V} \end{aligned} \tag{7}$$

where V_{ij} is the number of vehicles of class i sold by manufacturer j, and $\overline{V}$ is the current total sales of vehicles.

The problem as specified in (7) allows manufacturers to abate their emissions by either changing the emissions characteristics of each vehicle or by selling different mixes of vehicles (e.g., small vs. large cylinder vehicles). An implicit assumption is that when manufacturers change their sales mix, the profit margins on vehicles do not change. Since it is not clear how much of change in the sales mix of vehicles could occur before the profit margins would be affected, limits of 10, 20, and 30% on the changes in the sales mix from the current position will be considered in the simulation.

Finally, it may be reasonable to assume sales mix trading will occur, but only in such a way as the total amount of vehicles within a class (small, medium, or large cylinder) will remain constant. The problem can be easily altered to consider this possibility as follows

$$\begin{aligned} \underset{HC_{ij},\, V_{ij}}{Min} \quad & \sum_{i=1}^{n}\sum_{j=1}^{k} C_{ij}(HC_{ij}, CO_{ij}, NO_{x_{ij}}, X_{ij})\, V_{ij} \\ s.t. \quad & \sum_{i=1}^{n}\sum_{j=1}^{k} HC_{ij}V_{ij} \le \overline{HC} \\ & \sum_{j=1}^{k} V_{1j} = \overline{V}_1, \quad \sum_{j=1}^{k} V_{2j} = \overline{V}_2, \quad \sum_{j=1}^{k} V_{3j} = \overline{V}_3. \end{aligned} \tag{8}$$

where $\overline{V}_1, \overline{V}_2$, and $\overline{V}_3$ are the current sales of vehicles in the three separate vehicle classes. Again, limits on trading of 10, 20, and 30% relative to the current mix of vehicles will be applied.

The simulation results using each of the eight sets of cost functions described in the last section for each of the three trading scenarios described above (models (6), (7), and (8)) are presented in Tables 7.1 and 7.2.[8] Table 7.1 contains the results for the semilog cost functions and Table 7.2 contains the results for the doublelog functions.

The first row of each of the tables reports the estimates of cost savings from a permit system relative to CAC when only HC emissions per vehicles are traded, i.e., when the number of vehicles for each manufacturer

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[8] The solutions are computed using the nonlinear programming algorithm in GAMS. MPG, CO, and NO_x are fixed at current levels in the simulations.

Table 7.1: Emission Control Cost Percentage Savings

Semilog Cost Functions

TRADING RESTRICTIONS	GEOGRAPHY		CYLINDER		MEAN
	HC	ALL	HC	ALL	
HC ONLY[1]	9.29	3.25	8.64	3.83	6.24
HC & V(10%)[2]	11.82	6.66	12.35	7.61	9.61
HC & LV(10%)[3]	11.17	5.76	11.16	6.41	8.63
HC & V(20%)	14.34	10.07	15.97	11.41	12.95
HC & LV(20%)	13.05	8.29	13.64	9.03	11.01
HC & V(30%)	16.85	13.47	19.47	15.18	16.24
HC & LV(30%)	14.82	10.80	16.14	11.64	13.38
BASELINE($ Millions)	1300.1	1284.2	1312.3	1362.9	1314.9

1. The HC ONLY scenario corresponds to model (2); only emissions per vehicle are traded, vehicle sales in each category are held constant.
2. The HC&V scenario corresponds to model (3); both emissions per vehicle and vehicle sales are adjusted by manufacturers. The restriction on the amount of vehicles that can be altered from current levels is given in parentheses.
3. The HC&LV scenario corresponds to model (4); emissions per vehicle and vehicle sales <u>within a class</u> can be changed, but the total number of vehicles in each class must stay the same. The percent of vehicle sales changes allowed is given in parentheses.

Table 7.2: Emission Control Cost Percentage Savings

Doublelog Cost Functions

TRADING RESTRICTIONS	GEOGRAPHY		CYLINDER		MEAN
	HC	ALL	HC	ALL	
HC ONLY[1]	1.90	0.73	1.95	0.77	1.34
HC & V(10%)[2]	4.98	3.94	5.62	4.25	4.70
HC & LV(10%)[3]	4.23	3.12	4.49	3.33	3.79
HC & V(20%)	8.07	7.15	9.26	7.71	8.05
HC & LV(20%)	6.54	5.52	7.02	5.88	6.24
HC & V(30%)	11.15	10.36	12.88	11.16	11.39
HC & LV(30%)	8.85	7.91	9.55	8.42	8.70
BASELINE($ MILLIONS)	1276.6	1273.7	1272.0	1251.4	1268.4

1. The HC ONLY scenario corresponds to model (2); only emissions per vehicle are traded, vehicle sales in each category are held constant.

2. The HC&V scenario corresponds to model (3); both emissions per vehicle and vehicle sales are adjusted by manufacturers. The restriction on the amount of vehicles that can be changed from current levels is given in parentheses.

3. The HC&LV scenario corresponds to model (4); emissions per vehicle and vehicle sales <u>within a class</u> can be changed, but the total number of vehicles in each class must stay the same. The percent of vehicle sales change allowed is given in parentheses.

and each class are held at current levels (model 6). The second row reports the percent cost savings when the number of vehicles in each class sold by each firm can vary (model 7). The third row contains the results when the number of vehicles in each class is fixed at current levels, but the number of vehicles sold by each firm can vary (model 8). For models (7) and (8), three sets of limits on the amount of vehicle trading are examined (10, 20, and 30%). Naturally, the percentage cost savings increases with an increase in these limits.

The final row in each of Tables 7.1 and 7.2 contains the estimates of the current emission control costs which are computed using the estimated cost functions.[8] This is the baseline against which cost savings from the permit system are compared. As can be seen from the table, the estimates of current control costs do not vary much across the cost functions and are on the order of $1.3 billion annually.

In general, the cost savings estimated here are smaller than those reported in other empirical studies contrasting incentive-based regulatory schemes with CAC schemes. The apparent explanation for this is that the current CAC scheme has already taken advantage of much of the cost savings associated with differences in emission control costs among sources. Recall again that there are two choices for "abatement" facing manufacturers: improving the emissions performance of each vehicle (changing HC_{ij}) or changing the number of vehicles sold (V_{ij}). Unlike the typically conceptualized CAC regulation where each source of pollution is forced to have the same level of emissions (implying that all HC_{ij}'s are equal and all V_{ij}'s are equal), the current set of motor vehicle regulations has resulted in the lower cost sources of emission control being used at higher amounts than higher cost sources. Specifically, there are already more small cylinder vehicles being

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[8] Different estimates of the baseline emission control costs occur due to nonlinearity in the cost functions. As a consequence of the logged forms, the mean of the predicted total costs does not equal the mean of the actual total costs. Including the correction factor of $\sigma^2/2$ generated cost savings results that were substantially unchanged from those reported in the tables and so was not done.

sold in California than large cylinder vehicles. Further, manufacturers with lower costs of emission control sell more vehicles (American and Japanese) than higher cost producers (European). As a consequence, the permit system cost minimization is not being compared to a grossly inefficient case where all emissions from all sources are equal.

To test this argument, the simulations for the models with HC emissions only (model 6) were re-run with a new baseline for comparison. The baseline imposed all of the HC_{ij}'s and V_{ij} 's to be equal across sources (that is, the number of vehicles sold in each category by each manufacturer was equal to 1/9 of the total vehicle sales and the HC emissions per each vehicle was set at the average). This provides an estimate of the costs of emission control when all sources are treated truly equally and is analogous to the textbook notion of CAC where uniform abatement levels are applied. As expected, the percentage cost savings jumped dramatically. For the doublelog models, the savings jumped from 1.90% and 1.95% to 23.76% and 17.57%, respectively. For the semilog models, the savings jumped from 9.29% and 8.64% to 54.71% and 46.44%, respectively.

These results suggest that consumer preferences for small vehicles and corporate average fuel economy requirements that may encourage smaller vehicles, have had positive effects on the aggregate costs of pollution control. The cost savings associated with a permit system are smaller than they would be if there were a protypical CAC system as the baseline where emissions and vehicle sales were equal across sources.[9]

B. Sensitivity Analysis

Tables 7.1 and 7.2 also contain the necessary information to examine the sensitivity of the cost saving estimates to differences in the cost functions.

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[9] There are certainly other possible explanations for the low cost savings estimate. For one, the use of nine functions rather than one for each engine family may reduce the estimated savings. However, as noted in footnote 7, when 28 functions were used the estimates were within 1-2% of those reported here. This provides mild evidence that this is not the cause of the small estimated savings.

The effects of the different assumptions about the cost functions will be examined in turn.

1. Disaggregating by geography or cylinder size.

The two approaches to estimating disaggregate functions, dividing the data up by geographic region vs. by cylinder size, generate cost savings estimates that are quite similar. For example, in Table 7.1, the second and fourth columns contain the results when semilog cost functions are estimated using only HC as the measure of pollution. The numbers in these two columns generally differ by only a percentage point or so. The same is true regarding columns three and five which provide an equivalent comparison when all of the pollutants are included in the estimating equations. The results in Table 7.2 for the doublelog functions are also quite similar between the geographic and cylinder size approaches. These results suggest the percent cost savings estimates are relatively robust with respect to estimation approach.

2. Semilog vs. doublelog functional forms.

The sensitivity of the cost savings estimates to the choice of functional form can be examined by comparing each of the elements in Table 7.1 with its corresponding element in Table 7.2. As can be readily seen, the semilog cost functions generate larger estimates of cost savings than the doublelog form. This is true regardless of whether the functions are disaggregated by geography or cylinder size and whether HC enters the function alone or in combination with CO and NO_x.

In this circumstance, it would be desirable to appeal to underlying goodness-of-fit of the cost functions to determine which set of results to put the most weight on. However, traditional goodness-of-fit statistics such as the R^2 show very little difference between the two functions (see Tables 7.1 and 7.2).

3. HC alone vs. all three pollutants.

A final consideration in specification of the cost functions was the use of HC as a single regressor or the additional inclusion of CO and NO_x. Columns 2 and 4 of each table contain the results of the cost function specified in terms of HC only and columns 3 and 5 contain the results in terms of all three pollutants. In each case, the cost savings from the functions with all three pollutants are smaller than those with HC alone.

At first blush, it might seem reasonable to disregard the savings estimates from the functions that contain only HC since it could be argued that a clear case of omitted variables bias is occurring. That is, the coefficient on HC is biased since the clearly relevant and correlated variables CO and NO_x are omitted. However, the omission of CO and NO_x and their corresponding correlation with HC imply that the coefficient on HC reflects the effects of changes in all three pollutants rather than just changes in HC alone. Thus, counter-intuitively, the results of the simulations on the cost functions that omit CO and NO_x can be interpreted as the cost savings from a permit system where trading in HC, CO, and NO_x are all permitted. In this context, the larger cost savings estimates when HC enters the cost function alone are completely understandable: they reflect savings from averaging and trading in CO and NO_x as well as trading in HC. Since the three pollutants are not perfectly correlated, one cannot push this argument too far, yet it does indicate in a rough sense the magnitude of cost savings from a permit system in all three pollutants.

The results on the sensitivity of cost savings estimates to assumptions about functional form, method of disaggregation, and variable choice, though somewhat mixed, are encouraging. The main differences appear to occur from the choice of functional form.

C. The Value of Emission Reductions from AFVs

The data collected on the abatement costs of conventional vehicles can be used to infer the value of clean fueled vehicles in a permit system such as CARB's Low Emission Vehicle Program. AFVs would be sold without a sales requirement if manufacturers find it in their best interest to sell these vehicles (i.e., when it contributes to maximizing their profits). If manufacturers are faced with an average emissions regulation over their entire fleet, they will produce AFVs if the emission benefits from so doing exceed the costs of producing and selling the vehicles.

To determine the value of clean fueled vehicles to manufacturers faced with meeting an average emission standard, a simple model of car manufacturer's behavior under a marketable permit scheme is examined. Suppose there is only one type of alternative fuel vehicle and that all manufacturers of AFVs will have the same costs and the same emission characteristics of the vehicles. Then the problem for the manufacturer facing a permit scheme is to choose the number of AFV vehicles, the number of conventional vehicles, and the emissions levels for conventional vehicles.

The problem faced by a manufacturer is to find the least cost array of vehicles and emissions to achieve a given emissions level can be written

$$\begin{aligned} \underset{V_1,\, e_{CV}}{Min} \quad & V_{CV}C_{CV}(e_{CV})+V_{AFV}C_{AFV} \\ s.t. \quad & V_{CV}e_{CV}+V_{AFV}e_{AFV} \le \bar{E} \\ & V_{CV}+V_{AFV} = \bar{V}_{CV} \\ & V_{CV}\geq 0,\, V_{AFV}\geq 0 \end{aligned} \tag{9}$$

where V_i, i= CV, AFV, are the number of conventional and alternative fuel vehicles, e_i and C_i are the emission levels and the emission control costs for each of the respective vehicle types, $\bar{V}_{CV}$ is the current number of conventional vehicles, and $\bar{E}$ is the emission standard. Note that we are solving this problem for the number of vehicles in each of the categories and the amount of emissions from conventional vehicles. This model simplifies the problem by assuming that the amount of emissions from AFVs is fixed and cannot be varied by design changes.

The solution to this problem (assuming the emission constraint is met with equality and assuming interior solutions for the V's) yields the following:

$$-\frac{\partial C(e_{CV})}{\partial e_{CV}}=\frac{C_{AFV}-C_{CV}}{e_{CV}-e_{AFV}}, \tag{10}$$

Written this way, the condition states that the marginal abatement costs from reducing emissions on a conventional vehicle (the LHS) must just equal the cost savings per unit of emission reduction over conventional vehicles on the AFVs. Thus, the right hand side can be interpretted as the marginal abatement cost of reducing emissions by producing an AFV.

Note that there are two ways a manufacturer can obtain emission reductions: by controlling more emissions on conventional vehicles (through installing additional pollution control equipment for example) or by producing an AFV which emits less pollutants than the conventional vehicle. The condition in (10) simply states that the marginal abatement cost between the two forms of abatement must be equal.

Finally, we can write the condition that defines the optimal number of AFVs by combining the condition in (10) with the first two constraints as

$$V_{AFV} = \overline{V} - \frac{\frac{-\partial C(e_{CV})}{\partial e_{CV}}(\overline{E}-e_{AFV}\overline{V})}{C_{AFV}-C_{CV}}. \tag{11}$$

This expression indicates the number of AFVs will be positive as long as it is possible to meet the standard if all vehicles were produced as AFVs (i.e., as long as $\overline{E}\geq e_{AFV}\overline{V}$). The number of alternative fuel vehicles will equal the difference between the total number of vehicles and a term indicating the emissions benefits from producing AFVs.

The above model can be used to infer the value of permits from AFVs by rewriting condition (10) as

$$C_{AFV} = C_{CV} - \frac{\partial C_{CV}}{\partial e_{CV}}(e_{CV}-e_{AFV}). \tag{12}$$

Written this way, the condition states that manufacturers will choose the level of emissions (e_{CV}) such that the abatement costs of the AFV will just equal the abatement costs of the conventional vehicle plus an additional term. The additional value is the marginal abatement cost on conventional vehicles (which measures the value to firms of a unit of emissions) times the reduction in emissions associated with the AFV over conventional vehicles. Thus, the

RHS can be interpreted as the benefits to manufacturers from producing AFVs due to their emission characteristics. Manufacturers will set the costs of AFVs just equal to their value: the costs of conventional vehicles plus the value of the additional emissions reductions enjoyed by the AFV.

Equation (12) provides the basis for estimating the value of the emission benefits of AFVs. For any given emission level, the RHS of the expression indicates the value of an AFV due its superior emission characteristics. So, if manufacturers must meet an average emission level of $e=e^*$, then the RHS of equation (12) evaluated at this emission level represents that value of an AFV with emission level e_{AFV}.

This argument can best be understood in terms of opportunity costs. If no AFVs are available to manufacturers, they must meet the emission standards with current technology vehicles. Thus, the benefit of producing an AFV is the savings of the abatement cost on the conventional vehicle (the first term) plus the additional benefits generated by the additional emission reductions generated by the AFV over the conventional vehicle.

This procedure was implemented for the vehicle categories defined in CARB's Low-Emission Vehicle Program: ZEVs, ULEVs, LEVs, and TLEVs. To implement the procedure, an abatement cost function for conventional vehicles is needed. The cost functions generated by dividing the data into three groups by geographic region of manufacturer (european, american, japanese) and estimating double log functions were used. The regressors are HC, MPG, and dummy variables for medium and large cylinder vehicles. (This are the cost function results reported in the first three columns of Table 5.1).

Using these cost functions, the value of permits generated by the four vehicle categories listed above was estimated for three vehicle sizes: small, medium, and large vehicles. Table 7.3 contains the estimates of these values and the first four graphs (Diagrams 1-4) depict these values over time. The reported values for each cylinder size represent averages over the three manufacturer groups. The values change over time since the emission standards become more stringent in each of the years listed.

To compute these values, the RHS of equation (12) is evaluated at the emission levels (of HC) that are assumed to occur in order to meet the standard set for that year. This emission level differs from the standard by the estimated safety margin. The safety margin is assumed to be the same percentage as the current margin, i.e., the current average certification level for HC=.20 whereas the standard is .41. This implies a safety margin of about 50%. It is assumed that manufacturers will keep roughly the same percentage safey margin as standards tighten (thus the absolute margin will fall). Likewise, the emission levels for the clean vehicles (the values for e_{AFV} in equation (12)) are also assumed to have the same safety margin below the standard.

Examining first the data on ZEVs from the table and Diagram 1, several obvious and predictable patterns appear. First, the value of ZEVs increases over time as emission standards rise. This is expected since as standards tighten, manufacturers must spend more to meet standards on conventional vehicles so the value of an alternative that yields zero emissions also rises. Second, the value of large ZEVs is greater than medium and small ZEVs. This comes about due to the assumption that manufacturers will produce the same mix of small, medium, and large vehicles as the current fleet. A large ZEV will generate more emission benefits since it replaces a relatively dirty vehicle.

Turning next to the graphs for ULEVs, LEVs, and TLEVs, the same patterns exhibited and discussed for ZEVs emerges with one notable exception. Unlike ZEVs where the value rises in each period considered, the values of each of the other three categories first rise and then at some point start to fall again. This initially counterintuitive result can be explained by the fact that although these three vehicle categories more than meet the current emission standards, at some point in time (differing for each vehicle category), this is no longer true. That is, by the year 2003, TLEVs do not meet the standard in that year. Hence, if a manufacturer produces a vehicle in the TLEV category, it needs to either produce a lower emission vehicle at higher cost to offset the fact that this vehicle doesn't meet the standard or

Table 7.3: Clean Fueled Vehicles Estimated Values

Year	ZEVs			ULEVs			LEVs			TLEVs		
	SMALL	MEDIUM	LARGE	SMALL	MEDIUM	LARGE	SMALL	MEDIUM	LARGE	SMALL	MEDIUM	LARGE
1993	901	1093	1583	889	1078	1560	878	1065	1540	863	1047	1512
1994	929	1128	1636	909	1104	1599	892	1083	1567	868	1053	1522
1997	943	1146	1663	918	1115	1617	897	1088	1576	866	1050	1517
1998	960	1167	1696	928	1126	1634	899	1091	1580	858	1041	1504
1999	981	1192	1735	936	1136	1649	896	1087	1574	839	1017	1468
2000	1017	1236	1802	938	1140	1655	870	1056	1526	772	935	1342
2003	1026	1247	1819	936	1137	1651	856	1041	1503	746	903	1292

buy permits.

Referring to equation (12), the second term on the RHS becomes negative, the difference between the certification levels and the emission level of the TLEV is negative. The second term is then a cost of producing a TLEV instead of a benefit. Comparing the graphs for the ULEVs, LEVs, and TLEVs, it can be seen that the downturn occurs first for TLEVs (in about 1997), next for LEVs (in about 1999), and finally for ULEVs (in about 2000). This is simply in reverse order of their emissions levels.

Diagram 5 compares the average permit values of all four vehicle categories for 1993, 1998, and 2003. This graph demonstrates that although all four vehicle categories will have similar values in 1993, their values are quite different in 2003 when standards are much tighter.

Note that the values presented in the table and diagrams 1-5 do not represent the price of permits. Permits will be defined in terms of HC whereas the values reported here are per clean fueled vehicle. Rather, these values should be interpretted as the benefit to a manufacturer of producing an AFV. Some of those benefits come as savings on their own average costs of meeting the emission standards since when they produce an AFV that more than meets the standard they can produce a conventional vehicle that less than meets the standard. Additional benefits come in the form of creating permits that can be sold. If a firm produces enough AFVs so that their average fleet emissions are below the standard, they will earn credits that can be sold. The estimates reported in the five diagrams represent the sum of both values.

Finally, a note of caution in considering these numbers is in order. The cost functions for conventional vehicles upon which these numbers are based indicate relatively flat marginal abatement costs. That is, as HC emissions fall, the cost rise, but not very steeply. For example, the cost functions predict that the change in total manufacturer costs for an American, medium cylinder vehicle going from HC levels corresponding to the 1998 standard to the 2000 standard will only be about $30. Though these costs seem low, the introduction of cleaner fuels in the future combined with technology advances may make them reasonable approximations.

D. Summary

The results presented in this chapter on cost savings from a MPS for HC emissions from conventional vehicles and the value of AFVs to vehicle manufacturers are preliminary. Additional work examining the sensitivity of these results to emission control cost functions and underlying assumptions of the model is necessary before definitive results are available.

The data collected suggests that the costs of meeting the 1990 automobile emission standards in California was approximately $1.3 billion. The results to date suggest that cost savings of a MPS for conventional vehicles to meet HC standards in effect in 1990 may range from 2-20%, depending on the amount of changes in sales assumed. This translates into savings of roughly $26 to $260 million from a MPS. The lower figures can be treated as clear lower bounds since they assume that there are no changes in sales mixes.

The value of AFVs to manufacturers in a MPS like the Low-Emission Vehicle Program initiated by CARB are also estimated. The values of AFVs are estimated to rise over time, as long as the emissions from the vehicle are less than the emission standard in the period under consideration.

Diagram 1: Estimated Values of ZEVs

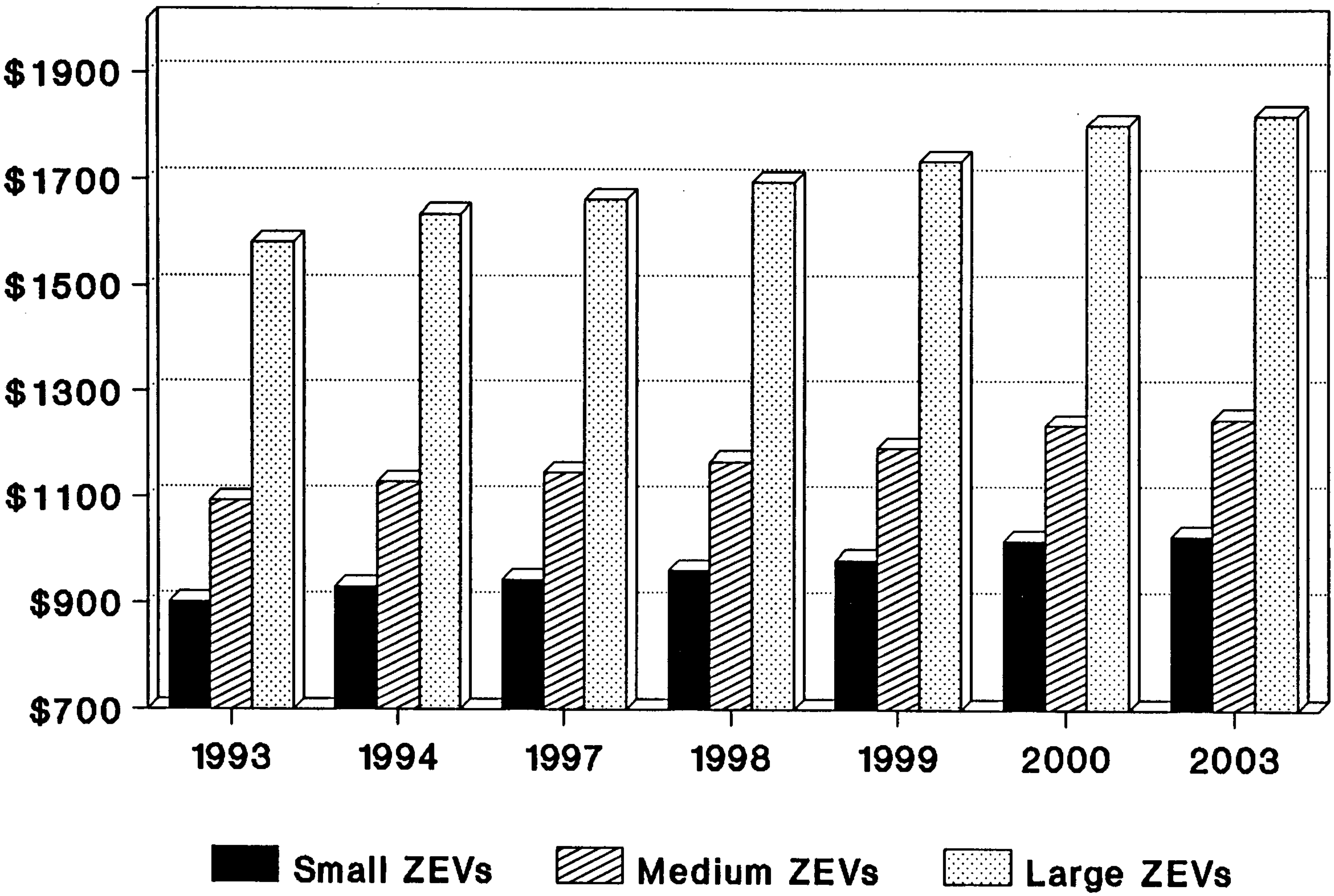


Diagram 2: Estimated Values of ULEVs

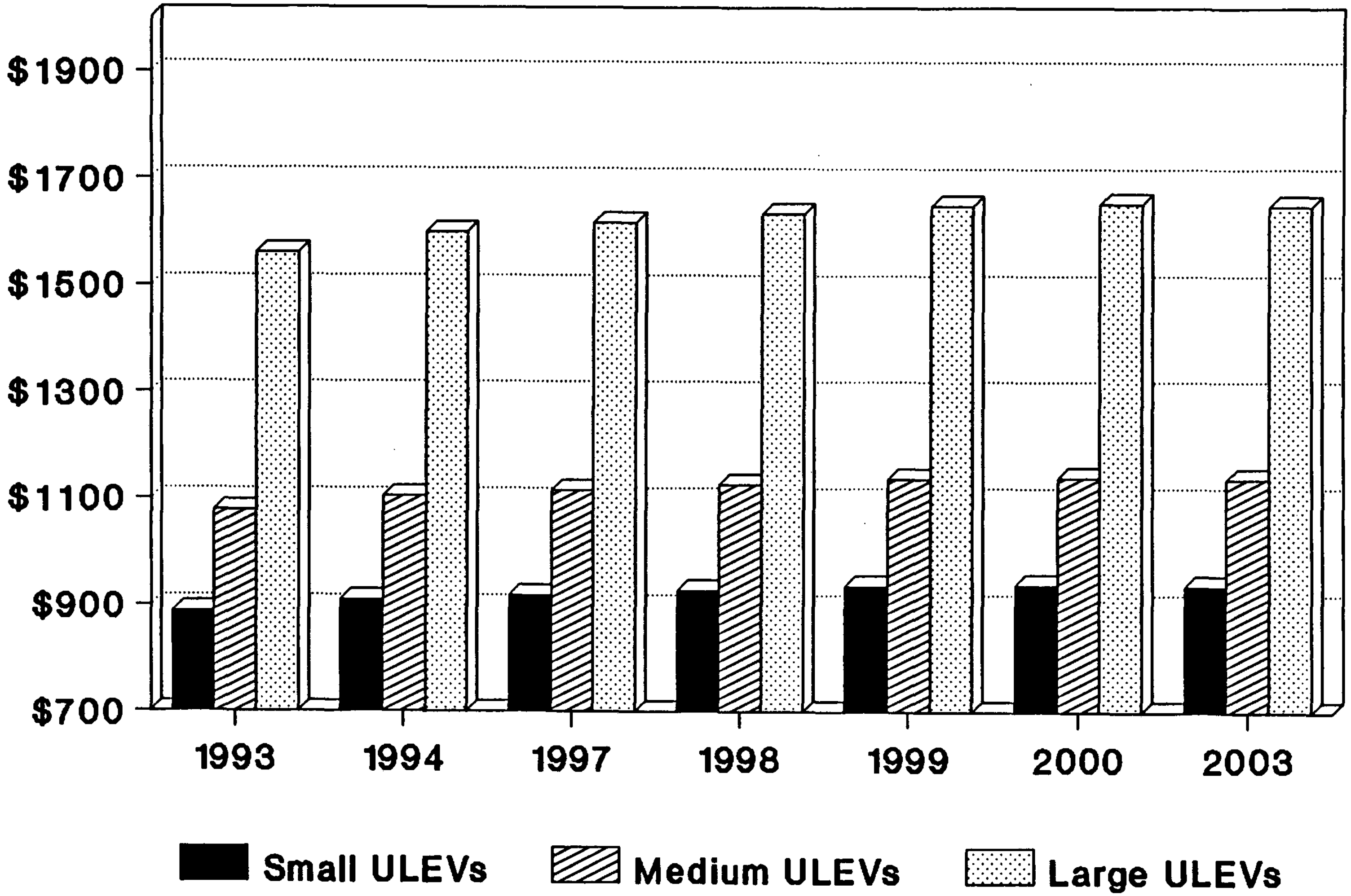


Diagram 3: Estimated Values of LEVs

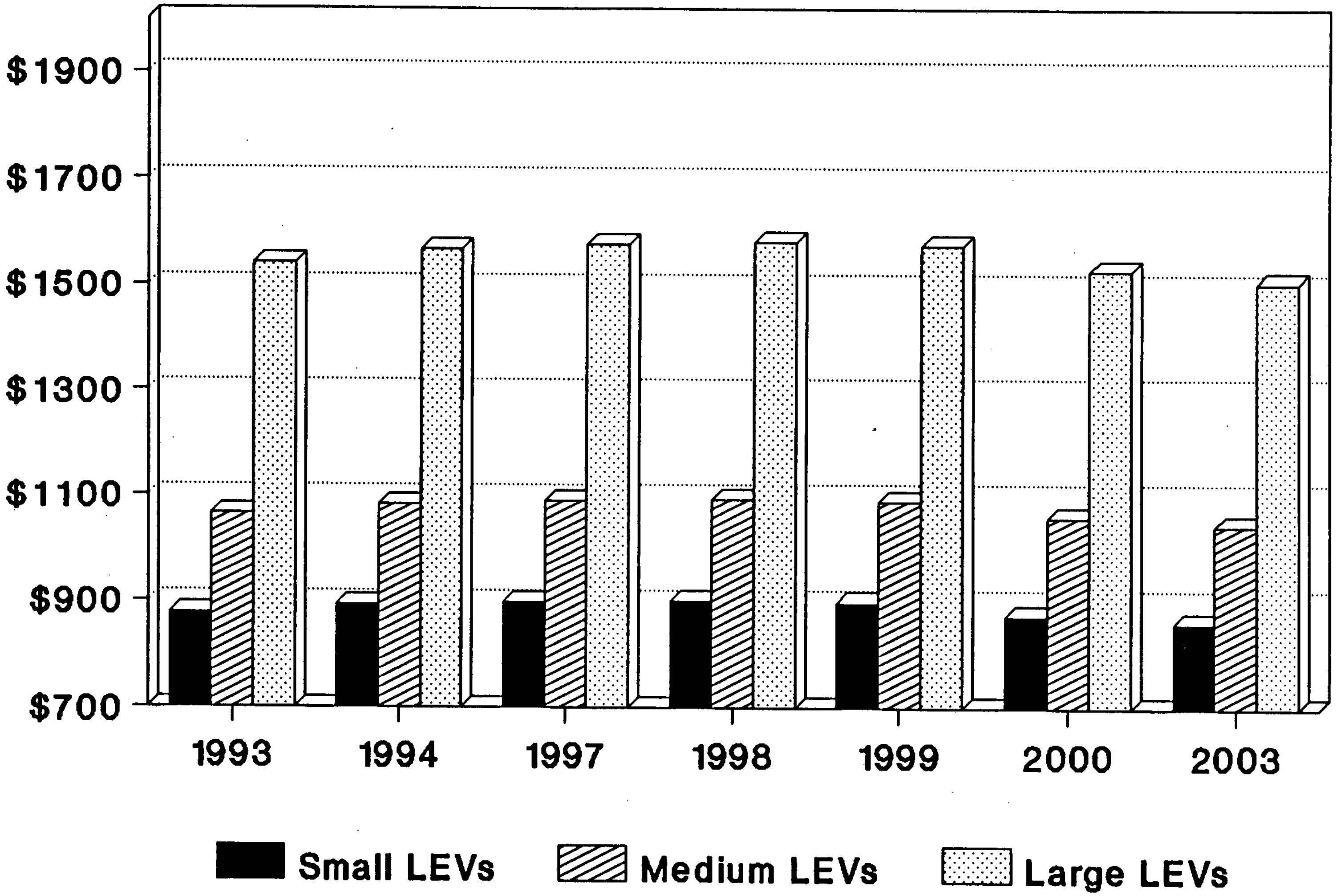


Diagram 4: Estimated Values of TLEVs

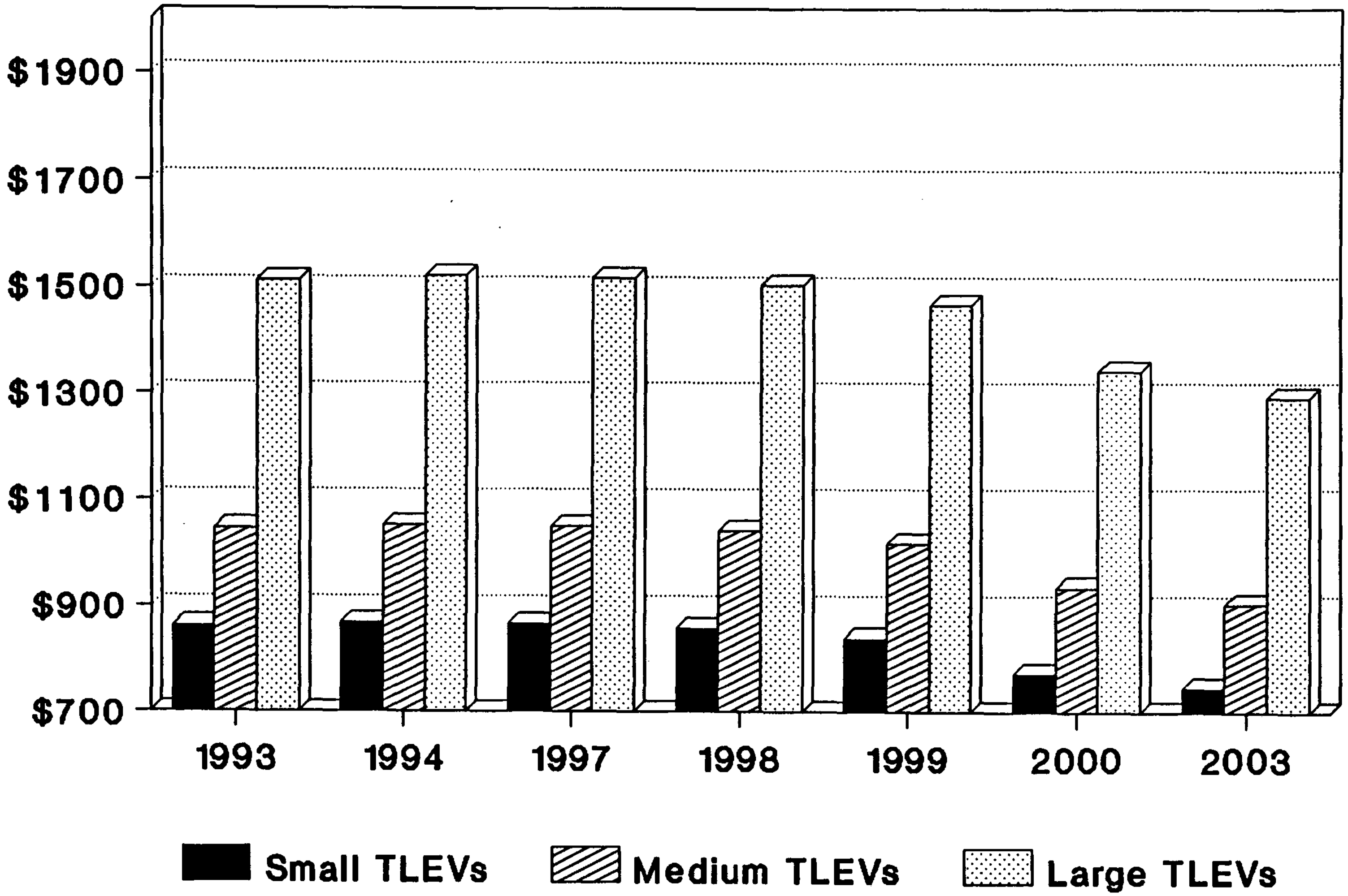
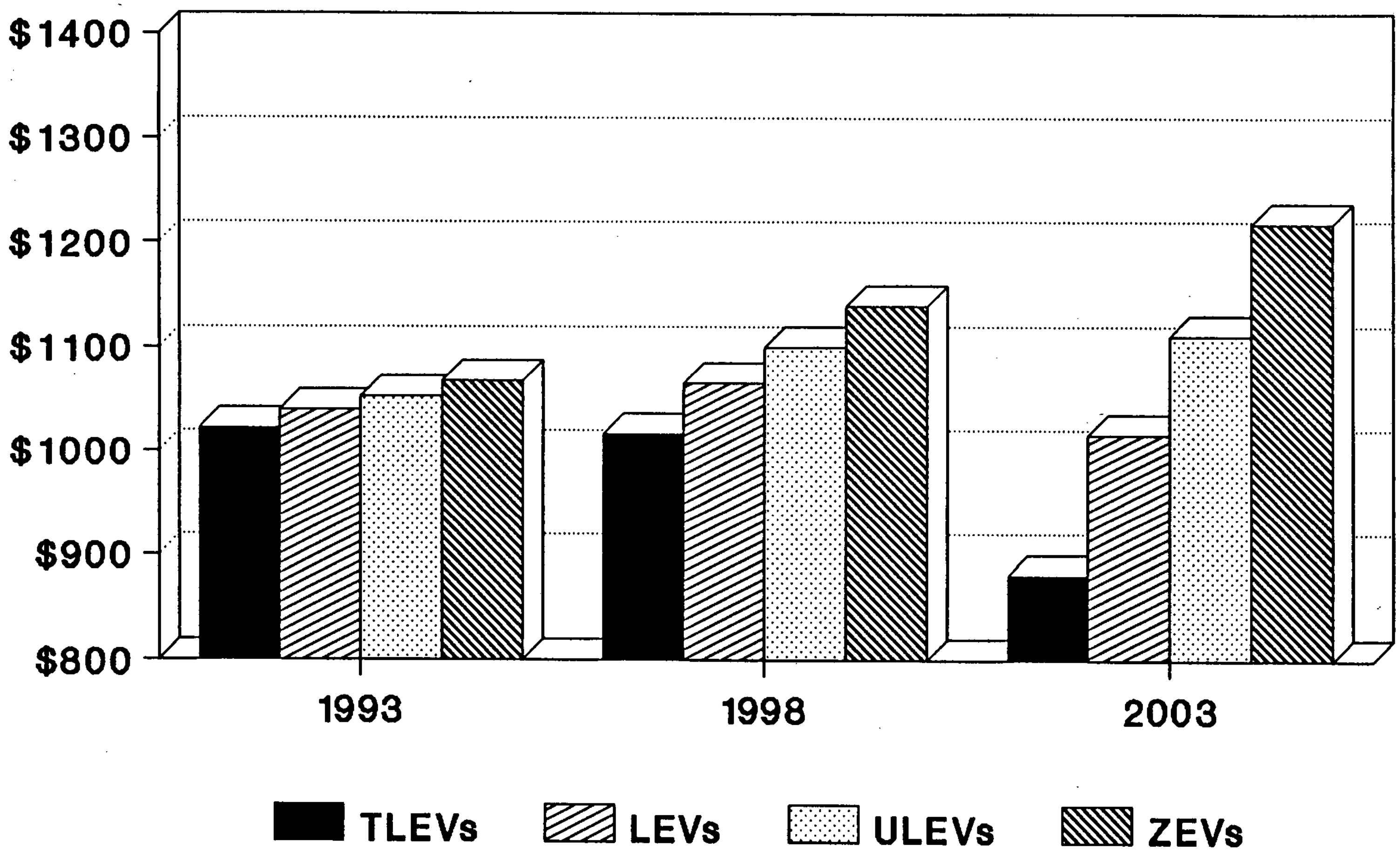


Diagram 5: Estimated Values of TLEVs, LEVs, ULEVs, and ZEVs



Chapter VIII. Marketable Permit Systems for Fuels Supplies

This chapter discusses issues and research objectives in the design of a MPS to integrate alternative fuels into future fuel supplies. Alternative fuel use could be mandated through CAC regulations. As discussed in Chapters II and III, however, a MPS is a potentially important cost saving tool to acheive emission reductions.

A. Objectives

Specifically, the objectives of this research are to: 1) Construct theoretical models of incentives for fuel producers and distributors based upon the technology and market structure of fuel production and distribution, and upon the generation and transmission of pollution; 2) Construct an empirical model of fuel producers' and distributors' behavior and use this model to simulate responses to the regulations and to alternative marketable credit systems; 3) Critique federal and California State regulatory regimes in light of these theoretical models; 4) Produce formulas for the temporal and spatial value of the marketable permits (credits) for use by regional policy makers for region-specific plans for improving air quality; and 5) Use the models to estimate the cost savings of an incentive based approach (marketable credits) over an inflexible standard.

B. Theoretical Model - Designing an Emission Trading System for Vehicular Fuels

There is widespread agreement that both vehicle emission control systems and fuel type simultaneously effect mobile (vehicle) emissions and the reactivity of those emissions. The total cost for attainment of any pollution or emission standard thus includes both the additional cost to produce new fuels and the cost of improved vehicle emission controls. Vehicle and fuel manufacturers do cooperate in joint research efforts to study vehicle pollution (e.g. Auto/Oil Air Quality Improvement Research Program), and do take account of one another's product characteristics, but they face independent regulatory constraints and make independent business decisions. One would ideally like to set up a permit system that allowed the trading of emission permits between vehicle and fuel manufacturers. There are no current federal or state regulatory programs that allow this type of trading, and there appear to be no such proposals.

Given that trading between vehicle manufacturers and fuel suppliers does not exist and is not likely to exist in the near future, how should mobile source air pollution abatement be structured? Let us assume for the sake of argument that all conventional and alternative fuel vehicles have identical performance, ease of use, expected lifetimes and so forth. The only differences between vehicles, then, are their lifecycle costs, costs of fuels, and costs of achieving pollution abatement. When vehicle manufacturers face the burden of meeting new, stricter emission standards, they can either use advanced technology for conventional vehicles (such as electrically heated catalysts) or produce AFVs. If a vehicle manufacturer decides to produce an AFV whose fuel cost is greater than gasoline, such as M85, then the vehicle manufacturer (in order to sell the vehicle) must lower the vehicle price by an amount equal to the discounted lifetime cost differential between the alternative fuel and gasoline. The price discount will be compared to the cost of emission control equipment for conventional vehicles. Conversely, if the price of the alternative fuel is cheaper than gasoline, such as CNG, then the vehicle price can be raised by the appropriate amount.

Let us reverse this scenario for a moment. Suppose fuel suppliers are required to meet the burden of new stricter emission standards by producing and selling fuels that generate less pollution. One way to do this is to produce reformulated gasoline; another way is to produce alternative fuels to use in vehicles that may cost more or less than conventional vehicles. Thus, fuel suppliers may have to subsidize the price of alternative fuels to encourage their use. In no case can reformulated gasoline or any fuel used in a dual-fueled vehicle sell for more than gasoline.

What is occurring in both scenarios are efforts by fuel and vehicle manufacturers to define the demand curve for vehicles and fuels. If vehicle manufacturers must produce the emissions benefits, they will price their vehicles such that one particular demand for vehicles, fuels, and emissions is generated. If fuel suppliers are required to attain the emission reductions, then a different demand for fuels will be generated. When the incidence is on the vehicle side, consumers face fuel prices equal to their private costs of production; when the incidence falls on fuel suppliers, fuel prices reflect private and social costs. Historically, regulations have been applied mainly to vehicles. As discussed above, fuels are now beginning to get more attention, and as just argued, this attention appears warranted because it forces consumers to more directly face the externalities of their driving decisions.

This study takes vehicle design characteristics and costs as given; it thereby concentrates on fuel manufacturers' choices and costs to meet expected future standards. Following federal and California approaches to the regulation of the composition and performance of gasoline (CAAA; Title II, CARB 1990d, 1990e), this study will place the burden of meeting fuel compositional and performance standards on gasoline refiners, importers and suppliers.[10]

The scope of analysis will be restricted to the State of California and various air management districts within the State. This restriction is warranted both for institutional and geographic reasons. Institutionally, California already has stricter automobile emission standards than other states. Moreover, California is the only state currently implementing regulations to encourage alternative fuels. Geographically, the California fuel market can be sensibly separated out from the other states. Though restricted to California, this fuel-emissions trading program will have meaningful implications for the rest of the country. This is because the permit systems, if not the actual data, should be generally applicable. Finally, it is worth stressing that this study takes a "fuel neutral" approach. That is, performance goals are set, but no particular fuel is

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[10] Except where noted explicitly or by context, the words "gasoline supplier" will mean any agent who refines, imports, distributes, or sells gasoline for public consumption.

favored in advance.

Lastly, before discussing trading schemes, there needs to be a cost and allocation benchmark to judge the alternatives. The primary benchmark to which the various trading schemes will be compared is a regulated command-and-control (CAC) allocation in which gasoline suppliers are given a slate of fuels to distribute and sell. There will be some calculable cost to this allotment; the amount will depend on, among other things, whether gasoline suppliers are all allowed to purchase fuel from third parties who are able to use the aggregate quantity of fuel demanded to capture economies of scale. A second benchmark is a set of taxes on fuels which will generate the same slate of fuels as under the CAC allotments.

C. Four Permit Systems

Discussed below are incentive systems that use marketable credits defined in four different ways. What differentiates one system from another is what is being traded: fuels, emissions, or fuel components. The first system considers trades of actual volumes of different fuels; system two trades amounts of each criterion pollutant emitted from vehicles; system three bundles fuel emissions into a single index number; finally, system four discusses permits based upon fuel components. Some aspects of systems one, two, and four are currently being discussed and implemented by California or federal regulators.

1. Fuel Volumes

System one follows an approach similar to CARB's original proposed regulations for clean fuels. This proposal gave vehicle manufacturers the right to choose the type of fuel on which to certify low-emission vehicles; gasoline suppliers would then be required to distribute minimum assigned volumes of each clean fuel (CARB, 1990d, 1990e). Assignments would be based upon the expected demand for the fuel and the market share of gasoline sales of each supplier.

The original version of the CARB regulations required the actual sale of clean fuels, and included market mechanisms to allow the trading of clean fuel credits between different gasoline manufacturers and markets. In the near term, before fuel distribution systems are established for alternative fuels, dual-fueled vehicles will potentially make up a large percentage of the clean-fuel vehicle market. If there is no practical way to force owners of dual-fueled vehicles to purchase clean fuels if gasoline is also available, consumers are unlikely to purchase alternative fuels at a price that reflected the full costs of production and distribution. Instead, it was felt that consumers would most likely buy gasoline to use in their dual-fueled vehicles. The petroleum industry perceived that the distribution requirement, even with its trading provisions, might well require the subsidization of alternative fuels, and argued that the regulations put an undue burden on them. These subsidies would be paid for by an increase in the price of gasoline, a decrease in profits from gasoline sales, or from imposing costs on other ventures, and would probably vary by company. With the cross-subsidy scheme, the relative prices of gasoline to clean fuels would better reflect the private and social costs of the fuels.[11]

The petroleum industry's argument rests on two premises: that the clean fuel will be more expensive than gasoline on a per mile basis, and that the fuel need not be used by the vehicle owner. This is likely to be the case for methanol, LPG, and reformulated gasoline. On the other hand, CNG and electricity are likely to be cheaper than gasoline on a per mile basis.

2. Separate Criterion Pollutants

A second permit system approach is to require that gasoline suppliers meet separate fuel-sales-weighted standards for NMOG (reactivity adjusted), CO, NO_x, toxics, greenhouse potential, and energy security. Gasoline

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[11] The recently adopted regulations do not require the actual production, distribution and sale of clean fuels, but rather a capacity to do so (CARB, 1990f). If all alternative vehicles were dedicated to a particular fuel, then this capacity requirements could be sensibly incorporated into a fuel-neutral emission program. Since dual-fueled vehicles are likely, and since the price of one heavily promoted fuel, M85, is likely to be greater than gasoline, vehicle owners are likely to purchase gasoline rather than M85. Hence, CARB's adopted regulations are not likely to achieve the emission reduction expected from this program.

suppliers could meet the standards through any combination of fuel production and distribution, or by any purchase of attribute credits from producers or refiners who have generated excess attribute reductions. This model would allow emission attributes to be "unbundled" from their fuel source. These standards would be defined in terms of vehicle emissions and could be made greater, equal to, or less than those faced by vehicle manufacturers. There are, however, several practical and conceptual complications to this type of permit system.

One issue concerns how to calculate the emission characteristics of each fuel, since those characteristics depend heavily on specific vehicle technology. This is especially relevant because different vehicle-fuel combinations represent technologies at different stages of maturation. For example, if a methanol vehicle manufacturer develops technology that substantially lowers formaldehyde emissions (and, hence, reactivity adjusted NMOG), should all fuel manufacturers who sell methanol get increased credit for all VMT of vehicles using this new technology? Is it practical to keep track of all the potential technology-vehicle-fuel combinations that are possible and to estimate sales data or VMT for them? Given that the prices of alternative fuels will differ and, therefore, the marginal cost of an additional mile travelled, alternative-fuel and gasoline vehicles can be expected to be driven different amounts, ceteris paribus. Hence, are sales-volume-weights adequate, or are or VMT-weighted emissions credits necessary? Is the correct weight the VMT of the new vehicle, or the VMT of the vehicle replaced?

A practical compromise is to put vehicles into certification classes and require that fuel volume-sales-weighted emissions from these vehicle classes equal the vehicle fleet average emission standard. CARB's rules (CARB, 1990d, p. 23) allow vehicle manufacturers to meet the fleet average standard by certifying vehicles to any combination of transitional low-emission vehicles (TLEVs), low-emission vehicles (LEVs), ultra-low-emission vehicles (ULEVs), zero-emission vehicles (ZEVs) or conventional vehicles so as long as their sales-weighted emissions do not exceed the fleet average NMOG emissions standard.[12] This standard is shown below in the last column of Table 8.1 (CCR 1960.1.5(g)(2)).[13] CARB does not have any standards for greenhouse gas emissions or relative energy security. Under CARB's plan, only NMOG standards are averaged; all vehicles must meet the standards for other pollutants applicable to the emissions category to which they certify.[14] Although any combination of sales-weighted NMOG emissions that meet the fleet standard is acceptable, CARB believes the following implementation schedule is "sensible" (CARB, 1990d; Table 3, p. 24).

Table 8.1 NMOG Standards

Model Ave. Year	0.39	0.25	TLEV 0.125	LEV 0.075	ULEV 0.040	ZEV[15] 0.0	Fleet Standard
1994	10%	80%	10%				0.250
1995		85	15				0.231
1996		80	20				0.225
1997		73		25%	2%		0.202
1998		48		48	2	2%	0.157
1999		23		73	2	2	0.113
2000				96	2	2	0.073
2001				90	5	5	0.070
2002				85	10	5	0.068
2003				75	15	10	0.062

This fleet average NMOG standard can be achieved by various vehicle-fuel combinations. A fuel emission trading program could be established by requiring each gasoline supplier to meet the NMOG emission standard by selling

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[12] ZEVs are expected to be electric vehicles.

[13] Fleet average NMOG exhaust standard requirements for light-duty vehicle weight classes in grams per mile. In addition to the emission categories shown, there are additional emission standards that apply to hybrid electric vehicles (CCR 1960.1.5(g)(2), note 3).

[14] For dual-fueled vehicles CARB is allowing two different NMOG standards, one for certification with a clean fuel and one for gasoline.

[15] These ZEV percentage requirements are mandatory. Vehicle manufactures may satisfy this requirement by selling the listed percentage of vehicles, or by purchasing ZEV credits. Manufacturers may make up a one model-year deficit by selling the appropriate number of vehicles in the following year. There are also some additional rules.

a combination of fuels such that the seller's sales-volume-weighted emissions equal the standard in each year. This requirement could also be met by the purchasing of credits or by using previously banked excess emission reductions. The unit of credits and banked emissions will be in grams. As discussed above this type of system ties fuel attributes to vehicles emissions without accounting for any "inherent" fuel properties. Modelling this type of system, however, requires the ability to forecast which vehicles are going to certify on which fuels. An example of this type of system is shown in Table 8.2 below.

Table 8.2 Tailpipe NMOG Emissions Credits and Debits

Fuel type	(A) Reactivity adjusted[16] NMOG fleet standard (g/m) (1994)	(B) Reactivity adjusted[17] observed emissions by category (g/m)	(B-A) Difference (g/m)	(C) Volume[18] gasoline equivalent gallons (1000)	(C)*(B-A) Credit(deficit) kg
Phase 1 gas	0.25	0.39	0.14	1000	14
Reformulated gas	0.29	0.39	0.10	0	
M85	0.35	0.39	0.10	0	
Electric	0.25	0.0	0.25	0	
Total					(14 kg/m)

This table shows that in 1994 one particular gasoline supplier has a 14 kg deficit of NMOG. In the scenario envisioned here, each gasoline supplier could meet the sales-volume weighted standard in any of the following ways: directly produce (or import) and distribute the slate of fuels; purchase the fuels from a third party and then distribute them; contract with a third party

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[16] The numbers in this column are purely illustrative; they are intended to represent the reactivity adjusted fleet average NMOG certification standard for vehicles certifying on the listed fuels.

[17] This number represent the observed reactivity adjusted NMOG emitted by each vehicle certifying on various fuels.

[18] For all fuels which can be used in more than one vehicle emission certification class, such as reformulated gasoline which can be used as a certification fuel for TLEVs and as an optional fuel for conventional vehicles, the volume sold must be allocated to each category based on vehicle sales or VMT.

to produce and distribute fuels on their behalf; purchase credits from another gasoline supplier; or any combination of the above.

3. Fuel Pool Emission Standard

The third permit system approach is to establish a numerical "index" value for the fuel pool that all gasoline suppliers would have to meet. In such a system, each fuel would be assigned a rating representing the relative potential to meet emission or other goals for that fuel with respect to a baseline, such as gasoline. The establishment of each fuel's rating would require the aggregation of the different emissions attributes of each fuel into one number. The emissions value for each fuel would depend upon the number, VMT and type of vehicles (e.g. conventional, TLEV, LEV, ULEV, ZEV) which use it for certification. To meet the required pool rating, sales of fuels with high emissions would have to be offset by sales of fuels with low emissions. For theoretical purposes, these trades could be unrestricted. The permit system's results and sensitivity, though, could be tested by restricting trades to minimum and maximum volume requirements. These requirements could be set equal to the actual or projected demand for fuels based upon the number of vehicles using or projected to use each fuel.

4. System Four - Fuel Components

The fourth permit system for emission trading is one based upon the trading of fuel components. Probably the best known example of this type of system was EPA's lead trading program as part of its phaseout of lead from gasoline. Currently, in a very limited way, component trading is authorized for CO nonattainment areas under the CAAA (Title II, Sec. 219 (m)) which establishes a credit system under which gasoline suppliers can supply gasoline with an oxygen content of less than 2.7% (by weight) if they purchase credits from other gasoline suppliers selling gasoline with an oxygen content greater than required. In California, draft regulations for Phase 2 reformulated gasoline (to be sold starting January 1, 1996) allow component banking of benzene credits for use by the same refinery at a later time (CCR, Title 13, Chapter 5, Article 1, Subarticle 2 - draft). Similar banking provisions are being proposed for oxygenates and possibly other gasoline components (see Appendix A for the Phase 2 specifications).

One characterisitcs all of these component systems share is a presumption that fuel components affect fuel emissions for their designated vehicle types and classes in a systematic way. If this is true, then a permit system can be established by setting a component standard and allowing trading by various gasoline suppliers. If such a system encompasses alternative fuels, regular and reformulated gasolines, then sensible emission reductions require knowing the inherent or potential cleanliness of fuels. The main drawback of this system is that these relationships are not well established.

D. Additional Issues in Fuel Permits

1. Spatial and Enforcement Considerations

The choice of permit system for fuels should also take into account spatial and enforcement considerations. For air pollution from motor vehicles, gasoline or alternative fuels can best be modelled as an area source, with regional (NO_x, NMOG, CO, toxics) and global (CO_2) impacts. As discussed above in Chapter II, when emissions from a source have differing effects on spatially separated receptors it is, in theory, important to take these differences into account. In practice, it is argued that the gains in efficiency may be outweighed by considerations of administrative burden and technical complexity. An important condition for a spatially differentiated permit system is that the gains in efficiency (or equity) must outweigh the added cost and complexity of designing, implementing, and enforcing location specific regulations.

Under current regulatory regimes, NMOG and CO do face region specific regulation. To control NMOG, California will tighten the Reid vapor pressure (RVP) of gasoline sold after January 1, 1992 and before January 1, 1996 during summertime months to a maximum of 7.8 pounds per square inch (CCR, Title 13, Sec. 2251.5); the months of control vary by basin.[19] For example, in the

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[19] Similar restriction apply after 1996 under Phase 2 gasoline regulations, but the RVP is restricted to 7.00 PSI.

South Coast, San Diego and Southeast Desert Air Basins face restrictions from April 1 through October 31, while in the North Coast, Lake County and Northeast Plateau Air Basins are only restricted from June 1 through September 30. In terms of CO pollution, the CAAA (Title II, Sec. 219(m)(2)(B)) requires, beginning November 1, 1992, that gasoline be sold in CO nonattainment areas be blended to contain a minimum oxygen content of 2.7% (by weight) be sold during the winter months. The administrative and technical requirements to administer CAC and permit systems are not the same; nonetheless, since region and time specific regulations are felt justified to calculate two criteria pollutants (ozone and CO) under CAC regulations, then the same ought to be true for permit systems.

It is worth emphasizing that the incidence of these regulations falls upon the composition of fuels, not tailpipe emissions. This is because it is felt that there is a strong enough link between fuel composition and tailpipe emissions, across differing vehicle technologies, to cost-effectively regulate fuel composition.[20] When technologically feasible, a fuel composition change may be easier and cheaper than hardware changes for existing and, perhaps, new vehicles. Also worth noting is the seasonal nature of both regulations. In this way, stricter and more costly regulations are only applied when most warranted.

Beyond these considerations is the issue of enforcement. Fuels by their nature are consumed within a one-half tank radius of their purchase point. Fuels are, therefore, area specific, and compliance can be checked at centralized locations (e.g. service stations or refineries). Vehicles are mobile, and it would seem very difficult to ensure that the fleet of vehicles passing through or residing within a given area actually meets area specific hardware standards. Regulations of fuel composition may, therefore, have real advantages over vehicle emission systems when implementing area or season specific pollution regulations whether through a CAC or zonal permit system.

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[20] It should be pointed out, though, that these regulations apply to regular unleaded gasoline, reformulated gasoline, and sometimes, gasoline blends containing ethanol, not other alternative fuels.

2. Reformulated Gasolines

The above discussions of fuel emission trading programs were framed in terms of new vehicle-fuel systems. Reformulated gasolines, however, can affect the emissions of the existing fleet stock as well as be used as a new fuel for vehicles certifying under the various emission categories. This suggests that the fleet average emission standards that must be met by fuel suppliers should be based upon the entire fleet stock, not just the fleet of new model year vehicles. This requires keeping track of each model year's stock of cars, VMT and emissions standards. If fleet standard emission requirements are based upon all model years then it is quite likely that fuel suppliers could meet fuel emission standards for the next several years through exclusive use of reformulated gasoline.[21]

3. Supply Side Considerations and Permit Trading

Marketable emission permits derive their optimality properties by allocating abatement activities such that the marginal cost of abatement is equated across all agents. Savings are generated because of differences in the marginal costs of abatement between different suppliers. In the scenarios described above, savings are generated when gasoline producers have different marginal production and distribution costs for the various fuels.

Fuels such as reformulated gasoline are now being widely produced and distributed (See Appendix B for a list of reformulated gasolines). Electricity and natural gas are generally supplied by regulated public utilities. Other fuels such as E85, M85 and CNG are currently produced, but not in a way that most observers believe they would be if they were used on a wider scale. Hence, actual data do not exist on the marginal costs of production of these fuels by different producers. What exist are various

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[21] Both federal and California laws allow fuel suppliers not to produce reformulated gasolines with the specifications described above, and shown fully in Appendix A, if they produce fuels that are certified equivalent to the specified formulas. Both sets of regulations allow for certification of equivalency to be based on either direct testing using a specified vehicle fleet, or via a predictive model (Federal Register, v. 56, no. 131, p. 31202; CCR, Title 13, Chapter 5, Secs. 2265-2266). EPA and CARB are currently working to develop their respective predictive models, though neither one is yet complete.

estimates by government agencies and consulting firms of the likely costs of these fuels under different scenarios. Moreover, it is uncertain if the various gasoline suppliers would produce non-petroleum based alternative fuels themselves, or contract out to third parties. Some small suppliers, though, will not be able to do so.

The foregoing implies that except for reformulated gasoline, alternative fuels are either only produced by one supplier or are not currently produced in a way that is representative of widescale use. Cost savings from emissions trading, then, are estimatable in two ways. One is to not attempt to capture trading between different producers of the same fuel, but instead concentrate on capturing savings by using different slates of fuels. Assuming only one supplier for each non-petroleum based fuel, mandated production volumes based on demand side considerations will lead to a no trading solution. The cost minimizing model degenerates into a simple calculation of the cost of producing the given slate of fuels. A second way to capture cost savings from trading is by assuming different cost structures for different manufacturers and levels of fuel demand. This exercise would only be interesting if realistic differences in production costs could be estimated.

If instead of mandating a given slate of fuels, gasoline suppliers are allowed to produce any combination they desire, the relationship between vehicles and fuels will be ignored and a degenerate solution is likely. For example, one likely solution is that gasoline suppliers will sell only gasoline and buy credits from electric utilities. Suppose that a restriction is placed on the model that, say, no more than 10% of the credits can be generated from electricity. The model now might return an answer that says that the fuel mixture includes only M85 and the 10% electricity credits. Further restrictions could then be placed upon the model and a new solution calculated. In effect, one would generate out a series of solutions predicated on assumed demand. These vehicle-fuels combinations would give us an m-dimensional isoquant[22], where m is the number of fuels. This isoquant would represent the various ways of using alternative fuels and vehicles to reach a given level of pollution abatement. There would be a calculable cost associated with each slate of fuels.

4. Demand-Side Considerations

The isoquant approach maps out all combinations of (emissions-acceptable) technology-vehicle-fuel combinations. Consumer's actual choice, though, is a derived demand based on the type of vehicle owned, price of fuel, and other demand-side considerations.[23] What the isoquant approach is missing are consumer demands for each of the fuels. By making the quantity of each fuel demanded a function of the number of each type of vehicle and of the price of each fuel, the fuel distributor's supply problem is transformed from being a degenerate solution to one of real significance. This is because unrealistic fuel combinations are eliminated at the same time that flexibility is provided to gasoline suppliers to adjust the relative price of fuels and thereby change the quantity of each fuel sold and the average cleanliness of the fuel slate. This solution is still without inter-firm trading of the same fuel. This approach requires the derivation of a demand curve for each fuel. A study is currently underway by Kitamura et al. (1991) to develop demand curves for alternative fuel vehicles.

5. A Dynamic Permit System

A dynamic model is appropriate if the relative costs and benefits per ton of criteria pollutant abated are likely to depend on the *level* and *rate of change* in the level of each criteria pollutant or the *level* and *rate of change* of each fuel used or both. Banking of emission credits allows firms to alter the rate of emissions through time. With this approach firms are able to

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[22] An isoquant is a series of points that produce the same quantity. In this case, it is combinations of fuels and vehicles to produce the same pollution.

[23] Although consumers could have preferences over a particular type of vehicle or fuel, one usually postulates that consumers have preferences over "transportation." Transportation is a bundle of attributes such as comfort, privacy, contribution to the emissions burden, and so forth.

reduce the rate of emissions for some initial period, and then release them at a later point in time. Banking, then, potentially gives legal authority for the future violation of standards.

The benefits of banking are the near-term reductions of emissions beyond given standards and potential cost savings to firms (and ultimately consumers) from being able to smooth out emission rates. This tradeoff may be desirable if there are not really thresholds at which environmental or human harm occurs, but rather less pollution is less harmful and more pollution produces greater harm. Firms would like the option of banking if their allowed pollution rate will fall over time or if the price of permits will rise. Given that emission standards are increasing in severity through time, it is likely that firms would desire the ability to bank emission credits.

Important theoretical and public policy questions are: the degree to which firms would actually make use of banking provisions; the effect of banking provisions on human health and the environment; and the cost savings to firms and consumers. These question can be addressed by respecifying the above static models in terms of dynamic ones where banking is allowed.

E. Conclusions

The above discussions make it clear that emission trading systems could be based on fuels, fuel components, vehicle emissions, or some combination of them all. A difficult issue to resolve is the relationship between alternative fuels, gasoline reformulations, vehicle technology, emissions, reactivity and, what we care about, pollution. If permits are measured in terms of emissions, then it becomes necessary to make assumptions about how many vehicles will certify under each category and what fuels they will use. If permits are measured in terms of components or fuels, then demand and supply equations for those fuels will tell us how much trading will occur and what the costs will be. Emissions and pollution reductions must then be estimated, which requires knowing the links between fuels, vehicles and emissions. We can either use these links to assign vehicles to emission categories and then allow trading, or we can allow the trading of components and figure out the emission reductions ex post. A final choice on permit system requires further research into the areas of uncertainty discussed above.

Chapter VIII. Appendix I: Fuel Specifications

A. Certification specification: "All vehicles designed to use a given type of fuel must certify on the fuel meeting the adopted certification specifications for that fuel." (CARB; 1991a)

B. Commercial Specification: "A fuel of a given type sold for vehicular use in California must meet the adopted commercial specification for the fuel." (CARB; 1991a)

1. Industry Average Gasoline[24]

API gravity	57.4
Sulfur, ppm	339
Color	Purple
Benzene, vol. %	1.35
RVP	8.72
Driveability	1195
Antiknock	87.3
Distillation Range, °F	
IBP	91
T10	114
T50	218
T90	330
EP	415
Hydrocarbon Type, vol. %	
Aromatics	32.0
Olefins	912
Saturates	58.8

2. Summertime baseline (CAAA; Sec. 219(k)(9)(B)(i))

API Gravity	57.4
Sulfur, ppm	339
Benzene, %	1.53
RVP, psi	8.7
Octane	87.3
Distillation Range, °F	
IBP	91
T10	128
T50	218
T90	330
EP	415
Hydrocarbon type, vol. %	
Aromatics	32.0
Olefins	9.2
saturates	58.8
Lead	0.0
Detergents	yes
Oxygen	0.0

3. Winter baseline (Fed. Reg. vol 56, No. 131 p. 31160)

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[24] This is the industry average gasoline blend used in the Auto/Oil Air Quality Improvement Research Project.

Benzene, % vol.	1.64
Aromatics, % vol.	26.3
Olefins, % vol	11.9
T90, °F	332
T50, °F	199
Sulfur, ppm	340
RVP	12.3
Oxygen	0.0

4. Phase I gasoline (January 1, 1992)

RVP, psi (high O_3 season)	7.8
Detergents	yes
Lead	0.05

5. Phase II gasoline (CCR, Title 13, Chapter 5, Subarticle 2 - Standards for Gasoline sold Beginning January 1, 1996)

RVP (PSI)	7.00[25],[26]
Sulfur, ppm (weight)	30
Benzene, vol. %	1.0[27]
Olefin, vol. %	5.0
Oxygen, weight %	
min	2.0
max	2.1[28]
Distillation Range, °F	
T90, max	300
T50, max	200
DI[29], max	1100
Aromatics, vol. %, max	25

6. Federal reformulated gasoline, the more stringent (toxics - all year; VOC - high ozone season) of:[30]

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[25] This RVP restriction applies during the high ozone season defined in the regulations. Because of reproducibility, the average RVP is expected to be 6.7 psi.

[26] There is a special provision for blends of gasoline that contain ethanol. Any blend of gasoline that contains at least 10% ethanol (by volume) will not result in a violation of the RVP standard as long as the gasoline used in the blend exceeds the RVP standard.

[27] Gasoline suppliers have the option of banking excess benzene reductions for later use (up to a maximum of 1.2 % of one-half of the yearly volume average of gasoline) if they meet a 0.80% standard.

[28] If the oxygenate used is MTBE, the maximum oxygen content shall not exceed 2.7% by weight.

[29] The driveability index = (1.5)*(T10) + (3.0)*(T50) + (T90)
Where: T10 = the temperature, in degrees Fahrenheit, at which 10 percent of the gasoline evaporates; T50 = the temperature, in degrees Fahrenheit, at which 50 percent of the gasoline evaporates; and, T90 = the temperature, in degrees Fahrenheit, at which 90 percent of the gasoline evaporates.

[30] It is probable that the more stringent standard, formula or performance, will be different for VOCs and toxics. This is because EPA estimates show that the formula is expected to reduce VOCs from between 2-11% (Federal

a. Formula[31]

Benzene, % vol (max)	1.0
Aromatics, % vol (max)	25
Lead,	0.0
Detergents	yes
Oxygen, % weight (min)	2.0[32]

b. Performance

VOC emissions reduction, % mass	
(1995-2000)	15
(2000 +)	20-25
Toxic emissions reduction, % mass	
(1995-2000)	15
(2000 +)	20-25

The emissions of both VOC and toxic emissions shall be assessed on a mass basis, rather than an ozone-formation or reactivity basis for VOCs, or a cancer-causing basis for toxic air pollutants.

7. Methanol

    a. M85

    b. M100

8. Compressed natural gas (CNG)

9. Liquified natural gas (LNG)

10. Ethanol

11. Electricity

For electricity, associated powerplant-based attributes will be assigned to electricity used for motor vehicles based upon models developed by Sperling and his graduate students (Wang, et al., 1990; Wang and Deluchi, 1991).

Register, Vol. 56, No. 131, p. 31187) and toxics by greater than 15% (Federal Register, Vol. 56, No. 131, P. 31189).

[31] Parameters not listed are consistent with baseline fuel.

[32] In carbon monoxide nonattainment areas the required oxygen content is 2.7 % by weight.

Chapter VIII. Appendix II: Reformulated Gasolines

The fuels listed below represent various voluntary "reformulations" of gasoline. Some are currently produced and distributed, while other are still prototypes.

ARCO EC-1 regular for pre-1975 cars and pre-1980 trucks without catalytic converters, introduced in September 1989.

Vapor pressure	7.6	
Benzene, vol %	1.0	
Aromatics, vol %	19.0	
Olefin, vol %		10.0
Oxygen, wt %	1.0	
T50, °f		209
T90, °f		351
Sulfur, ppm	41	

EC-P, a premium blend with an octane rating of 92, introduced in September, 1990.

Vapor pressure	8.1	
Benzene, vol %	1.0	
Aromatics, vol %	23.6	
Olefin, vol %		12.5
Oxygen, wt %	2.3	
T50, °f		202
T90, °f		320
Sulfur, ppm	113	

EC-X, prototype

Vapor pressure	6.7	
Benzene, vol %	0.8	
Aromatics, vol %	21.6	
Olefin, vol %		5.5
Oxygen, wt %	2.7	
T50, °f		201
T90, °f		293
Sulfur, ppm	41	

Chevron Supreme

Conoco RXL

Diamond Shamrock RG-87

Exxon Supreme-Plus

Exxon Supreme-Extra

Marathon Amaraclean

Phillip Superclean Unleaded Plus

Shell SU-2000E

IX. Summary, Conclusions, and Directions for Future Work

This report documents the research plan, economic modelling completed to date, and preliminary results from a study on cost savings from marketable permit systems for automobile emissions in California. These results are not final and should be viewed as work in progress.

This research project addresses the form of government intervention for introducing electric and natural gas vehicles. Marketable permit systems for the control of mobile source emissions are modelled. Two forms for a MPS are examined empirically: averaging and trading by vehicle categories (analagous to CARB's low-emissions vehicle program) and averaging and trading by engine family or vehicle class. The primary focus of this research is the cost savings from employing a marketable permit system relative to traditional regulatory approaches for meeting current and future emission control standards.

To estimate the costs of emissions control with an MPS, data on emission control costs for conventional gasoline vehicles were collected. A survey of car dealers for twelve vehicle manufacturers in the Sacramento area was performed from January 1991 through July 1991. Dealers were asked to provide cost information on emission control parts for a variety of engine families. These data were combined with information on manufacturers' and dealers' markup and assembly costs to estimate the total costs of emission control per vehicle. These data suggest that, on average, vehicle manufacturers spend about $840 per vehicle for emission control purposes. There is substantial variation among manufacturers, with American producers reporting the lowest emission control costs and European reporting the highest. Total emission control costs for cars sold in California are estimated to be about $1.3 billion. Data on the emission characteristics of conventional vehicles were obtained from CARB's certification data. These data provide an important baseline for establishing the economic competitiveness of EVs and CNGVs.

Cost functions relating the total cost per vehicle to emissions from that vehicle were estimated using the data collected for conventional vehicles. Significant differences were found in the cost functions by manufacturer and vehicle class. A simulation model of manufacturers' behavior was built wherein manufacturers are assumed to minimize the costs of emission control subject to meeting an emission standard. The effects of emission averaging and trading on the costs are estimated in this framework.

In our simulation model, we used the current certification levels rather than the true standards so that emissions are not allowed to increase over current levels. The cost savings estimated by the model can then be attributed to the marketable permit system rather than to a worsening of air quality.

In the first series of simulations using this model, we estimated the cost savings of using a permit system for gasoline vehicles to meet current HC emission levels. In this system, manufacturers were allowed to average emissions by vehicle class (small, medium, and large cylinder) and to trade emissions across manufacturers. Preliminary results indicate cost savings attributable to the permit system to be up to 20%, depending upon assumptions regarding changes in vehicle sales. This translates into savings per vehicle of up to $170.

In the second set of results, a permit system similar to CARB's low-emission vehicle program is simulated and the value of emission reductions from clean fueled vehicles is estimated. These values are found to be largest for the lowest emitting vehicles. The values increase over time as emission standards tighten as long as the vehicle meets the standards in that period.

In the next phase of the research, the preliminary results on an MPS for conventional vehicles will be further refined and the analysis will be extended to include AFVs. Data collection described in Chapter VI will be completed, providing the necessary information to compute costs and emission characteristics of AFVs. This data will be combined with the conventional vehicle cost functions to estimate the cost savings from a MPS that includes both conventional and alternative fuel vehicles. Likewise, a marketable permit system for the regulation of alternative fuels will be examined. Some of the issues associated with developing and analyzing such a system were identified in Chapter VIII.

Although the results presented here are preliminary, they suggest that there may be sizable cost savings associated with a permit system relative to an inflexible standard. Information on the likely cost savings of a marketable permit system can be an important input into public policy debates about the form regulation of mobile source emissions should take. If a permit system can achieve sizable cost savings, industry can more easily adopt emissions reducing technologies such as electric and natural gas vehicles. As a result, a marketable permit system can be beneficial to both industry and the environment.

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