GREENHOUSE GAS CONTROL STRATEGIES: A REVIEW OF "BEFORE-AND-AFTER" STUDIES

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1. INTRODUCTION

The Federal Highway Administration (FHWA) is participating in an OECD research effort to compile and evaluate greenhouse gas (GHG) abatement policies. One aspect of this research requires data on “before and after” studies of GHG reduction strategies implemented in the U.S. This paper summarizes the results of a literature search on such assessments of U.S. efforts to reduce GHG emission from on-highway vehicles and public transit modes.

The actual number of strategies implemented in the U.S. affecting GHG emissions from the on-highway transportation sector are relatively few. The most prominent of these is the Corporate Average Fuel Economy (CAFE) standards program, which required each auto manufacturer selling cars and light trucks in the U.S. to meet or exceed a fuel economy standard on a fleet average basis. A less widely know regulation requires vehicles with very low fuel economy to pay a graduated tax known as the Gas Guzzler Tax that can be as large as $7,000 per vehicle annually.

Regulations that require or encourage the use of alternative fuel vehicles constitute a second set of programs that can reduce GHG emissions, although the intent of such regulations is generally to promote energy security and encourage domestic fuel production. There are several regulations with overlapping requirements that mandate or encourage alternative fuel and vehicle sales. These regulations include the Alternative Motor Fuels Act (AMFA) of 1988, the Energy Policy Act (EPACT) of 1992, and the Clean Fuel Fleet Program (as part of the Clean Air Act Amendments of 1990).

Transportation Control Measures (TCMs) have been widely implemented in an effort to reduce traffic congestion and smooth traffic flow. TCMs related to trip reduction reduce vehicle travel, and the resulting improvement in traffic flow improves fuel economy. Both of these aspects of

TCMs reduce GHG emissions even if the primary implementation goals of TCMs are not directed towards GHG reduction.

Motor vehicle emission controls have been adopted in response to emission regulations designed to reduce ambient criteria pollutant (HC, CO, NO_x, particulate) concentrations as required under the Clean Air Act. While these regulations also do not directly address GHG emissions, they may have indirectly resulted in reductions of methane and nitrous oxide emissions. In addition, they may have forced the adoption of new vehicle technologies that resulted in improved fuel economy, thus reducing GHG emissions.

Studies that have addressed the effects of regulations in each of these areas are available, but the majority of such studies have focused on the CAFE program; especially since the program has been so contentious. "Before and after" studies of other regulations are comparatively limited, and their analysis and conclusions does not necessarily focus on the level of GHG emissions reduced since GHG reduction is not a primary program goal. Nevertheless, a comprehensive literature search was performed to identify available studies in all areas as summarized in the following sections. Section 2 addresses studies on the CAFE standards and the Gas Guzzler Tax. Section 3 examines studies related to alternative fuel programs. Section 4 addresses studies on TCMs, while Section 5 provides an overview of studies related to vehicle and engine emission standards.

2. FUEL ECONOMY REGULATIONS

2.1 REGULATORY REQUIREMENTS

Congress passed the Energy Policy and Conservation Act in 1975, which required auto manufacturers to meet fuel economy standards that started at 18 miles per gallon (mpg) in 1978 and increased to 27.5 mpg in 1985. Congress also required efficiency standards for light trucks that were to be set administratively by the Department of Transportation (DOT). These fuel economy targets were specified as sales weighted harmonic means for all new vehicles sold by each manufacturer. Manufacturers who sold both domestic and imported vehicles (based on domestically manufactured content) had to meet the standards for these fleets separately.

Failure to meet the standards results in a fine that amounted to $50 per car sold for each mpg below the standards. Manufacturers could earn credits by exceeding the standards, and the credits could be used to offset shortfall through a three year carry-forward and carry-back provision. In addition to these provisions, the DOT administratively rolled back the standards for cars during the 1986-1989 period due to a collapse in oil prices that resulted in reduced demand for fuel efficient cars. Standards for light truck have been set at around 20.5 ± 0.5 mpg for the last 15 years.

Since these rules have been implemented, actual fuel economy for the entire new vehicle fleet (i.e., across all manufacturers) have exceeded the standards in all years. The domestic manufacturers (GM, Ford, and Chrysler) have been very close to the standards with shortfalls in some years, but they have yet to pay any fines due to the carry-forward and carry-back provisions. Most import manufacturers have comfortably exceeded standards, but some luxury vehicle manufacturers such as Mercedes and BMW have been well below standards and have paid substantial fines as a result.

The Gas Guzzler Tax was also passed by Congress, applying to vehicles below a particular threshold level of fuel economy, now set at 22.5 mpg. Until recently, the tax was $500 for each mpg below the standard up to a maximum of $3,750 per year, but the tax rate was doubled in 1997. The tax, which does not apply to light trucks, is paid by the purchasers of any passenger car that falls below the applicable threshold. At current fuel economy levels, few vehicles are subject to the tax, with those that are being taxed are mostly large or high-powered luxury imports. Domestic manufacturers have managed to design even their largest and most powerful cars to exceed the taxable mpg threshold, so that the tax has not applied to any domestic cars. To some degree, the tax has forced the least efficient domestic cars to become more efficient (on a percentage basis) than other vehicles.

2.2 SUMMARY OF ISSUES

Several studies are available on the effects of CAFE, and they largely fall into two groups. Studies that have found CAFE has had a significant effect on fuel consumption are largely sponsored by the federal government, and most of these have been performed by Dr. David Greene of Oak Ridge National Laboratory, in conjunction with various co-authors. Studies that suggest CAFE has had little or no effect on fuel consumption are largely sponsored by the auto industry. There are also one or two academic studies that claim CAFE has had an effect on fuel consumption, but that the fuel economy benefits were not very cost effective. Prominent studies that found no benefit to CAFE are by Robert Crandall (also Nivola and Crandall), Leone and Parkinson, and Kleit. Since actual fuel economy values attained in the U.S fleet are a matter of record, the entire debate has focused on the reasons for the observed increase in fuel economy and, to some degree, the cost-benefit of the CAFE approach relative to alternative approaches such as a higher tax on gasoline.

2.3 STUDIES SHOWING SIGNIFICANT BENEFITS

As noted, Dr. David Greene has authored a number of papers (some with co-authors) that address issues related to the CAFE standards. One entitled "CAFE or Price?" published in 1990,[1] provides a careful statistical analysis of the causality behind the observed increases in fleet average fuel economy. A second, more recent paper[2] entitled "Why CAFE Worked," contains a broader discussion of the effects of CAFE and addresses a range of arguments against CAFE raised by Crandall, Kleit, and others.

The "CAFE or Price" analysis recognizes that some auto manufacturers were constrained by CAFE regulations, while others (notably the Japanese manufacturers) were not. The analysis methodology was sophisticated enough to recognize that constrained manufacturers may wish to exceed standards (not just meet them) as insurance against unexpected shifts in consumer taste or to guard against shortfalls in future years. The statistical analysis indicated that CAFE regulations were twice as important as fuel prices in future fuel economy planning for constrained manufacturers. In contrast, unconstrained manufacturers' fuel economy planning was responsive to lagged (due to the three year lead time to affect product designs) fuel prices.

"Why CAFE Worked," enumerates a number of objections to the CAFE standards and provides an analysis of their effects. First, the study addresses the issue of why the market for fuel economy should be inefficient. Dr. Greene shows that there is a significant range of fuel economy values over which the costs of fuel saved roughly balance the increased cost of new technology, so that consumers are largely indifferent to actual mpg over this range. Hence, the case for standards is that they could be set six to eight mpg above current market levels with little loss of customer utility, but significant social benefits. Second, the decreased cost of driving associated with increased fuel economy does cause an increase in travel. However, Dr. Greene argues that the "rebound" effect is small, and causes a loss of 20 percent of the benefits of increased fuel economy at most. Third, Dr. Greene addresses the issue of the market shift to light trucks. He shows that this shift has resulted in a loss of 1.6 to 1.9 mpg, depending on the analysis methodology employed, a loss that is small relative to the 14 mpg increase that has been observed for cars. Lastly, he addresses the issue of reduced scrappage, and finds a maximum potential reduction of four percent, or about one mpg. However, he attributes reduced scrappage not to CAFÉ, but to improved vehicle quality. He also considers other arguments against CAFE for public welfare and producer surplus, and finds little damage there. Hence, he concludes "CAFE Worked."

2.4 STUDIES SHOWING SIGNIFICANT DISBENEFITS

Among the earliest and most frequent critics of CAFE standards is Dr. Crandall[3] who has argued that fuel taxes are a far superior instrument to reduce fuel consumption and GHG. He does not support the argument advanced by Dr. Greene that the market for fuel efficiency is imperfect in that consumers do not value energy savings properly, pointing to the fact that consumers have good information on fuel economy and the vehicle market is very competitive. He argues that CAFE regulations have caused manufacturers to subsidize small efficient vehicles and points to calculations by Kleit (discussed below) that show no fuel savings as a result of CAFE regulations. His analyses have generally used very high elasticities of travel (VMT) to the cost of driving, in the range of -0.5 in the short run and -1.0 in the long run. Hence, increasing fuel economy at constant fuel price leads to such large increases in driving, so that the fuel savings per mile are largely offset by increased travel. However, most data analyses, including one by Nivola and Crandall,[4] show a much smaller response to the cost of driving, in the range of -0.1 to -0.2.

Another argument advanced by Dr. Crandall is that the fuel economy improvements that occurred between 1978 and 1983 would have occurred anyway due to the fuel price shock of 1979/1980. This argument is based on the observation that similar increases were observed in Europe where (he asserts) there were no CAFE regulations. In reality, most car producing countries in Europe, such as Germany, the U.K. and Sweden had "voluntary" agreements with manufacturers to improve fuel economy. While fuel prices undoubtedly had an effect, other analyses have attempted to allocate the increases to both regulations and fuel price. Dr. Crandall's earlier analyses have argued that none of the increase in fuel economy was due to fuel price, while also arguing, somewhat paradoxically, that CAFE regulations have greatly harmed consumer welfare.

Kleit used a simulation model[5] to examine the changes in consumer and producer surplus associated with CAFE regulations, but his effort focused on changing CAFE regulation in a single model year. The model employed by Kleit assumes that the only way to change fuel economy to meet CAFE standards was by altering the mix of size classes of vehicles sold, as opposed to improving vehicle technology. While altering the mix may be a valid possibility for short run changes to fuel economy, it is not a valid assumption for meeting the CAFE targets in general and so the results of this analysis cannot be extended to a five or ten year time horizon. Kleit concludes that this strategy would produce no changes in fuel consumption (again due to a high assumed VMT elasticity) and that it would result in a large loss to consumer surplus. Other researchers have also found that size class shifting is not a very cost-effective method of obtaining fuel efficiency improvements due to the inelastic nature of consumer size preferences.

Leone and Parkinson[6] conducted a more sophisticated analysis of the effects of CAFE that considered the different effects on different types of manufacturers, as well as the role of vehicle technology. They attempted to estimate the fuel economy increase that would have occurred in the absence of CAFE regulations. In one scenario, they assumed that manufacturers that exceeded the standards by even a small margin in a particular year were not constrained by regulation, and therefore, their fuel economy level was a result of free market forces, not CAFE regulation. (This assumption appears unrealistic as most manufacturers plan to exceed the standard by at least a small margin as insurance against unexpected movements in fuel prices or consumer preferences). Under this scenario, they find that CAFE resulted in a fuel economy improvement of only 1 to 1.5 mpg, with the rest ascribed to market forces. A second scenario assumed that CAFE-constrained manufacturers (in any year) would have had the same relative improvements in fuel economy in the absence of regulations as manufacturers who were never constrained by CAFE regulations. In this scenario, Leone and Parkinson find that CAFE regulations were responsible for about 3.5 to 4 mpg of the total change in fuel economy. Based on these estimates, they derive a cost of gasoline saved of $0.60 per gallon above its market value in the first scenario. The cost under the second scenario was derived as $0.48 per gallon. They estimate that a fuel tax of just 2.5 cents per gallon (based on a VMT elasticity of -0.3) would have saved as much fuel as the CAFE regulations. They conclude that while CAFE did increase fuel economy, it did so at very high cost to society.

While the analysis by Leone and Parkinson is more comprehensive, the assumptions tend to bias the results against CAFE. For example, while Japanese manufacturers may have been unconstrained by CAFE in the U.S., they may have been constrained by CAFE-type regulations in Japan. Hence, the observed fuel economy increases for unconstrained manufacturers may have been caused by both market forces and home country regulations. A second factor that permeates all CAFE analyses, including those by Dr. Greene, is that the role of income has been ignored. The period of high gasoline prices in the U.S. coincided with a severe recession, and it is well known that both gasoline demand and demand for larger, more luxurious vehicles drop in such periods. Hence, by not including income effects, the analyses tend to overstate the role of fuel prices and potentially understate the role of CAFE.

2.5 GAS GUZZLER TAXES

The gas guzzler tax has received little attention from either the auto manufacturers or from the government in terms of its role in increasing fuel economy. As a result, there appears to be only one unpublished study, by Dr. Patterson[7] of the Department of Energy's Office of Transportation Technology, on the impacts of the tax. The analysis showed that if the three domestic manufacturers had held their product mix and fuel economy constant by size class at 1978 levels, then the total gas guzzler tax paid would have been significantly larger than CAFE-related fines in 1985. A large fraction of midsize cars and most large cars would have paid Gas Guzzler Taxes under this scenario, and calculations show that the ratio of gas guzzler taxes to CAFE fines would have been in the range of 1.43 to 1.88 for the three manufacturers. These findings do not directly relate to the question of GHG emissions reductions associated with the tax or to CAFÉ. The fact that no vehicles sold by the three domestic manufacturers paid the Gas Guzzler Tax in 1985, and the analysis of fuel economy increases by car model line, showed that manufacturers had paid special attention to avoiding the tax. As a result, the fuel economy of potential gas guzzlers was increased by a much larger percentage than other vehicles in the fleet. However, it is also more cost effective to raise the fuel economy of low mpg vehicles, so that cost effectiveness criteria could explain at least some of the larger improvements.

Nevertheless, the gas guzzler tax may have been a significant factor in the overall increase in fuel economy, but the analyses available do not explore the interplay between CAFE-driven and tax-driven increases in fuel economy. It would be useful for future analyses of CAFE to consider the role of the Gas Guzzler Tax as well as other factors in allocating the observed mpg increase to different causal factors.

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3. ALTERNATIVE FUELS AND VEHICLES

3.1 THE LEGISLATIVE AND REGULATORY CONTEXT

There are a number of legislative and regulatory programs that affect the use of alternative fuels and vehicles capable of using such fuels, and these regulations have some degree of overlap in their requirements. However, one regulatory initiative in particular stands out and has superseded others in terms of importance in the overall U.S. government strategy to enhance use of alternative fuels. The various alternative fuel strategies are incorporated under the Alternative Motor Fuels Act of 1988 (AMFA), the Clean Air Act Amendments of 1990 (CAAA), the Congestion Mitigation and Air Quality Improvement Program (CMAQ), the Zero Emission Vehicle (ZEV) program, and the Energy Policy Act (EPACT), with EPACT now serving as the primary regulatory initiative.[1]

EPACT was passed in 1992 to stimulate the research, development, and accelerated introduction of technologies that can potentially shift the focus of national energy demand from imported oil and toward renewable or domestically produced energy sources. EPACT requires the U.S. Department of Energy (DOE) to establish a program that promotes the replacement of petroleum-based motor fuels to the maximum extent possible. In addition, DOE is to determine the technical and economic feasibility of achieving EPACT's petroleum replacement goals: 10 percent of transportation fuel with replacement fuel by 2000 and 30 percent by 2010.

AFMA and the CAAA laid the groundwork for these EPACT initiatives and helped to shape the DOE's program. AMFA is a federal statute that encourages the development and widespread consumer use of methanol, ethanol, and natural gas as transportation fuels and the production of methanol, ethanol, and natural gas powered vehicles. AMFA calls for the federal government to acquire the maximum number of passenger cars and light duty trucks powered by alcohol, dual alcohol/gasoline systems, natural gas or dual natural gas/gasoline vehicles as is practical. AMFA conducts several studies of light-duty, heavy-duty and bus alternative fueled vehicle (AFV) fleets. The EPACT expanded AMFA activities, adding propane and other alternative fuels and expanding R&D programs.

The CAAA created several initiatives to reinforce the goal of the original Clean Air Act of 1970 to reduce mobile source emissions. The Clean Fuel Fleet Program (CFFP) is one such initiative implemented by the U.S. Environmental Protection Agency (EPA). The CFFP requires cities with significant air quality problems to introduce vehicles that will meet clean-fuel emissions standards.

These acts were further strengthened by Executive Order 12759 in 1991 that requires federal agencies to purchase the maximum practicable number of AFVs annually. In 1993, Executive Order 12844 was issued which accelerates federal fleet AFV acquisition targets mandated for 1993-95 by 50 percent. It also established a Federal Fleet Conversion Task Force (comprised of federal and state officials, representatives of commercial fleet operators, and executives from auto and fuel provider industries) to recommend ways for developing and producing AFVs and for expanding refueling facilities.

The CMAQ program[2] under the Transportation Equity Act for the 21st Century (TEA-21), was reauthorized to fund transportation projects or programs that will contribute to attainment or maintenance of the National Ambient Air Quality Standards (NAAQS) for ozone and carbon monoxide. TEA-21 also allows CMAQ funding to be expended in particulate matter (PM) nonattainment and maintenance areas. CMAQ funding is also available for the purchase of alternative fuel vehicles.

The California Air Resources Board (CARB) has developed programs to reduce emissions from mobile sources. Mobile sources account for well over half of the emissions that contribute to ozone and particulate matter air pollution in California. Zero emission vehicles (ZEVs) and near-zero emission vehicles are a key element of California's plan for attaining health based air quality standards. CARB originally required that, beginning in 1998, two percent of all vehicles[3] sold by major automakers must be ZEVs, increasing to 10 percent by 2003. In 1996, CARB suspended the two percent requirements for the years 1998-2002. Only electric vehicles meet the zero emissions criteria established by the CARB standards.

The federal government has set up a number of programs to meet the goals of the different legislative requirements, including the following:

- the Clean Cities Program;
- the Federal Fleets Program;
- the State, Local & Private Fleets Program;
- the Alternative Fuel Provider Program;
- the Incentives and Credits Program;
- the Zero Emission Vehicle Program; and
- the Clean Fuel Fleet Program.

The Clean Cities Program,[4] sponsored by the DOE, is designed to encourage the use of AFVs and their supporting infrastructure. Unlike traditional command-and-control programs, the Clean Cities Program takes a unique, voluntary approach to AFV development, working with coalitions of local stakeholders to help develop the AFV industry and integrate this development into larger planning processes. The hallmark of Clean Cities is the local planning process that reflects a community's choice for AFVs and the ongoing commitment to that choice. Clean Cities works directly with local businesses and governments, guiding them through each step in the process of building an alternative fuel vehicle infrastructure and having participants buy alternative fuel vehicles.

The EPACT specifies that, of the total number of light duty vehicles acquired by a federal fleet[5] each year, at least 75 percent shall be AFVs in fiscal year 1999 and thereafter. Each federal fleet that operates at least 20 light duty vehicles meeting certain physical and usage criteria in specified metropolitan areas must comply with this requirement. This program firmly establishes federal leadership in the acquisition and use of AFVs, a leadership traceable to the early AFV emissions testing requirements of the AMFA. Through fiscal year 1995, AMFA provided financial assistance to federal agencies in complying with EPACT AFV acquisition requirements by covering the incremental cost of AFVs relative to equivalent conventionally fueled vehicles. Since that time, Congress has eliminated such vehicle acquisition funds and the AFMA program's role has shifted from a funding source to a technical coordinator and educator of federal fleet managers. To address the issue of low alternative fuel use in federal fleets, an interagency task force, led by the DOE and General Services Administration (GSA), has developed the Federal AFV USER Program (Utilization Supporting Expansion of Refueling). The USER Program's goal is to support the expansion of the alternative fuel infrastructure by concentrating large quantities of federal AFVs and substantially increasing their use of alternative fuel in six selected cities.

EPACT also requires state government purchases of AFVs.[6] State governments are required to acquire 25 percent of new vehicle as AFVs in 1999, 50 percent in 2000, and 75 percent thereafter through 2006. In addition, DOE must undertake a rulemaking process to determine whether or not AFV purchase requirements should be extended to local government and private fleets.

EPACT mandates that alternative fuel providers must also acquire increasing percentages of AFVs. This mandate applies to companies and business that produce, store, refine, process, transport, distribute, import, transmit or sell alternative fuels. Starting with model year 1996, the covered providers must ensure that AFVs constitute at least 30 percent of their total light duty vehicle acquisitions, with purchase requirements increasing each year through model year 2000 by which time AFVs must constitute 90 percent of total light duty vehicle acquisitions. AFV purchase requirements remain at 90 percent of total acquisitions thereafter.

EPACT establishes an incentive program for the purchase of AFVs and the conversion of conventional gasoline vehicles to alternative fueling. Through federal tax incentives, companies and private individuals can offset a portion of the incremental costs associated with the purchase or conversion of an AFV. A $2,000-$5,000 federal income tax deduction is available for the purchase or conversion of a qualified clean fuel vehicle and an income tax credit of up to $4,000 is available for electric vehicles. Tax deductions are also available for the installation of refueling or recharging facilities for AFVs. The Congressionally authorized incentives program allows states to seek federal assistance by submitting creative plans for the introduction of alternative fuels and vehicles.

Congress also created a credit program to encourage fleets covered by EPACT AFV purchase requirements to adopt the use of AFVs early and aggressively. Credits for light duty vehicles are earned at a rate of one credit per vehicle in excess of the minimum acquisitions required. One credit may also be allocated for each year the AFV is acquired before required. Once the fleet's light duty AFV purchase requirements have been fulfilled, credits may be earned for medium and heavy duty AFVs. These credits can be traded and sold, or used to satisfy acquisition requirements in subsequent years.

Independent of EPACT, the CAAA defines a clean fuel as any power source upon which a vehicle is certified to meet federal Clean Fuel Vehicle (CFV) emission standards.[7] The CAAA requires that fleets that own, operate, lease or control at least 10 light duty vehicles, trucks, or heavy duty vehicles in certain nonattainment areas of the U.S. must purchase CFVs, but fleets that are not capable of being centrally fueled can be exempted. The percentage of new vehicle acquisitions that must be CFVs are:

- for light-duty trucks: 30% in model year 1999, 50% in model year 2000, and 70% thereafter;
- for heavy-duty trucks: 50% in model year 1999 and thereafter.

CFV purchases can also earn credits if they occurred before September 1998 or meet emission standards that are more stringent than required.

3.2 ACTUAL RESULTS FROM THE VARIOUS PROGRAMS

Although many of the AFV programs have been in existence for a decade or more, there has been only limited success in popularizing alternative fuel vehicles. Probably the most significant development arising out of these programs is the fact that all three of the major domestic manufacturers now offer a wide variety of alternative fuel vehicle models that are capable of using natural gas, electricity and alcohol fuels. The expanded vehicle availability could facilitate further expansion of the AFV infrastructure and fleet. There are now about a dozen models that offer CNG capability and about half a dozen models of electric vehicles and flexible-fuel vehicles that are available from original equipment manufacturers (OEMs).[8] Aftermarket conversions to CNG and LPG fuel have been available for two decades.

As of October 1999, the Clean Cities program has 76 participating cities with over 3,500 stakeholder organizations.[4] Over the last five years, nearly 70 communities have joined the national Clean Cities effort featuring over 240,000 AFVs in both public and private fleets and over 6,240 alternative fueling stations. Theses vehicles are estimated to reduce petroleum use by an estimated 100 million gallons per year and emissions by an estimated 40,000 metric tons through 2005.

As of the end of 1998, over 20,000 alternative fuel vehicles were either on the road or on order at federal agencies. The federal AFV program has dramatically increased the use of important classes of AFVs, has prompted automakers to expand AFV availability, and is encouraging the alternative fuel industry to plan and invest in a growing refueling infrastructure.

Sales of AFVs for the last few years that were based on original manufacturer equipment (as opposed to aftermarket conversions) have been in the range of 10,000 vehicles per year. The total fleet of AFVs in the U.S. is over 400,000 vehicles, over half of which are owned by gas utility companies.

While these numbers are not small in absolute terms, it must be recognized that they are small in comparison to the total U.S. vehicle fleet of over 180 million vehicles and total annual U.S. vehicle sales in excess of 16 million.

3.3 STUDIES ON POLICY EFFECTIVENESS

The small market share of AFVs in spite of a relatively long federal effort to promote AFV sales has led most researchers to conclude that the program has failed in the larger goal of making AFVs popular and attaining a significant share of the vehicle market. Hence, there has been little analysis of the effects of regulation since the outcome is regarded as obvious. Most studies have focused on the prospects for new strategies rather than the evaluation of existing ones. Several studies have analyzed the characteristics of AFVs that are in the market and these studies constitute an evaluation of the state-of-the-art in vehicle technology and the resulting GHG benefits. There appears to be only one study that has addressed the issue of the effectiveness of the policies implemented in expanding AFV use.

Evaluations of the state-of-the-art in alternative fuel vehicle technology have been completed by Argonne National Laboratory,[9] and Delucchi[10] in the last few years. The studies have relied on actual test data from available AFVs to examine actual GHG benefits. For many AFV types and fuels such as neat methanol (derived from natural gas), ethanol from corn blended with gasoline and MTBE/gasoline blends, the estimated GHG emissions are within 2 percent of gasoline vehicle GHG emissions. There is little or no GHG benefit from the use of such vehicles and fuels. On the other hand, there are significant benefits from the use of dedicated CNG and LPG vehicles and fuels, as well as from the use of neat ethanol. The Argonne Study has estimated the GHG benefits at 10.7% for CNG, 12.3% for LPG and 26.5% for vehicles fueled with neat ethanol. Electric vehicles were also estimated to provide a 25% GHG benefit, but do not provide the same attributes as gasoline vehicles. These actual benefits are somewhat lower than the benefits forecast in the early 1990s. It also appears that most forecasts of vehicle price for AFVs were very optimistic and that OEM equipment is considerably more expensive than anticipated. This is partly because of the low sales volumes and also because many cost reduction technologies have not been successful. For example, the actual retail prices of CNG vehicles are in the range of $4500 to $7000 more than a conventional gasoline vehicle, which is more than twice as high as the price forecast in the early 1990s. Electric vehicle (EV) prices are typically $10,000 to $20,000 more than a similarly sized gasoline vehicle. In particular, forecasts of electric vehicle battery price declines were not in line with actual experience, which is one of the reasons for the very low sales of such vehicles. The ARB has delayed the requirement for auto-manufacturers to meet mandatory sales targets for zero-emission vehicles as a result of the high prices for EVs.

The only study that has retrospectively examined the success of EPACT was sponsored by DOE as the Section 506 Study.[11] Section 506 of EPACT requires DOE to explore and analyze various programs and policies to implement EPACT goals. It specifically requires and evaluation of the following:

- the progress made in achieving the EPACT goals,
- the actual and potential role of replacement fuels and alternative fueled vehicles in significantly reducing U.S. reliance on imported oil,
- the actual and potential availability of various domestic replacement fuels, and
- the availability of dedicated and dual fueled AFVs.

The study, last completed in 1997, examines the goals in the context of very low world oil prices and the significant barriers to investment in alternative fuel production or infrastructure. It concludes that the EPACT goals of 10 percent fuel displacement by 2000 and 30 percent fuel displacement by 2010 are very ambitious, with the 2010 goal being classified as extremely ambitious. The U.S. appears to be on the way to meeting the 10 percent goal, due largely to the addition of oxygenates to conventional gasoline, the resulting blend being classified as a replacement fuel under EPACT. An important point to be noted is that the use of such blends results in little or no benefit to GHG emissions, as per the discussion on actual GHG benefits from AFVs. If natural gas liquids were also counted as replacement fuels, the U.S. could possibly reach the 10 percent goal by 2000. The 30 percent goal for year 2010 is more remote at this point and its attainment is considered unlikely. However, the study found that:

- Replacement fuel use in the transportation sector at the 30 percent goal for 2010 could be sustainable based on underlying economics if transitional impediments to AFV use could be overcome.
- Reaching the goal of 30 percent replacement fuel use would entail a very steep ramp up of AFV purchases from the present through 2010. The AFV purchases required by the EPACT fleet mandates barely begin the progression toward these goals.
- The degree of spillover from fleet AFV use into household use is very uncertain but will almost certainly be determined by the perceived economic advantages and disadvantages of the different fuels. Current price and tax structures do not appear to favor substantial spillover.
- A smoother progression of AFV sales could reach the 30 percent goal but probably not before 2020.

Despite many uncertainties, it now appears that the programs authorized by Congress in EPACT will fall substantially short of the year 2010 goal of 30 percent. DOE may need to modify that goal, possibly by rolling back the target dates. EPACT provides ample flexibility for DOE to do so, and it appears likely that target dates will be shifted.

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4. TCM IMPACTS

4.1 INTRODUCTION

Transportation Control Measures (TCMs) include a broad range of strategies to reduce emissions from motor vehicles. TCMs as discussed here include two major approaches:

- Travel Demand Management (TDM) strategies, which are designed to reduce emissions by changing *travel behavior*, therefore reducing vehicle miles of travel and fuel consumption; and
- Transportation Systems Management (TSM) strategies, which are designed to reduce emissions by changing *traffic flow* characteristics.

Before-and-after evaluation studies that credibly estimate the area-wide impacts of TDM and TSM measures on greenhouse gas emissions are rare. Nonetheless, the literature is sufficient to illustrate the magnitude of impacts of a number of strategies.

Screening criteria for the studies discussed include:

- The study is based primarily on observed conditions before and after program implementation. Evaluations based on modeling or cross-sectional data analysis are not included.
- The evaluation adequately considers experimental design issues such as statistical significance and control for external influences.
- The study estimates the potential area-wide impacts of a strategy, rather than simply providing a case study for a specific site.
- Impacts are measured in terms of CO_2, fuel consumption, or vehicle miles of travel (VMT). While most TDM studies do not estimate reductions in fuel consumption or greenhouse gas emissions, many estimate VMT savings, which can be considered a reasonable proxy for these impacts.

Studies that meet only some of these criteria are also discussed, as long as they provide significant and credible contributions toward understanding the potential impacts of TCMs on greenhouse gas emissions.

4.2 HISTORY OF TCM IMPLEMENTATION

Implementation and evaluation of TCMs in the United States has been driven by a number of factors, with objectives that include energy conservation, air quality improvement, and congestion management. The Clean Air Act – adopted in 1970 – introduced the concept of a TCM and placed a federal policy emphasis on the adoption of TCMs to improve air quality. This act, and its subsequent amendments in 1977 and 1990, required that states and metropolitan areas establish timelines and specific programs to achieve compliance with ambient air quality standards. Section 108(f) of the act included a list of TCMs that could be used for reducing emissions from the transportation sector.

The 1990 amendments to the Clean Air Act and the 1991 Intermodal Surface Transportation Efficiency Act (ISTEA) led to additional emphasis on TCMs, through the requirement that adopted state and metropolitan transportation plans be consistent with air quality objectives. In response to Federal requirements, the *modeling and prediction* of air quality impacts have generally received greater attention than the *evaluation* of actual implemented programs. Evaluations that have been conducted have focused primarily on emissions of criteria pollutants rather than on greenhouse gas emissions. A number of evaluations conducted for air quality purposes are nonetheless relevant, however, as they estimate VMT savings as an intermediate step.

During the mid to late 1970s, in response to the energy crisis, the federal government sponsored the development, implementation, and evaluation of measures to reduce transportation energy consumption on a broad scale. These included TDM programs such as ridesharing and transit service provision, and to a lesser extent TSM programs aimed at improving traffic flow. Federally sponsored evaluation work during the late 1970s and early 1980s added considerably to the body of knowledge on TCM program impacts. When the energy crisis ended in the early 1980s, the federal emphasis on energy conservation diminished, as did the support for rigorous evaluation of program impacts.

A third driving factor for TCM implementation has been to improve traffic flow and reduce congestion. State and local transportation agencies frequently implement TSM measures, such as signal synchronization and ramp metering with this objective. The focus is usually on reducing travel delays, but some evaluation studies have also measured fuel savings. Some municipalities have also adopted trip reduction ordinances with the objective of reducing local congestion. These ordinances provide requirements or incentives for employers to reduce the number of vehicle trips by their employees.

A final policy initiative as well as funding source for TCMs is the Congestion Mitigation and Air Quality Improvement Program (CMAQ), initiated under ISTEA.   CMAQ provides federal funds for state and local TCM-type programs to reduce congestion and/or improve air quality. CMAQ has required that projects report actual or estimated benefits, and a significant database of reported benefits has been established. The evaluations have usually been predictive in nature, however, and methodologies have been inconsistent and not always rigorous. The 1998 Transportation Efficiency Act for the 21st Century (TEA-21) has continued the CMAQ program as well as the broader linkage between transportation planning and air quality attainment established under ISTEA.

4.3 EVALUATION APPROACHES AND FINDINGS

Evaluation approaches and key evaluation issues largely differ according to three general categories of TCMs:

- Site-based TDM strategies;
- System-based TDM strategies; and
- TSM strategies.

4.3.1 Site-Based TDM Strategies

Site-based TDM strategies focus on changing the travel behavior of people traveling to and from a specific site. The vast majority of site-based strategies have centered on workplaces, although some TDM programs have also included schools, shopping centers, entertainment facilities, or other sites. Site-based programs may be implemented as a result of state and local mandates (e.g., employer trip reduction ordinances); federal, state, and local voluntary programs; or at the initiative of site management.

Site-based programs are generally evaluated through surveys of employees or other site attendees, to determine mode usage before and after implementation of the TDM program. Mode share data are commonly translated into changes in average vehicle occupancy (AVO) and vehicle-trip reduction, and sometimes into VMT savings if trip lengths can be estimated. Numerous case studies of specific TDM programs have been conducted.[1,2,3,4] It is less common, however, that the area-wide impacts of a TDM program are measured or estimated. Some of the more noteworthy and rigorous before-and-after evaluations of specific TDM programs include the following.

Employer trip reduction ordinances – As of 1993, at least fifty metropolitan areas or local jurisdictions in the U.S. had implemented Employer Trip Reduction (ETR) programs.[5] These programs contain requirements or incentives for employers of a given size, usually 100 or more employees, to reduce vehicle trips by their employees. Employers may do so through ridesharing or transit promotion, financial incentives or disincentives, alternative work schedules, or other means. From an evaluation perspective, the most significant ETR program has been the so-called Regulation XV in Southern California, which required employers with 100 or more employees to meet designated targets for average vehicle occupancy (AVO). Using a database of before-and-after employee mode choice at over 1,100 worksites, Giuliano et al.[6] estimated a decrease in single occupant vehicle (SOV) mode share from 75.7 to 70.9 percent (mostly from shifts to carpooling), with a corresponding increase in AVO of 2.7 percent, after one year of program implementation. Some additional benefits were noted in preliminary data after two years of implementation. Specific incentives with a statistically significant relationship to AVO included financial incentives for alternative modes, guaranteed ride home programs, and various employee benefits.

Orski estimated an upper-bound decrease in total regional VMT of 3 to 4 percent for Regulation XV, if AVO could be increased by 25 percent at all affected sites.[*] Based on Giuliano et al's findings of a 2.7 percent increase in AVO, this suggests an actual regional VMT impact of 0.3 to 0.4 percent, assuming that observed AVO changes were representative of all affected sites.

Significant databases on before-and-after employee mode share have also been collected for Employer Trip Reduction ordinances in Phoenix and Tucson, Arizona, which also applied to employers with at least 100 employees. Data from six years of observations at 2,500 sites in Phoenix suggested a one-time reduction in work-trip VMT of approximately 4 percent as a result of the program.[7] Data from 217 sites (representing 94,000 employees) in Tucson indicated a decrease in work-related travel of 4.5 percent over the time period of program implementation.[1] While these two studies were not rigorous in nature, the results are consistent with the results of the Regulation XV analysis described above.

<u>Ridesharing programs</u> – The U.S. Department of Transportation sponsored large-scale demonstrations and evaluations of ridesharing programs in the late 1970s and early 1980s. Wagner[8] examined over 60 state and local carpooling projects, in which impacts were measured based on direct observation of program participation and on the prior mode of new carpoolers. He estimated area-wide work-trip VMT reductions of 0.3 percent for specific matching programs and 1.2 percent for broader programs. In a comparative evaluation of area-wide ridesharing demonstration programs in five U.S. cities, Booth and Waksman[9] found no statistically significant change in mode share (based on a random sample of area employers), although they did find other indications that the programs assisted in carpool formation.

<u>Parking management and pricing</u> – Shoup[10] conducted before-and-after surveys at eight worksites that implemented state-mandated parking "cash-out" programs in Southern California. On average, SOV mode share at the sites decreased from 76 to 63 percent, and work-trip VMT and CO_2 were reduced by 12 percent. Other studies of parking have found that the mode share

[*] This is based on estimates that affected sites represent roughly 40 percent of area employment, and that the average work trip represents 32 percent of total daily VMT.

impacts of parking pricing at the worksite are significant (c.f. Cervero, 1994), but these studies have not generally translated mode share impacts into overall VMT savings.

Work schedule changes and telecommuting – A study of federal employees in Denver[11] assessed the impacts of alternative work schedules on VMT and fuel consumption. The study estimated fuel savings of 15.6 percent for employees in affected agencies, which was extrapolated to 0.3 percent region-wide. The study measured non-work as well as work-trip travel impacts. A handful of recent studies (c.f. Henderson et. al. [12]; Koenig et. al.[13]) have used travel diaries to estimate changes in VMT for employees participating in telecommuting programs. These studies have found offsetting increases in trip-making for other purposes that are roughly 15 to 35 percent of the VMT saved from eliminated work trips. These studies, however, have not attempted to estimate the total potential market for telecommuting or the area-wide VMT impacts.

Other synthesis evaluations – Wagner[14] attempted to estimate the potential regional impacts of multiple TDM strategies, by synthesizing the results of a number of program evaluations. He estimated a combined overall impact on energy use of 3 percent as a result of travel demand strategies. This estimate includes reductions of 1 percent for ridesharing and employer incentives, 1 percent for expanded public transit, 0.4 percent for comprehensive HOV treatments, and 0.7 to 0.8 percent for compressed work weeks and flexible work hours. Wagner’s estimates, however, assume that these programs can be implemented on a comprehensive basis, and thus represent an “upper bound” on program impacts.

A review of the existing literature illustrates some general issues for consideration in conducting and interpreting site-based TDM evaluations. These include:

- The quality of individual surveys may vary. The statistical significance of results is often not estimated; samples may not be comparable from year to year; and the evaluation usually does not control for external factors (such as changes in gasoline prices) that could affect travel behavior.
- Results at a given site do not guarantee similar results at another site or indicate potential area-wide impacts. Site-specific differences in program implementation, employee characteristics, worksite characteristics, and existing transportation services may cause

large differences in the success even of similar programs. An area-wide estimate of program impacts requires an estimate of the market potential for program adoption across all worksites and employees.

- Simple mode share surveys may not capture the full complexity of travel behavior changes. Telecommuting, alternative work schedules, or shifts to ridesharing and transit may induce changes in other household trip-making. For example, employees may make trips from home on their day off or may run errands that they could not complete on their work trip. These changes may offset some of the VMT reductions from the avoided vehicle work-trip. TDM programs are frequently evaluated for their effect on *peak-period* trips; they may be successful in achieving this objective even if corresponding changes in VMT are not realized.
- Multiple TDM strategies may interact with each other, in either positive or negative ways. For example, ridesharing, transit, and non-motorized travel to some extent borrow from the same market.[15] On the other hand, site-level land use characteristics such as pedestrian friendliness and availability of services have been found to interact positively with other TDM strategies (Cambridge Systematics, 1994).

4.3.2 System-Based TDM Strategies

System-based TDM strategies include infrastructure improvements, service improvements, or policy changes that are implemented at the level of a facility, corridor, or area-wide transportation network. Before-and-after studies of system-based TDM strategies commonly utilize time-series analysis of VMT, average vehicle occupancy, or transit ridership.
A few studies have directly reported VMT changes before and after an infrastructure, service, or policy change. Most often, however, studies focus on estimating *elasticities,* which indicate the percentage change in ridership, VMT, or other outcome variable for a given percentage change in the underlying variable (e.g., transit service frequency, transit fare, price of gasoline, cost per mile of roadway). Some types of elasticities are more relevant to this discussion than others; estimates of the elasticity of VMT with respect to per-mile driving costs or parking costs, for example, can be loosely translated into energy and CO_2 emission reductions, whereas transit service or fare elasticities require additional assumptions. The literature on elasticities is extensive (c.f. *Journal of Transport Economics*, May 1992) and is not fully reviewed here. (Note also that many elasticity studies are based on cross-sectional rather than time-series data.)

Some of the key evaluation findings and issues are described below.

High-occupancy vehicle facilities – Henk[16] estimated energy savings of 8 percent on freeways with added HOV lanes, based on observed changes in vehicle occupancy and a freeway traffic simulation model. This estimate, however, assumed no increase in travel demand, whereas actual person-throughput on the freeway (in the peak hour and peak direction) was found to increase significantly. Most HOV evaluations have focused on average vehicle occupancy (AVO), person throughput, and travel speeds, but have not translated occupancy or traffic flow changes into changes in fuel consumption. Also, HOV lane effects can vary significantly depending upon existing traffic flow conditions and the travel time savings provided by the lane.

Fixed-guideway transit – One study of new rail systems[17] compared actual regional VMT with baseline conditions from model projections. While the Washington, D.C. Metrorail produced a one-time 5 percent drop in VMT, the regional impacts of other new systems in the U.S. were estimated at less than 1 percent. Most studies of rail transit have looked only at new ridership and are insufficient to estimate energy savings. In addition, construction as well as operating energy can be significant but is rarely estimated.[*]

Transit fare and service improvements – Case studies of free transit fares in Denver, Colorado and Trenton, New Jersey estimated maximum reductions in area VMT of 0.5 percent and 0.1 percent, respectively.[19] A number of time-series analyses have been conducted to estimate elasticities of ridership with respect to fares and service levels. Elasticities can vary significantly depending upon the baseline conditions, specific changes implemented, and external conditions. In order to estimate fuel savings, transit ridership studies also require additional assumptions about the alternative choices (modes, trips, etc.) made by those whose travel behavior changes as a result of the fare or service change, and should also estimate offsetting increases in fuel consumption from additional transit service. It is rare that studies have made a direct link between specific transit service improvements and reduction in energy consumption or greenhouse gas emissions.

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[*] A series of studies attempted to estimate the overall construction plus operation energy of the Bay Area Rapid Transit (BART) system in San Francisco, California. Results varied, with some authors estimating little or no net savings from the system. (Reference 18).

Road pricing – Road pricing strategies, such as congestion pricing, VMT or gasoline taxes, and area-wide pricing, have seen little implementation in the U.S., and as a result there are few, if any, before-and-after studies on their effects. In the absence of empirical data, most estimates of road pricing impacts are based on modeling of travel behavior (Reference 1). Most of these studies have predicted regional impacts on the order of 5 to 10 percent for the adoption of significant region-wide pricing. The coefficients used in the modeling efforts are usually estimated from cross-sectional or stated preference survey data, and a number of the better modeling efforts have probably yielded reasonable estimates of impacts.

Area-wide parking strategies – In a few cases, shifts in parking demand and/or mode share have been measured as a result of area-wide parking strategies such as surcharges or supply restrictions. These impacts, however, have generally not been translated into VMT reductions. Feeney[20] notes that parking measures can have complex impacts that are generally not given adequate consideration in evaluations. For example, travelers may shift trips to off-peak hours or to alternative locations in the region where prices are lower or the supply is less constrained. Travelers also make tradeoffs between the cost of parking and walk distance to their destination.

Non-motorized travel – Area-wide incentives for non-motorized travel may include bicycle infrastructure or pedestrian improvements. Time-series observations of bicycle and pedestrian traffic have been conducted in some areas,[21] but these are generally not conclusive with respect to the impacts of particular programs or projects. Furthermore, levels of non-motorized travel have been found to vary significantly depending upon the presence of other conditions supportive of non-motorized travel (e.g., existing infrastructure, population density, or the presence of student populations.)

Land use – Increasing attention has been provided recently in the U.S. to the potential for land use strategies (e.g., density, site design) to reduce vehicle travel. Since land use strategies take a long time to implement on a widespread basis, however, time-series analyses of impacts are rare, and most analysis has been performed on cross-sectional data.[22] A few studies have attempted to correlate regional VMT with regional density measures over time, but these have had difficulty identifying and controlling for other factors (e.g., infrastructure, demographics) that also change over a long time scale.

Overall, there are a number of reasons why before-and-after studies of VMT or fuel consumption are difficult to conduct for facility or area-level actions, and why few conclusive studies of this type exist:

- First, measuring demand on the affected facility alone (HOV lane, transit route, toll bridge, etc.) does not tell the whole picture. Trips may be diverted to other facilities or modes or to alternative destinations. As a result, comprehensive studies must either measure *area-wide* travel changes or they must survey users of the facility before and after the change to determine the full nature and extent of changes in their travel patterns.
- Time-series analyses at the *area-wide* level, of measures such as transit ridership and VMT, may have difficulty controlling for external changes or background trends that occur in conjunction with the implemented policy. This is particularly the case when the relative effect of the change compared to total area travel is small (as with most TCM programs) or occurs slowly over a long period of time (as with land use changes).
- “Short run” effects may differ from “long run” effects. The effects of a travel price increase may be greater in the long run as people make changes in the locations of their activities (work, home, etc.) as a result of long-term changes in travel conditions. Yet it is particularly difficult to conduct controlled evaluations over the required long-term time frame.

In part because of these difficulties, most estimates of the VMT and energy consumption impacts of facility or area-level actions are developed using travel demand models, which are usually developed based on cross-sectional or stated preference data obtained from travel surveys.

4.3.3 TSM Strategies

In contrast to TDM strategies, TSM strategies are generally not designed to reduce VMT. Instead, energy savings result directly from changes in traffic flow characteristics, such as average speed, acceleration and deceleration, and stopped times. Most evaluation studies of traffic flow improvement strategies have focused primarily on travel time savings, although some have also estimated criteria pollutant emissions. A few studies have estimated changes in fuel consumption through the use of equations or simulation models, which relate fuel savings to observed traffic flow changes.

TSM strategies for which energy impacts have been evaluated include the following.

Traffic signal synchronization and control – Skabardonis, Singh, and Deakin[23] evaluated the fuel savings for a signal management program affecting 3,172 signals in California. They estimated an 8.6 percent reduction in fuel use in affected areas, leading to a potential overall savings of 1.7 percent on a statewide basis. The City of Los Angeles[24] estimated the fuel consumption benefits of a corridor-level adaptive signal control system to be 13 percent compared to "old timing" and 9.4 percent compared to optimized static timing. Fambro[25] estimated a 13 percent reduction in fuel consumption for traffic signalization improvements in 26 locations in Texas. (Potential region-wide impacts were not estimated in either of these studies). These studies were based on field measurements of travel times, stops, and delay combined with simulation modeling to evaluate fuel consumption.

Wagner estimated the potential area-wide fuel savings for traffic signal coordination and automation to be roughly 3.5 percent.[26] This estimate was based on before-and-after data on improvements in travel *speed* from programs in a number of areas, which averaged between 10 and 12 percent. Fuel savings were estimated using an equation relating fuel consumption to vehicle miles and vehicle hours of travel. Program-level benefits were extrapolated to a regional level, based on estimates of the number of signals that could potentially be affected by control systems.

Freeway incident detection and response – At least two studies have estimated the fuel savings of incident management programs, based on observations of traffic flow characteristics and changes in incident durations. Skabardonis[27] estimated a savings of 31 gallons of fuel savings per incident for a California program; Henk[28] estimated a savings of 2,600 gallons per *major* incident for a program in San Antonio, Texas. Potential regional savings were not reported.

Some of the primary evaluation concerns in assessing the fuel economy benefits of TSM measures include:

- *Latent demand.* Perhaps the greatest issue of controversy in evaluating traffic flow improvements is the effect of latent or induced demand. Essentially, the argument is that by making travel easier, more people will travel, thus offsetting some of the energy consumption or emissions benefits of the flow improvements. Wagner[14] (1980) claims a small short-term increase in VMT of less than 1 percent (based on modeling), compared to an observed decrease in VHT of 10 to 12 percent. More recent studies to quantify vehicle travel as a function of overall roadway capacity have estimated elasticities of VMT with respect to lane-miles as high as 1.0, suggesting that long-term offsetting impacts may be significant.*
- *Shifts in traffic demand.* Improvement of flow along an arterial, or restriction of flow at a freeway entrance ramp, may not only affect flow on that facility but may shift traffic to or from other facilities. Simulation or measurement of an individual facility will not capture changes in energy consumption resulting in changed traffic characteristics elsewhere on the transportation network.
- *Extrapolation of results to an area-wide level.* Most evaluations have focused only on the roadway or corridor affected by the TSM improvements. As with TDM programs, some estimate of the potential area-wide penetration of the improvements must be developed. This requires estimating the number of corridors, facilities, or small areas that could benefit from improvement programs as well as the potential benefit for each case of implementation.
- *The level of detail in describing traffic flow characteristics.* Simple models, such as those based on average speed and stopped time, may not give results that are as accurate as modal energy consumption models, although the results may nonetheless give a reasonable approximation of fuel savings. They may also vary in their ability to treat different types of traffic, e.g., trucks vs. cars.

4.4 CONCLUSIONS AND SUMMARY OF FINDINGS

Empirical before-and-after findings on TCM effectiveness are limited. Nonetheless, they provide some indication of the potential magnitude of impacts of these strategies. In the case of TDMs, while a few site-specific programs have resulted in substantial reductions in SOV work trips, these cases are exceptional. For any given site or region, there appears to be a measurable but limited market for additional TDM programs such as carpooling, vanpooling, supplemental transit, or non-motorized incentives. Experience in the 1990s with area-wide employer-based TDM programs has shown that an overall reduction in SOV work-trip mode share on the order of

* For example, Cambridge Systematics (Reference 29) estimates demand elasticities of 0.3 at the regional level. Noland (Reference 30) estimates short-run elasticities of 0.3 to 0.6 and long-run elasticities of 0.7 to 0.9. The extent to which VMT increases observed in time-series analysis have resulted from highway capacity expansion vs. other factors (such as demographic and socioeconomic changes) is a subject of much debate.

5 percent may be realistic. This translates into VMT impacts for all trips at a regional level of considerably less than 1 percent. These results are consistent with evaluations of ridesharing programs conducted during the early 1980s, which also showed region-wide VMT impacts of under 1 percent. Road and parking pricing strategies appear to have a potentially much greater impact than other TDM programs, although the magnitude depends upon the amount of the pricing and the nature and scale of its application.

Potential TSM impacts have been found to be somewhat greater. Traffic signal coordination and control strategies have resulted in fuel use reductions in the range of 8 to 15 percent in corridors or areas for which the improvements are implemented. Nevertheless, even with widespread adoption of these improvements, the regional impacts are diluted to perhaps 1 to 4 percent. Also, as more sophisticated control systems are more widely adopted, the additional benefits that can be realized will diminish. Furthermore, the extent to which latent demand may offset any short-term energy savings has not been adequately determined.

The magnitude of potential TDM and TSM impacts on greenhouse gas emissions can also be placed in perspective of continued background increases in VMT in the U.S., resulting from economic growth, social and demographic changes, and other factors. Annual VMT growth has recently been on the order of 1 to 3.5 percent per year.[31] Also, the potential *nationwide* – as opposed to metropolitan – impacts of TCMs on greenhouse gas emissions have not been estimated. It is likely that impacts at this scale will be further diluted, since TDM and TSM measures are likely to have the greatest impact – and potential for adoption – in larger metropolitan areas that have higher levels of traffic congestion and higher potential for alternative mode service.

The magnitude of potential energy consumption and greenhouse gas impacts of a number of TDM and TSM strategies – including (but not limited to) non-motorized travel incentives, land use changes, pricing strategies, telecommuting, freeway ramp metering, traffic management centers, and traveler information – has not yet been clearly documented through before-and-after studies. For the most part, this situation is not likely to change in the near future. Even carefully done case studies of specific TDM programs are not necessarily transferable to other situations, where a completely different context may lead to different results. TDM as well as TSM strategies may also lead to second-order changes in travel behavior that are much more difficult to measure than work-trip mode shifts or traffic flow changes. Finally, the overall impacts of most TDM and TSM strategies are too small to be measured through regional-level indicators such as VMT or fuel consumption. As a result, empirical evidence from the U.S. on the impacts of TCMs on greenhouse gas emissions remains limited, even after twenty-five years of implementation experience.

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5. EMISSION CONTROLS

5.1 REGULATIONS

The US EPA has required emission controls for all highway vehicles since the 1970s. These requirements have been to control criteria pollutants of HC, CO and NOx, but not the GHG emissions vehicles. The effects on GHG emissions as a result of emission controls are indirect, since the controls on HC emissions affect the methane emissions while controls on Nox affect the emissions of nitrous oxide, where methane and nitrous oxide are greenhouse gases. Another potentially significant effect on GHG is as a result of emissions control affecting fuel economy, which in turn affects the emissions of CO_2, a greenhouse gas.

Since the early 1980s, the emission standards remained almost unchanged till the passage of the Clean Air Act Amendments of 1990. The Amendments resulted in a number of changes to emission standards, which included:

- the imposition of new Tier I tailpipe emission standards;
- on-board refueling vapor recovery (ORVR) requirements;
- on-board diagnostics (OBD);
- new test procedures to reflect actual driving conditions;
- cold temperature CO standards;
- the National Low Emission Vehicle Standards;
- gasoline reformulation requirements;
- more stringent standards for heavy duty truck engines;
- phase out of CFCs.

By 1999, all of the above standards except the national Low Emissions Vehicle standards were implemented. None of these regulations were specifically targeted at GHG emissions except for the phase-out of CFCs.

There are also no specific studies that examined the before-and-after effects of these changes on GHG emissions, although there are programs that continuously monitor the actual emissions of criteria pollutants, and studies that monitor the performance of in-service cars to provide estimates of in-service emissions. From these studies, it is possible to infer the effects of these standards on GHG emissions, but these inferences are not contained in the studies themselves. Rather, we are providing an interpretation of the results that may not reflect the views of the authors (if they had any specific view on the topic of GHG emissions).

A capsule summary of each regulation is as follows. First, the Tier I standards required a reduction of tailpipe emissions of HC by 37 percent and NOx emissions by 60 percent, relative to the 1990 levels, in terms of standards. The Tier I standards also require compliance over the full useful life of the vehicle. The on-board vapor recovery standards require vehicles to recapture vapors that may have been expelled from the tank during refueling. On-board diagnostics require systems in the vehicle to be able to detect most types of emission control malfunctions and provide a warning signal to the driver to have the malfunction corrected. The test procedure revisions have resulted in the addition of a new driving cycle (called the supplemental FTP) that simulates high speeds and high acceleration rates found in some significant percentage of driving. The standards have to be met on the new driving cycle as well as the cycles used previously. The cold temperature CO standards require vehicles to meet a stringent CO standard at an ambient cold start temperature of 20 F. The National Low Emission Vehicle standard is a voluntary effort by auto-manufacturers to introduce California style low emission vehicles nationally.

While many of the above standards apply to new cars and light trucks, the last three are different. Gasoline reformulation regulations specify new gasoline quality and composition requirements and apply to gasoline sold only in specific areas of the U.S. The heavy-duty engine standards apply to 1998 and later engines and reduce the level of NOx standards by 20 percent relative to pre-1998 standards. The phase out of CFCs used in vehicle air-conditioners was required as part of an international agreement to end CFC use in air-conditioning systems.

The summaries above do not capture the full range of changes mandated by each regulation but are merely intended to serve as a guide to the nature of the changes mandated. In general, requirements for reducing HC and NO_x emissions tend also to reduce the emissions of methane and nitrous oxide respectively, thereby reducing GHG emissions. The issue of fuel economy impact is difficult to resolve since the new standards have resulted in new technology introduction where the technology itself could impact vehicle fuel economy.

5.2 STUDIES OF THE EFFECTIVENESS OF REGULATIONS

As noted, the studies on the effectiveness of regulations are largely based on the testing conducted by EPA and the auto-manufacturers to ensure compliance with the requirements. The two major testing programs are the vehicle certification program and the emission factors program. There has been some study of the regulations retrospectively for cost and technology, and these have been conducted by the California Air Resources Board (CARB) under the mandate to review the Low Emissions Vehicle program biennially. Manufacturers have provided comments to the EPA and CARB as responses to the Notice of Proposed Rulemaking, that have provided some insight into the nature of fuel economy changes with respect to regulation.

The Tier I emission standards have resulted in the certification levels of emissions declines by at least the same percentage as the standards, if not more. The certification data shows that manufacturers have provided a greater margin of compliance with the standard to offset the risk of non-compliance over the full useful life. Very limited data on methane and nitrous oxide emissions also show decreases in these emissions from Tier I standard vehicles, but the data is not adequate to determine if, on average, the declines are significantly less than the decline in HC and NOx emissions. However, it should be noted that methane and nitrous oxide emissions account for less than 0.5 percent of GHG emissions from light-duty vehicles, so that the changes are very minor. The issue of fuel economy losses is far more difficult to determine. Previous analyses by Sierra Research[1] and EEA[2] have indicated that the greater weight of the emission control equipment and the increased exhaust backpressure should decrease fuel economy, but by a small amount in the range of 1 to 2 percent. Since the variability of test results is of the same order of magnitude, it is difficult to validate the fuel economy loss forecast by engineering analysis.

Another important issue that has been discussed as part of many earlier rulemakings is the fact that manufacturers introduce new technology to meet standards. Manufacturers point out that the new technology would have provided a fuel economy gain if the previous standards had continued, and the fuel economy remaining unchanged is actually a gain "foregone". For example, the Tier I standards resulted in the adoption of sequential multi-point fuel injection that provided much better control of fuel over a driving cycle. The manufacturers have suggested that had the standards remained constant, fuel economy would have increased by about 2 percent, rather than remain unchanged. However, it is not clear if manufacturers would have adopted the technology as widely if the Tier I standards were not in effect. This illustrates the complexity of making determinations about fuel economy. However, it is clear that the magnitude of fuel economy change due to the imposition of Tier I standards, whether negative or positive, is quite small.

Both the On-board Refueling Vapor Recovery and the On-board Diagnostics requirements do not directly impact any of the GHG emissions in any significant way. In the absence of pump based vapor recovery systems, the ORVR system reduces HC emissions (but there is no methane in refueling vapor) and this recovered vapor could positively impact fuel economy in a minor way, but this is offset by the minor increase in vehicle weight. OBD could potentially influence all GHG emissions by assisting consumers keep their vehicles in better repair, but no studies have been done to validate this effect.

The changes to the test procedure has resulted in a 'de facto' change to emission standards due to the need to meet the standards over a more severe duty cycle. Hence, there are reductions in HC and NOx emissions over aggressive driving modes relative to earlier vehicles, but changes to the emissions of methane and nitrous oxide must be surmised in the absence of hard data. Issues on fuel economy changes are very similar to those for the Tier I standards discussed above, in that new technology has offset possible declines in fuel economy due to increased weight and exhaust backpressure. There has been little study on the effects of the cold temperature CO standard on GHG emissions, but the standard should have helped fuel economy at low temperature since the CO standard has been met by reducing fuel input at these temperatures.

The impact of gasoline reformulation on GHG emissions ahs been studied by a test program conducted by the Co-ordinating Research Council[3] (a joint effort by the auto-manufacturers and oil refiners). The program concluded that Federal Reformulated Gasoline increases fuel consumption by 2.5 percent. Studies by Wang at Argonne[4] show that reformulated gasoline causes a 1.8 percent increase in GHG emissions if upstream effects of fuel production energy are also taken into account.

The impact of the heavy-duty truck standards on fuel economy is controversial. According to manufacturer specifications, most post 1994 engines had better fuel economy than their pre-1994 counterparts, partly due to new technology introduction. However, the EPA claimed that manufacturers used illegal methods to improve fuel economy at the expense of emissions outside the defined emission test procedure criteria, and it is not clear if either the fuel economy increase or the observed emissions are a reliable guide to the future.

The phase out of CFCs is now complete and there is no question about the GHG emission decreases from this regulation. The benefits are estimated at about 2 percent of all GHG emissions from light duty vehicles. [5]

5.3 SUMMARY

The impact of criteria pollutant related emission regulations on GHG emissions have not been the objective of most before-and-after studies on these regulations but can be inferred from some of the data presented. It appears that most of the light duty vehicle related criteria pollutant emissions regulations have had small but favorable impacts on GHG emissions, although there are open questions on whether some of the prospective gains from new technology have been foregone. The phase-out of CFCs is also unquestionably beneficial to GHG emissions. On the other hand, the introduction of reformulated gasoline has been shown to have an unfavorable effect on GHG emissions. The GHG emissions impacts associated with the heavy-duty engine emission standards is not yet clear.

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3. Coordinating Research Council, *Auto/Oil Air Quality Research Program*, Final Report, 1997.

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5. Delucchi, M. A., personal communications.

6. SUMMARY

The actual number of strategies implemented in the U.S. affecting GHG emissions from the on-highway transportation sector is relatively small. The strategies in four areas have been examined, and the areas are

- Fuel Economy regulations
- Sales of Alternative Fuel Vehicles and Alternative Fuels
- Transportation Control Measures
- Vehicle Emissions Regulations

Of these, the one with the potentially largest GHG impact is the Vehicle Fuel Economy regulations.

The Corporate Average Fuel Economy (CAFE) standards have requires each auto manufacturer to meet a new vehicle fleet average standard of 27.5 mpg for cars and around 20.5 mpg for light trucks. These goals have been attained by the fleet, but 'before and after' studies of these regulation differ significantly about the impact of the regulation itself. Some studies have suggested CAFE regulations were not the cause of the fuel economy increase, and the levels of fuel economy attained were due to increases in fuel prices in the late 1970s. Others suggest that CAFE regulations saved no fuel since increased driving associated with the reduced cost per mile eliminated the benefits of increased fuel economy. The most comprehensive studies suggest that both CAFE and fuel prices may have caused the observed increase in fuel economy, but do not agree on the relative effects of each factor or on the net fuel savings. Studies by Dr. Greene have suggested over two-thirds of the observed increase in fuel economy was due to CAFE regulations, and that increased driving and the shift to light trucks may have decreased CAFE effectiveness in saving fuel but only by about 20 percent. Other studies are more pessimistic, but these conclusions may be based on unrealistically high consumer response to the cost of driving.

The gas-guzzler tax is a less well known regulation that affects the lowest fuel economy vehicles. Only one study appears to have examined its effect, and the study suggests that the tax may have also had a strong influence on vehicle fuel economy, but the interaction with CAFE regulations have not been examined.

A number of regulations affect the introduction of alternative fuel vehicles. Of these, the Energy Policy Act is perhaps the primary regulatory initiative, and the Act has set ambitious petroleum replacement goals. Other regulations, such as the Alternative Motor Fuels Act, and the Clean Air Act Amendments, assist in the introduction and marketing of AFVs and fuels.

While there have been some successes in the AFV area, these have been limited to niche markets. Current AFV sales are less than 0.05 percent of new vehicle sales, and the entire fleet of AFVs (including dual-fuel vehicles) is about 0.2 percent of the total fleet. On the other hand, non-petroleum derived fuels are sold in large volumes as fuel blends with gasoline.

Before-and-after studies of alternative fuel vehicles are of two types. The first considers the actual performance of AFVs, now that there a variety of models introduced into the marketplace. These studies find that several AFVs (notably CNG, LPG, neat ethanol and electric vehicles) do offer significant GHG benefits relative to gasoline fueled vehicles, although the benefits are less than originally estimated. Many other alternative fuels, notably MTBE and ethanol blended with gasoline, offer little or no GHG benefits. However, the studies also indicate AFV costs are significantly higher than originally estimated.

Only one study has examined the fuel sales goals in EPACT. The study has concluded that the 2000 goals will likely be attained by the use of alternative fuels blended with gasoline. This implies zero or minimal GHG emission benefits from attaining EPACT goal in the short term. In the context of current and expected low world oil prices, the analysis finds the lack of success of AFVs understandable, and finds it very unlikely that the 2010 petroleum replacement goals will be met.

Transportation Control Measures have been implemented for nearly 20 years, but there is a little empirical evidence on their effectiveness. These measures and their effectiveness are quite site specific so that their significance to national level GHG emissions is very small. In specific areas, transportation demand management programs such as ridesharing, vanpooling and transit have shown work trip reductions on the order of five percent, but total VMT even in a specific area may be reduced by less than one percent. Traffic signal coordination could lead to fuel consumption reductions of eight to 15 percent in corridors where such improvements are implemented, but region wide impacts are quite small. The effects of other TCMs such as land use changes, pricing strategies, etc., have not been documented in before and after studies. Nevertheless, there is a consensus that the combined effects of all TCMs on GHG emissions at the national level are very small, in the order of one percent.

Emission controls have been successfully implemented in terms of reducing criteria pollutant emissions and their impact on GHG emissions can be inferred from available before-and-after test data. Methane and nitrous oxide emissions have been reduced significantly but such gases account for less than half a percent of a vehicle's GHG emissions per unit of travel. The imposition of new emission standards can reduce fuel economy but the introduction of new technology offsets these reductions; the net change in fuel economy has been very small but there are arguments about the "foregone" benefits from new technology. Hence, it can be argued that criteria pollutant emission regulations have not impacted vehicle GHG emissions significantly. However, the use of reformulated gasoline has been a part of the strategy to meet emissions standards, but the reformulation increases GHG emissions by 2 to 3 percent.

The only emission regulation that has definite benefits for GHG emissions is the CFC phase-out from air conditioners. The benefit is on the order of two percent of total GHG emissions from light-duty vehicles.