TEXAS TRANSPORTATION ENERGY SAVINGS

STRATEGIES FOR REDUCING ENERGY CONSUMPTION

PREPARED BY

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AND

THE TELLUS INSTITUTE

JUNE 1995

REPORT FOR THE TEXAS SUSTAINABLE ENERGY DEVELOPMENT COUNCIL

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ACKNOWLEDGEMENTS

We wish to acknowledge the technical guidance, support, and review by Harvey Sachs, SEDC Technical consultant. His insight and expertise have been particularly helpful.

The research work of CTR was also facilitated by the contributions of many persons including Bridget Dickerson, Bonnie Malek, Judy McCullough, Balaji Mohanarangan, Jan Slack, and Karen Smith. Each of these individuals contributed in different ways to enhance the overall quality of the research effort.

Finally, we are grateful to SEDC for their outlook and interest in a sustainable transportation future. Judith Carroll and Charlotte Banks were instrumental in assisting our research team during the challenging administrative phases of the research work.

FOREWORD

Texas dependence on motor vehicles has led to an energy intensive transportation system. Texas is the nation's largest consumer of energy, 40% larger than the second highest state, California. Future sustainability efforts require a re-examination of the Texas transportation system. To evaluate transportation energy consumption, the Long-Range Energy Alternatives Planning/Environmental Data Base (LEAP/EDB) analysis system developed at the Tellus Institute was calibrated for use in Texas. Five scenarios are constructed reflecting different energy strategies for the state. Based on the Reference Scenario (base case in 1994), the Texas transportation system consumed 2,044 trillion BTU of energy. This energy consumption is projected to increase to 2,948 trillion BTU, a 44.2% increase, by the year 2020. The energy consumption estimates for the Reference Scenario include current State and federal policies promoting the use of alternative fuels. Elimination of these current policies would result in a 1.9% higher level of energy use by the year 2020. A Moderate Scenario is constructed and consists of policies that promote the purchase of more fuel efficient vehicles for consumers and more productive vehicles for truck-freight, as well as active use of transportation control measures in Texas cities. Implementation of these measures will lead to a 5.5% reduction in transportation energy use, relative to the Reference Scenario, by 2020. More significant policy measures are enacted in the Aggressive Scenario. The basic thrust of this scenario is accurate pricing of transportation use. Utilizing various congestion and road pricing measures results in a 20.1% reduction in energy use by 2020 (relative to the Reference case). Finally, the Visionary Scenario identifies the fullest potential for the Texas transportation system. The Visionary Scenario incorporates transportation sensitive land use, as well as expanded teletravel activities and full-cost pricing. Changing to this kind of transportation environment generates energy consumption levels in 2020 (1,960 trillion BTU) that are below current (1994) transportation energy consumption levels. The LEAP/EDB structure also provides a mechanism for identifying end use emissions. Implementation of the policies in each of the scenarios can lead to a reduction in harmful carbon monoxide, ozone (smog) forming emissions, and greenhouse gases. Based on the analysis in this study, Texas can significantly change its energy intensive transportation system to a system that is both sustainable and environmentally sensitive. Importantly, action must be taken immediately to achieve the long-term benefits of this goal.

ONE: INTRODUCTION

OVERVIEW

The United States is a major energy consumer and the world's largest consumer of petroleum. While consumption of petroleum appears to have a positive relationship with U.S. economic health, the fact that much of this energy is imported makes the nation more vulnerable to changes in the world market. Specifically, most of the world's oil supplies are located in politically and socially unstable Middle Eastern and African regions, and the U.S. is heavily dependent on the actions of these countries. This dependence was demonstrated by the oil embargo of 1973-74, the 1978-79 Iranian revolution, a period of significant price cuts in 1985-86, and most recently the 1991 Persian Gulf War.

In the nation, Texas is the highest state consumer of energy; as a political entity itself, Texas has the fifth highest energy consumption in the entire world, behind the entire United States including Texas, China, Japan, Germany and the former Soviet Union.* In 1992, Texas consumed 9,915.1 trillion British Thermal Units (BTUs) of energy, 40 percent more than California, the second largest state consumer. By energy source, Texas was the largest consumer of natural gas, petroleum, and electricity, and the fourth largest consumer of coal (Ref. 1). For the state, transportation plays a significant role in energy consumption. The principal energy source for transportation is petroleum, which has supplied over 90 percent of the state's energy needs since 1960. Natural gas is the next major source of energy for transportation but its share of total consumption declined from 6.8 percent in 1960 to 3.9 percent in 1992. Similarly, Liquid Petroleum Gas (LPG) represented less than 0.1 percent in 1992, down from 1.0 percent in 1960 (Ref. 1). Clearly, petroleum dependence is a relevant issue for Texas transportation. (*Calculated from the "State Energy Data Report 1991," Energy Information Administration, Washington D.C., May 1993, p. 297, Table 276, and "World Resources 1994-5," World Resources Institute, New York, 1994, pp. 334-335, Table 21.1)

Actions to reduce energy consumption are merited, but current efforts to address transportation demand are being driven primarily by air quality issues. Nationally, the Clean Air Act Amendments of 1990 (CAAA) and the Congestion Mitigation and Air Quality Improvement (CMAQ) Program of the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) were strongly influenced by the recognition that mobile sources are important contributors to air quality problems, and that the continuing growth of vehicle-miles traveled (VMT) still supersedes benefits derived from technical innovations related to pollution control. Such measures to decrease pollutant emissions may or may not have a significant impact on energy consumption. Programs to relocate traffic to off-peak hours can be effective in reducing some types of pollutant emissions, but have negligible impact on state-wide energy consumption, especially from a full-cycle perspective and considering the high level of Texas energy consumption.

Without question, Texas depends on its network of public roads to move people and goods. This dependence, however, is not without significant costs. The Federal Highway Administration (FHWA) reports that 25 percent of Texas urban interstates exceed 95 percent of their capacity and 43 percent are operating at over 80 percent of their carrying capacity. The resulting congestion is estimated to cost Texas motorists an additional $3.9 billion in delay and fuel costs each year (Ref. 2). At the same time the capacity of the system is being stretched to its limits, the quality of the road pavements are rapidly deteriorating. The FHWA reports that nearly 75 percent of the state's highway system is in "fair" or "worse" condition (Ref. 3). These poorly maintained roads mean higher operating costs for the Texas consumer. The Congressional Budget Office (CBO) estimates that consumer variable vehicle operating costs increase from 11 percent to 29 percent on roads in poor condition (Ref. 4).

Dependence on highways has led to worsening air quality, greater dependence on imported petroleum, more rapid depletion of non-renewable resources, and higher costs to the motoring public. All are major concerns and the impetus behind this study's effort is to explore future scenarios aimed at promoting greater efficiency in the transportation sector.

Study Objectives

The Texas Sustainable Energy Development Council (SEDC) sponsored this study to provide guidelines for reducing energy consumption and associated pollutant emissions in the Texas transportation sector. The problem is thus defined as finding viable alternatives that are conducive to an environmentally friendly and energy efficient transportation sector.

As shown in Figure 1.1, which illustrates the study framework, this objective was accomplished through the development and analysis of five transportation scenarios: a Reference, and then Moderate, Aggressive, Visionary, and Rollback possibilities. The Reference case provides the baseline for comparing alternative transportation scenarios. It reflects the current situation in Texas, as well as future trends with no additional policy measures. The Moderate, Aggressive and Visionary scenarios consist of increasingly aggressive policies and measures to reduce energy consumption and emissions in the Texas transportation sector. The Rollback Scenario is presented to discuss the consequences of revoking the current alternative fuels program. The background to each of these scenarios included research into available transportation technologies, types of fuel, and possible transportation control measures. This was the primary thrust of the first report. The analysis of the scenario results includes an examination of implementation costs, energy savings, and environmental impacts.

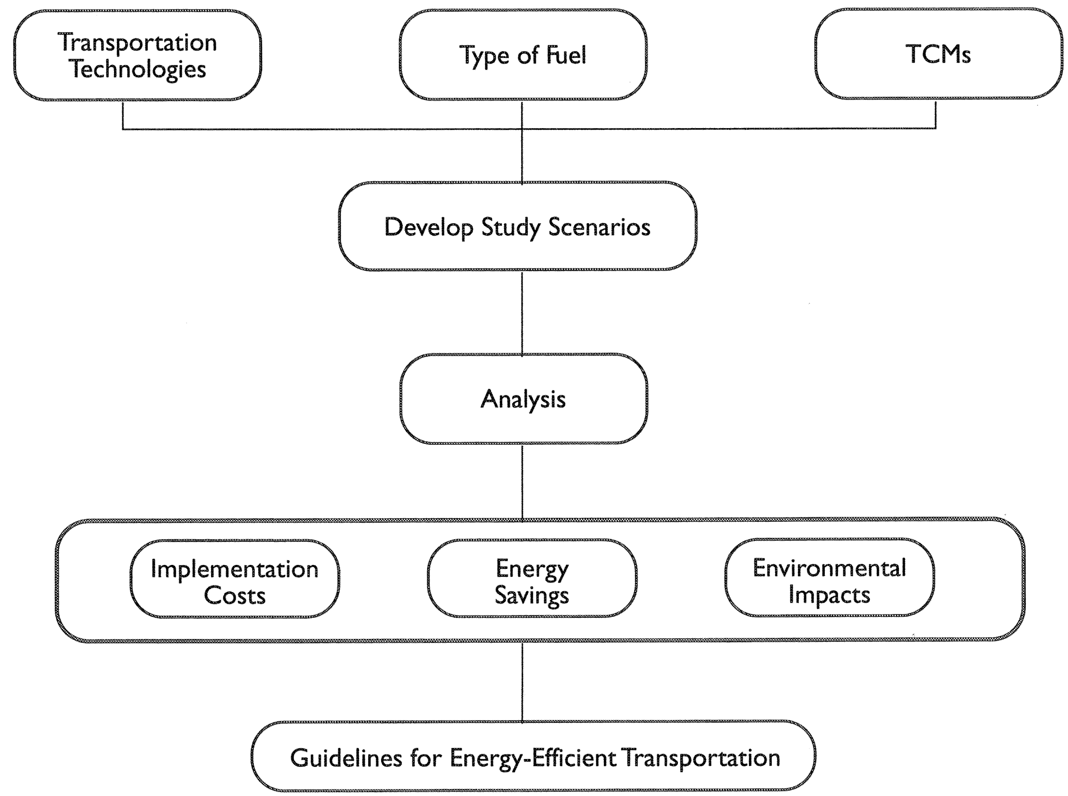


Figure 1.1 Study Framework

Again, it is important to note that air quality concerns drive the majority of current efforts to develop and implement alternative transportation policies. This being the case, this study has a double perspective: for each of the transportation scenarios outlined above, not only are measures to control energy consumption analyzed, but so are methods to reduce pollutant emissions. This recognition was one part of a comprehensive assessment of the available near-term policy and technology options, which, together with current assessment techniques, is detailed in the following section.

Options for Energy-Efficient Transportation

***Description*.** Energy use in transportation is driven by travel technology and travel demand, which in turn is driven by patterns of land use, work and production, and by people's lifestyles and preferences. Transportation policies can target all of these factors. Some policies are very specific to a single target, such as the mandate to employers of a certain size to induce their workers to participate in a rideshare program. Other policies, such as a motor fuel tax, are likely to affect many variables. This study analyzed transportation control measures (TCMs), technological innovations and various pricing and regulatory policies. The following outline summarizes the possible near-term options for energy-efficient transportation in Texas.

1. Transportation Control Measures (TCMs)
- 1.1 Transportation System Management Strategies
  - 1.1.1 Traffic Signalization
    - Update of equipment and/or software
    - Timing plan improvements
    - Signal coordination and interconnection
    - Signal removal
  - 1.1.2. Traffic Operations
    - Conversion of two-way streets to one-way operation
    - Restrictions on two-way street left turns
    - Continuous median strips for left turn lanes
    - Channelized roadways and intersections
    - Roadway and intersection widening and reconstruction
  - 1.1.3. Enforcement and Management
    - Enforcement for all of the actions described in this table
    - Incident Management Systems
    - Ramp metering
  - 1.1.4. Intelligent Transportation Systems (ITS)
    - Advanced Traffic Management System (ATMS)
    - Advanced Traveler Information System (ATIS)
    - Commercial Vehicle Operation (CVO)
    - Advanced Vehicle Control System (AVCS)
- 1.2 Transportation Demand Management (TDM)
  - 1.2.1 Trip Elimination Strategies and Peak Spreading
    - Telecommuting
    - Work schedule changes (flex time, compressed or staggered work week)
    - Non-motorized transport
  - 1.2.2. Increased Vehicle Occupancy
    - Public transportation
      - System/service expansion
      - Operational improvements
      - Marketing
    - Private high-occupancy vehicles (HOVs)
      - Ridesharing, carpool and vanpool programs
      - Parking management
      - Road pricing
      - HOV facilities
      - Auto restrictions

2. Technology Options
- 2.1 Improve Fuel Consumption
- 2.2 Alternative Fuels

3. Pricing Policies
- 3.1. Increase The Fuel Efficiency Of New Vehicles
  - feebates, tighter inspection and maintenance programs, old vehicle scrappage
- 3.2. Increase Share Of Low-Emission And Zero-Emission Vehicles In The Vehicle Fleet
  - procurement, tax incentives, or regulation of manufacturers
- 3.3. Increase The Cost Of Driving Alone
  - Motor fuel taxes, VMT charges, pay-as you-drive insurance

The State-of-the-Art in Assessing Transportation Alternatives. In order to develop scenarios for energy savings in the transportation sector, it is necessary to evaluate the potential impacts of the measures listed above on energy consumption and air quality. This evaluation was constrained by several factors:

1. Effectiveness in emissions reductions does not always correspond to cost-effectiveness (measured in dollars per ton of emissions reduced). Only TCMs that make use of pricing strategies to encourage higher occupancy vehicles (HOVs) have the potential to significantly reduce emissions.
2. The state-of-the-art in TCM analysis is restricted to individual TCMs, while they are usually implemented in groups and their combined effects may vary from additive to contradictory.
3. Most methods of TCM evaluation are geared toward estimating total emissions, while the requirements of the CAAA are expressed in terms of pollutant concentrations in the air.
4. Prediction of travel behavior (such as mode shifts) with respect to TCM implementation is somewhat incipient and uncertain.
5. The impact of TCMs over time is difficult to estimate, especially when TCMs are considered in groups rather than individually.
6. Prediction of TCM impacts on energy consumption is also rather incipient, and this study is pioneering in this regard.
7. The reported elasticities of vehicle-miles traveled (VMT) or traffic demand in general, with respect to specific TCMs, are very inconsistent.

Thus, the present state-of-the-art practice calls for the development of a modular analysis system that addresses the basic issues, an effort well beyond the scope of this study. Nevertheless, the literature survey enabled us to compare options and select those that appear to have the greatest potential for energy savings.

Potential Impacts on Energy Use and Air Quality. The results of the options assessment are discussed in detail in the previous report of this series ("An Assessment of Transportation Control Measures, Transportation Technologies, and Pricing/Regulatory Policies"). These results were organized in terms of the options' potential to:

- Improve speed.
- Decrease the number of single-occupancy vehicles (SOV) and/or number of trips.
- Decrease the vehicle-miles traveled (VMT).
- Improve fuel economy of vehicles.
- Use alternative fuels.

A wide range of observed and potential impacts were found in the literature, and sometimes there were limitations as to the applicability of data to Texas. The results of this assessment are discussed below and summarized in Figures 1.2, 1.3 and 1.4.

Figure 1.2 summarizes the findings from the literature review concerning transportation system management (TSM) impacts on vehicle speeds. The impacts ranged from a less than 1 percent increase in speed to as high as a 233 percent increase in speed. The transportation system management strategies considered include the use of ITS as well as more conventional technologies. The ITS research reports that only assessed the potential impacts of one vehicle in the traffic stream being equipped with "real-time" traffic information and bypassing a freeway incident. The high end of the speed improvements' range is assumed to reflect findings

Therefore, we have assumed that this is not a realistic speed improvement at a system-wide level and have chosen from the literature a speed improvement of 16 percent. Two issues concerned with the application of speed improvements are: (1) changes in overall vehicle energy efficiency, and (2) the percentage of the annual VMT that the change in speed applies to. In this study, we have assumed that the change in speed impact applies only to the functional road class of "other principal arterials" as specified in the 1992 Highway Statistics (Ref. 3) and

Transportation Control Measures (TCM)

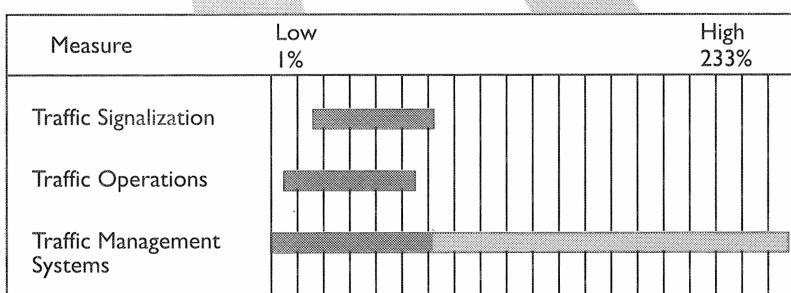


Figure 1.2 Potential Change in Speed for Selected TCMs

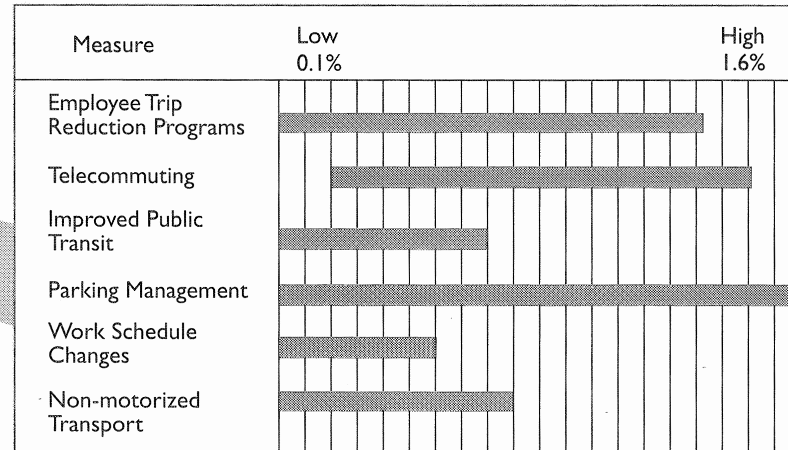


Figure 1.3 Potential Change in Vehicle Trips for Selected TCMs

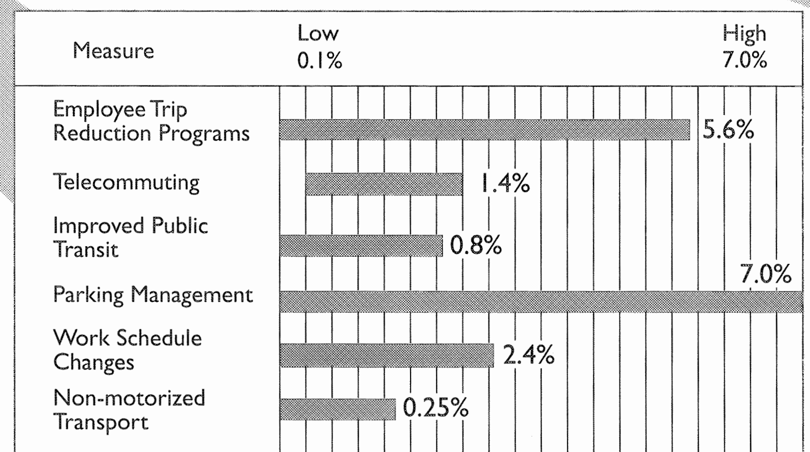


Figure 1.4 Potential Change in VMT for Selected TCMs

that the impacts are applicable to both peak and non-peak traffic.

Figure 1.3 summarizes the findings from the literature review concerning transportation demand management (TDM) impacts on vehicle trips in large urban areas. The impacts of the various transportation demand strategies range from a less than 1 percent reduction in vehicle trips in large urban areas to a high of 1.6 percent. Several issues arise when searching the literature for vehicle trip reduction impacts. First, vehicle trips presumably refer to total auto trips of various occupancies, not just SOVs; the studies reviewed take this into consideration by applying an occupancy factor. Second, these studies may or may not assume that transit users and carpoolers take an intermediate trip in a SOV on their way to a transit station or to meet another carpooler.

Figure 1.4 summarizes the literature review findings concerning TDM impacts on auto VMT in large urban areas. The impacts range from a less than 1 percent reduction in auto VMT in large urban areas to a 7 percent reduction. Presumably, the impacts on VMT (as well as on trips) are a result of government mandates and do not involve road pricing mechanisms, with the exception of parking pricing and employer transit subsidy.

When interpreting the various findings from the literature on transportation system management, the following issues should be considered:

- The percent reductions in the number of trips taken and the amount of VMT are relative to the total annual highway/roadway transport activity within a large urban area (except for telecommuting impacts which are national percent reductions).
- The percent reductions in the number of trips taken and the amount of VMT relative to the total transport activity on a statewide basis will, of course, be less than the reported percent impact for a single large urban area.
- The impacts on transport activity of TCMs reported in the literature represent either what has been accomplished to date or what is projected to be accomplished. Thus, the results are implicitly linked to the level of effort implemented to date or to the assumptions made in the projections of metropolitan area planning staff and their consultants.
- The duration of the impacts on transport activity with TCMs is unknown.

The effectiveness of TCMs in the reduction of emissions does not always correspond to cost-effectiveness (measured in dollars per ton of emissions reduced). TCMs that make use of pricing strategies to encourage HOVs, such as parking management and road pricing, have the potential to reduce emissions by 2 percent or more, while other TCMs, such as improved signal timing, have little effectiveness in reducing emissions but a very low cost per ton reduced.

Study Approach

The approach used in this study is organized in two phases, assessment and analysis, as shown in Figure 1.5. In the assessment phase, the viable near-term options for energy savings in the transportation sector were identified and then assessed in terms of costs, potential to reduce energy consumption, and potential to improve air quality. In addition, the quantitative data necessary to estimate energy consumption in transportation was identified, obtained, and projected. The main objective of this first phase was to obtain and evaluate all necessary information to construct the study scenarios.

The second phase started with the development and calibration of a model structure that could adequately represent the characteristics of the Texas transportation system. The results of this model calibration provided the Reference Scenario, or baseline results. Then, alternative transportation scenarios were developed by selecting a combination of strategies for energy savings. The data that captures the overall demand under each scenario is based on the results of the assessment conducted in the assessment phase of the study. The calibrated model is used to estimate energy use, emissions and costs (costs are estimated independently) incurred by each

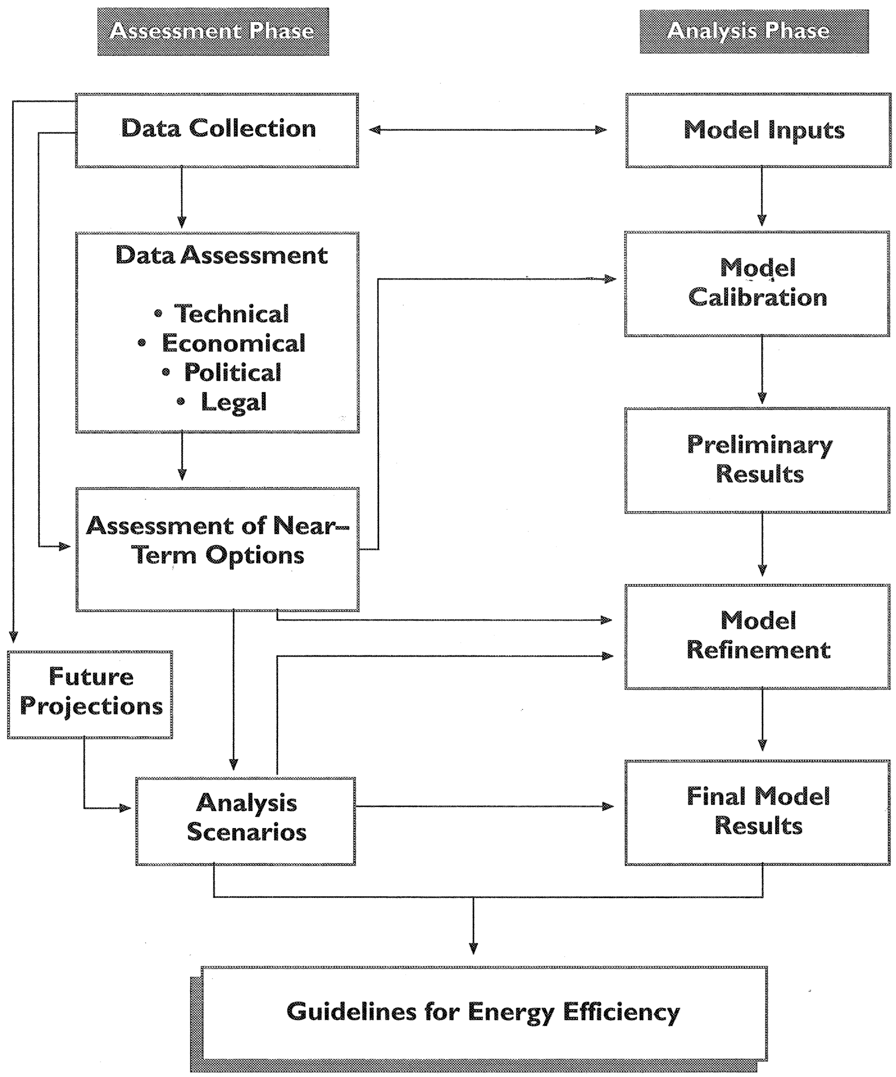


Figure 1.5 Study Approach

of these scenarios. A comparative discussion of the results of these scenarios provides the basis for developing the guidelines for energy savings in the Texas transportation sector.

The proposed scenarios include a number of alternative transportation policies, pricing strategies to modify travel behavior, and new technologies for both vehicles and infrastructure. Table 1.1 depicts a summary of the five analysis scenarios examined in this study, with a brief description of the different policies and alternatives that each represents.

As described on the next page, the Reference Scenario provides the baseline for comparisons and impacts of the alternatives analyzed, while the Moderate, Aggressive and Visionary scenarios consist of increasingly effective combinations of energy reduction policies. The specific policies for these scenarios were selected based on their potential effectiveness for the various transportation sectors and their feasibility in the short- and intermediate-terms, as well as in the future. Most of the selected policies target the surface transportation system. The results and conclusions provided basic guidelines and recommendations for energy savings in the Texas transportation sector.

Report Scope and Organization

Following the first report, which assessed various transportation systems management, technologies, and pricing/regulatory policies, this second report reviews the collection of the data, analysis of the

Scenario	Objective
Reference	Provides a transportation sector baseline to analyze the potential impacts of alternative scenarios.
Rollback	Estimates the consequences of a reversal of the current national and state alternative fuels programs.
Moderate	Examines measures that require moderate changes in current travel behavior, modal distribution, and vehicle choice in the short-term.
Aggressive	Examines measures that produce more substantial changes in current travel behavior, modal distribution, and technologies for the intermediate-term.
Visionary	Investigates more radical modal shifts and behavioral changes, significant land use changes, and visionary technological innovations that are realistic for the future.

Table 1.1 Summary of the Analysis Scenarios

alternatives, and final results. Within the second report, this first chapter outlines the objectives of the report. Chapter 2 describes current transportation demand in Texas and defines the model structure, which is critical for identifying and evaluating measures to reduce energy consumption and associated pollutant emissions. Chapter 3 details the Reference case, which provides a benchmark to measure potential impacts of alternative scenarios. Chapter 4 builds upon the previous findings to document the development of the analysis scenarios, namely Moderate, Aggressive, Visionary, and Rollback scenarios. It also discusses the levels of energy consumption and emissions under each one of the analysis scenarios. Chapter 5, "Conclusions and Recommendations," compares the level of energy consumption and pollutant emissions of the various scenarios against the Reference case.

TWO: MODELING APPROACH

INTRODUCTION

The energy savings in the Texas transportation sector were modeled according to a Reference Scenario which captures the current status of the overall state transportation network and fleet, including specific features of interest which reflect different traffic demand characteristics and potential measures to reduce energy consumption. This Reference Scenario was calibrated, i.e., developed as a working model, so that its results reflected the current energy use in the Texas transportation sector. Technically, the Reference Scenario is a baseline scenario for further case studies, but it can also be interpreted as a "status quo" scenario that serves as a basis for analyzing the impact of potential measures to decrease energy use.

Both energy use and pollutant emissions were estimated using the Long-range Energy Alternatives Planning system (LEAP), which requires the development of a structure that is representative of the case under study. This chapter begins with a discussion of the disaggregation of the state of Texas into regions that are significantly different in terms of their transportation demand and the applicable policy measures. Next, it presents a brief description of the LEAP model capabilities and characteristics. A structure and approach are then proposed for modeling the Texas Reference Scenario.

Categories of Texas Transport Demand

In order to coherently analyze prospective transportation policies for the state of Texas, a framework is needed that is conducive to representing the potential technologies and transportation control measures (TCMs) that are applicable under each condition. For example, areas within the state will vary according to their transportation characteristics and needs, so the model structure should reflect these differences and the different impacts suggested policies and strategies will have. Accordingly, the structure for the Texas energy model was devised to capture three issues:

1. The disaggregation of Texas into geographical regions that capture specific types of demand—these in turn call for specific measures for energy savings in transportation.
2. The flexibility to build the analysis scenarios based on the Reference Scenario.
3. The availability and accuracy of technical and cost information about alternative fuels, vehicle-miles traveled (VMT), ton-miles, and technologies within each category.

In order to obtain a model structure that reflects all three requirements listed above, the state of Texas transportation demand was disaggregated into nested categories and classifications, as shown in Figure 2.1. Column I of Figure 2.1 shows a primary differentiation between personal and freight transportation, since these two types of demand demonstrate unique characteristics and tend to require different approaches. Within personal and freight transportation, secondary and tertiary divisions were made, as shown in Columns II and III. These distinctions are discussed in the following sections.

Urban Demand. After personal and freight transportation, another crucial distinction which the chosen model represents is that between urban and intercity areas, as shown in Column II of Figure 2.1. Regarding urban areas, Texas metropolitan regions are growing at unprecedented rates. The three largest metropolitan areas–Dallas/Fort Worth, Houston, and San Antonio–contain nearly half the state's population and already experience congestion problems. Metropolitan transportation is primarily automobile-oriented, with vehicle occupancy rates close to one. Houston and Dallas/Fort Worth, being non-attainment areas, are in need of TCMs that provide travelers with an energy-efficient and environmentally friendly transport system. Houston has already implemented a High Occupancy Vehicle (HOV) program, with 47 miles of HOV lanes and an additional 4 miles planned. Dallas/Fort Worth, Houston, and El Paso are developing TCM programs to attain acceptable levels of pollutant emissions.

Greater urban concentrations such as those described above are potential candidates for TCMs and other energy-saving policies that attempt to reduce the demand, or VMT. Conversely, small urban areas are less attractive candidates for cost-effective demand-reducing policies. So, for both personal and freight transportation, the "Urban" category has been further divided into "Large Urban" and "Small Urban" subcategories (Column III). Large urban areas are defined as urban concentrations of 200,000 or more inhabitants. Small urban areas are those remaining communities with populations of less than 200,000. Because large urban areas require solutions specific to their needs, such a disaggregation allows for the explicit representation of policies and TCMs that target urban travelers in the more densely populated areas.

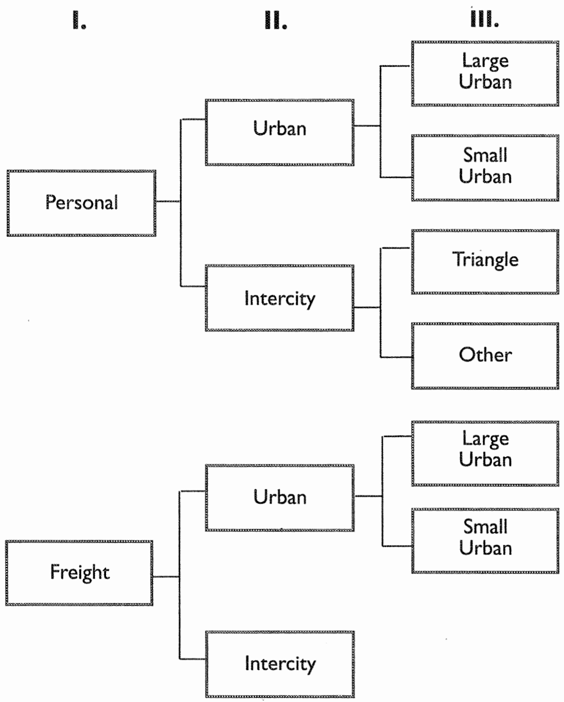


Figure 2.1 Major Categories of Texas Traffic Demand

Intercity Demand. Urban areas, as discussed above, are one group within the personal and freight transportation categories; intercity areas are the complementary group (as shown in Column II of Figure 2.1). Intercity areas are all those areas that are not already defined as "Urban," yet even these may be further delimited by intercity trips between the Texas triangle cities, and other intercity trips.

- ***Intercity-Texas Triangle***. The entire state of Texas covers an area of over 267,000 square miles, with a population of almost 18 million. Roughly 90 percent of this population is urban, with the greatest concentration within a corridor called the Texas Triangle. San Antonio, Houston and Dallas-Fort Worth are the triangle's vertices, and its sides pass through other cities such as Austin (the state capital) and Waco. Figure 2.2 depicts a map of Texas showing this triangle. The triangle bounds an area which is not itself "Urban" as defined in this study, but which bears characteristics notably different from the rest of intercity Texas. Accordingly, the Texas Triangle offers the possibility for

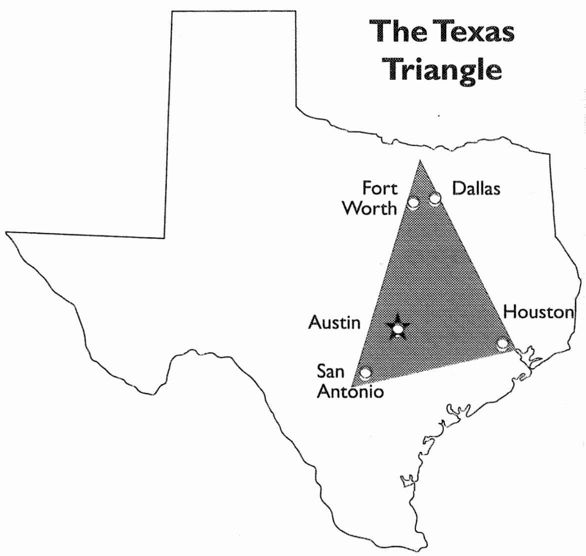


Figure 2.2 The Texas Triangle

distinct transportation solutions. For example, the average distances between cities linked by the Texas triangle suggests the potential feasibility of alternative modes, such as rail, to the Interstate and highway systems.

- ***Intercity-Other***. The intercity-other demand category serves roughly half the state population, in addition to trips that have origins and destinations outside Texas. Ideally, these trips should be further disaggregated into sub-categories that represent their typical origins and destinations. However, origin and destination data are not readily available and could not be obtained within the time frame and resources of this project. On the other hand, aggregated data are fairly reliable and available. Consequently, the intercity-other category represents all trips between cities that are not part of the Texas Triangle, as well as those trips which use Texas infrastructure but have origins and/or destinations outside the state. Figure 2.3 depicts the seven aggregated demand types included in the Texas energy model.

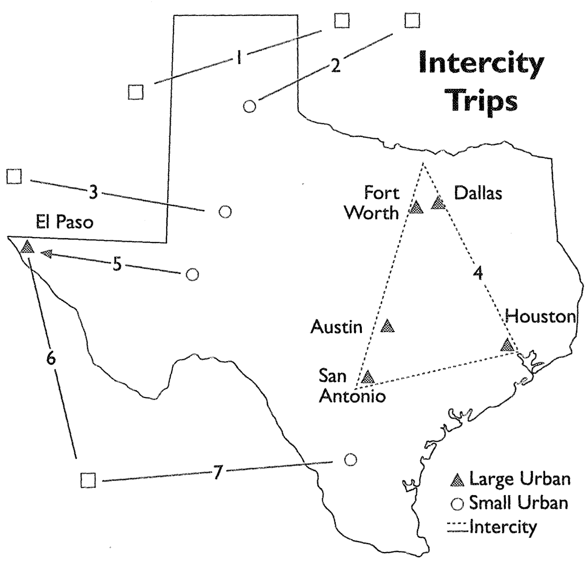


Figure 2.3 Intercity Trips

Of the seven aggregated demand types within the intercity trip groups, Type 1 includes all trips with origins and destinations outside Texas (domestic or foreign), but passing through Texas. Type 2 includes all trips with Texas origins and domestic destinations outside Texas. Type 3 comprises all trips with domestic origins outside Texas and destinations in Texas. Type 4 includes all trips between cities of the Texas Triangle, and Type 5 all other intercity trips with Texas origins and destinations. Type 6 includes trips with a Texas origin and a foreign destination, while Type 7 includes trips with a foreign origin and a Texas destination.

For intercity trips, personal and freight transportation are approached differently, as shown in Column III of Figure 2.1. That is, for freight intercity trips, Types 1 through 7 are aggregated. For personal trips, on the other hand, Type 4 (Triangle) trips are modeled separately in a personal-intercity-triangle category, while Types 1 through 3 and 5 through 7 are aggregated into the personal-intercity-other category.

The Texas transportation demand categories discussed above were used to structure a LEAP model tree that represents the Reference (baseline) Scenario and at the same time allows flexibility for the development of hypothetical analysis scenarios for energy savings and pollutant emission reduction in the transportation sector.

LEAP/EDB Analysis System

LEAP/Environmental Data Base (EDB)–referred to as LEAP throughout this report–is a computer model and data base system designed to provide information on the structure of an energy system and its costs and emissions characteristics, as well as to explore alternative energy futures with their predicted costs and principal environmental impacts. As a "bottom-up" model, its principal elements are the economic, energy, technology and emissions characteristics of end-use sectors and supply sources. It is designed to create scenarios to guide policy development.

Long-Range Energy Alternatives Planning (LEAP)

The LEAP model has two important characteristics. First, it allows flexible and detailed specification for key physical parameters in each end-use sector. This enables the embodiment in each scenario of the impacts of a variety of factors affecting energy use, including energy prices, technological change, demographic variables, and structural shifts in the economy. In addition, the accounting framework in LEAP enables it to take into account the end-use energy and emissions. For example, a reduction in petroleum use in the transportation sector automatically leads to reductions in distribution losses and energy use for petroleum refining, and LEAP takes these savings into account. LEAP can also track both the energy requirements for, and pollution resulting from, the extraction, processing, and distribution of fuels that provide the energy for each end-use.

LEAP is a user-friendly, computer-based tool for integrated energy-environment planning. It was first developed in 1981 and has been used in many applications since. With the support of numerous international agencies, LEAP has been continuously enhanced and updated to meet the needs of researchers and government agencies in both industrialized and developing countries.

Environmental Data Base (EDB)

In 1988, with support from the United Nations Environment Program (UNEP), the Stockholm Environment Institute—Boston (SEI-B) created the LEAP/EDB at Tellus. EDB was designed to enable easy access to energy-related environmental loading data and to encourage the formulation of environmentally-informed energy policy. Today, SEI-B and the UNEP Collaborating Center on Energy and the Environment (UCC) are jointly engaged in the further development of LEAP and EDB to cover a broader range of fuel-cycle issues. Notably, EDB was used to mount the landmark study "America's Energy Choices," which developed 40-year policy scenarios across all sectors and fuels, focusing on efficiency, renewables, and emissions reductions.

Computing Approach

For a transportation policy study, LEAP requires the development of a structure reflecting the various levels of accounting performed by the model. The computing approach used in this study is depicted in Figure 2.4 and consists of three primary inputs—transport demand category (personal or freight by geographic region, as shown in Figure 2.1), transport mode, and transport technology.

Following Figure 2.4, for each "Demand Category" LEAP uses internal algorithms to calculate the energy consumption and pollutant emissions associated with each technology ("Transport Technology and/or Fuel Type") for each "Transport Mode," The results ("LEAP Outputs") estimate the pollutant emissions and energy consumption due to current and future patterns of transportation demand,

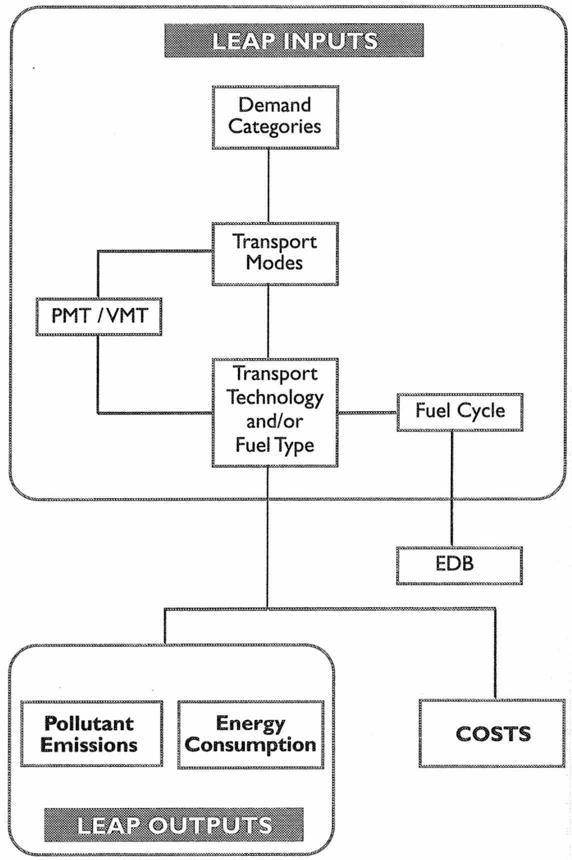


Figure 2.4 LEAP Computing Approach

based on the assumption that the current status will be maintained and no significant TCM measures or alternative technologies will be implemented. Clearly, with the appropriate changes in the inputs, this same modeling structure can be utilized to analyze alternative scenarios reflecting policies and technologies directed at changing the status quo trends in energy consumption. (Cost estimates are external to the LEAP model.)

Model Structure for Texas

As discussed previously, within the demand module of LEAP, personal transportation is separated into intercity and urban, which are further categorized into four sub-categories–triangle intercity, other intercity, large urban and small urban. Freight transport is analyzed in two categories: intercity and urban, which capture the two main types of freight demand in terms of applicability of TCM techniques and alternative technologies.

Figure 2.5 illustrates the "demand tree" developed to analyze Texas' transportation sector with the LEAP model. The first column, the Sector level (Level 1), reflects the demand characteristics: freight or personal, by geographic region. Within each of these categories, specific modes of transportation that make up Passenger Miles of Travel (PMT) are identified at the Subsector level (Level 2). Finally, at the End-Use level (Level 3), each mode is disaggregated further by the various fuels consumed by that mode. For example, automobiles include gasoline, diesel, CNG, and electricity as fuels. Disaggregation by vehicle efficiency was also made to reflect changes in average efficiencies over time in both the Reference Scenario and the four analysis scenarios. The same model structure applies to each of the scenarios. So that if a fuel is not used in the Reference Scenario, but is used in one of the other four scenarios, the consumption value for that fuel is merely recorded as zero for the Reference Scenario.

The Sector level of LEAP (example: Large Urban) contains the total PMT within that region and for that particular category. At the Subsector level (i.e. Transit-Work) the fraction of the PMT that is used by transit vehicles for trips relating to work is entered. At the End-Use level (i.e., Automobiles-Other) the VMT/PMT ratio is entered. At the device level (i.e., Gasoline) the share of that particular fuel for the particular technology is entered (i.e., 90 percent gasoline, 4 percent diesel, 1 percent CNG, etc.). At a subsequent level, the efficiency of the particular technology is included. Note that because Figure 2.5 is illustrative it does not include a complete fuel list or consumption rate for each mode; the actual analysis does include all available fuel options and consumption rates, which are documented with the scenario results in Chapter 4. All of these values are entered for both base and future years, the latter based on demand projections. Finally, each technology is linked to EDB through the LEAP fuel cycle to estimate pollutant emissions associated with each level of energy consumption.

Regarding the distinction between freight and personal transportation, the freight analysis does contain a slight variation as far as the demand categories by region are concerned, but the basic structure of transport modes and of fuel use within a mode is similar to the personal travel analysis. The categories that are considered for freight are intercity, large urban, and small urban, as discussed previously.

Summary

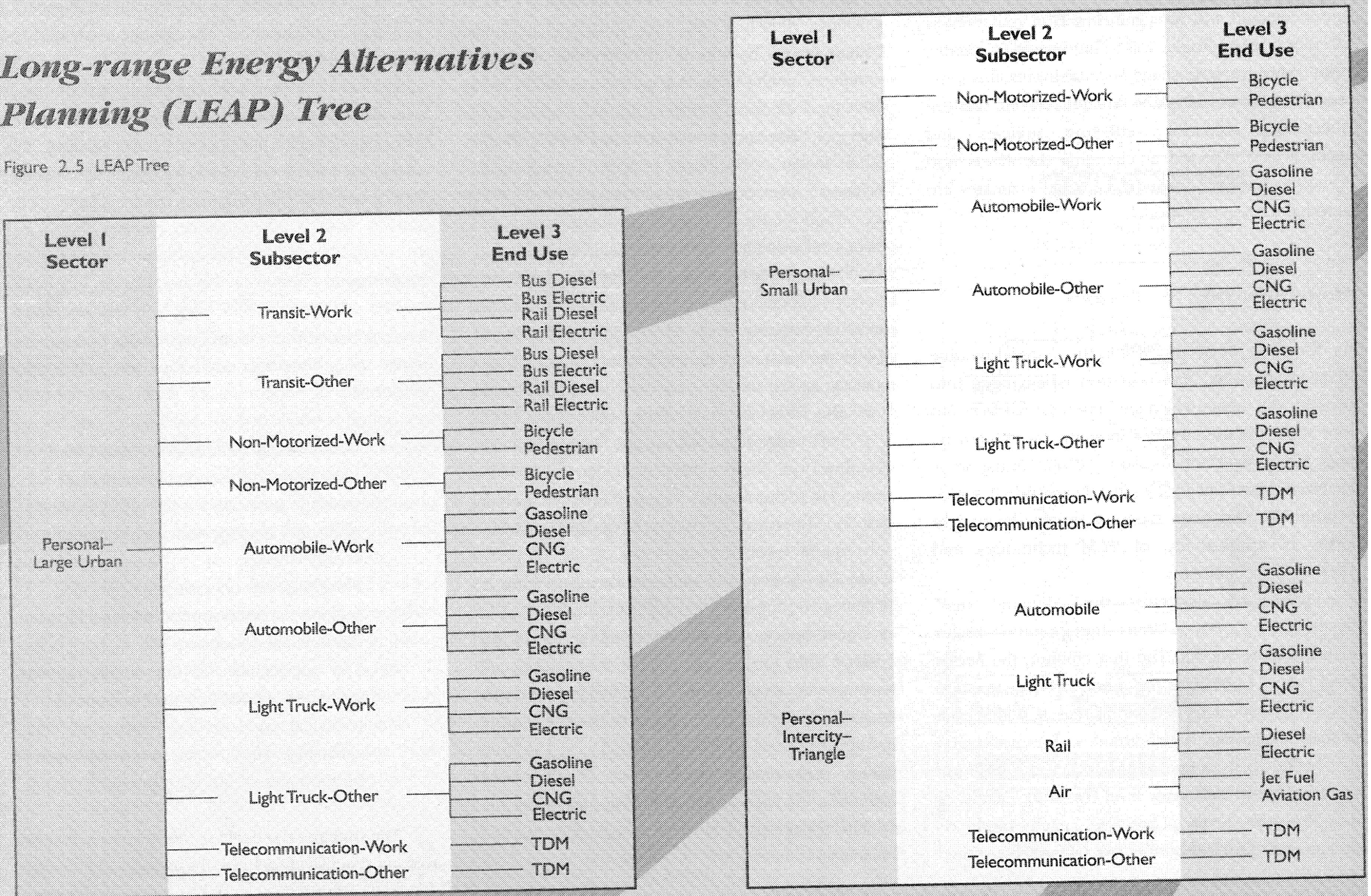
As described above, the structure of the Texas energy model using LEAP was devised to account for three concerns:

1. Certain geographic regions in the state have distinct demand characteristics, which in turn calls for the incorporation of distinct strategies for transportation energy savings.
2. Flexibility was necessary in order to build the analysis scenarios based on the Reference Scenario.
3. The applicability of the model relies upon the availability and accuracy of technical and cost information about alternative fuels, VMT, ton-miles, and technologies within each category.

The structure discussed in this document is suited to comprehensively achieve these goals. The first two

Long-range Energy Alternatives Planning (LEAP) Tree

Figure 2.5 LEAP Tree



Level 1 Sector	Level 2 Subsector	Level 3 End Use
Personal–Intercity-Other	Automobile	Gasoline
		Diesel
		CNG
		Electric
	Light Truck	Gasoline
		Diesel
		CNG
		Electric
	Telecommunication-Work	TDM
	Telecommunication-Other	TDM
Freight–Large Urban	Light Truck	Gasoline
		Diesel
		Alcohol
		Natural Gas
	Medium Truck	Gasoline
		Diesel
		Alcohol
		Natural Gas
	Heavy Truck	Gasoline
		Diesel
		Alcohol
		Natural Gas
	Automobile	Gasoline
		Diesel
		CNG
		Electric
	Pipeline	Natural Gas
	Telecommunication	TDM

Level 1 Sector	Level 2 Subsector	Level 3 End Use
Freight–Small Urban	Light Truck	Gasoline
		Diesel
		Alcohol
		Natural Gas
	Medium Truck	Gasoline
		Diesel
		Alcohol
		Natural Gas
	Heavy Truck	Gasoline
		Diesel
		Alcohol
		Natural Gas
	Automobile	Gasoline
		Diesel
		CNG
		Electric
		Natural Gas
Freight–Intercity	Light Truck	Gasoline
		Diesel
		Natural Gas
	Medium Truck	Diesel
		Alcohol
		Natural Gas
	Heavy Truck	Gasoline
		Diesel
		Alcohol
		Natural Gas
	Rail	Diesel
		Electric
	Water	Distillate
	Air	Jet Fuel
		Aviation Gas
	Pipeline	Electric
		Natural Gas

concerns have been adequately met by this model; the third merits a brief review. Disaggregate data is usually presumed to be more accurate with regard to transportation research, and so every effort was made to disaggregate the data as shown in the proposed Texas model structure. However, data disaggregation at these levels is not always available in the literature or from state and federal agencies. This level of disaggregation requires additional and extensive analysis beyond the limits of this study. Chapter 3, the "Reference Scenario," discusses in more detail the data used for the Reference Scenario and the baseline model results.

THREE: THE REFERENCE SCENARIO

INTRODUCTION

Energy savings in the Texas transportation sector was modeled based on a Reference Scenario which captures the current status of the overall state transportation network and fleet, including specific features of interest which reflect different traffic demand characteristics and potential measures to reduce energy consumption. Technically, the Reference Scenario is a baseline model for further case studies, but it can also be interpreted as a "status quo" scenario that serves as a basis for analyzing the impact of potential measures to decrease energy use in the transportation sector.

This chapter is organized into two major sections. The first defines the Reference Scenario in terms of the data used for each level of traffic demand, mode, and fuel type represented in the model structure. Next, the results of the Reference Scenario are presented and discussed in terms of potential energy savings in the Texas transportation sector. The previous chapter discussed the structure of the LEAP model used for this analysis, whose inputs and outputs are discussed in this document. All results from the analysis are detailed in the Appendices.

Reference Scenario Data

As discussed in Chapter 2, different freight and personal transport modes were analyzed for each geographic region represented in the model. Personal and freight demand are represented in LEAP in terms of passenger miles of travel (PMT) or ton-miles traveled, which are a function of the number of vehicles and the distances traveled. Transportation demand is more readily found in terms of vehicle-miles traveled (VMT), which can be converted into PMT or ton-miles traveled utilizing data respectively on vehicle occupancy rates and vehicle weights in each level of each demand category. However, VMT information is not always available in the level of disaggregation required by this study. Accordingly, estimates of the percentages of VMT and PMT in each mode were calculated using information from a number of different data sources: the Texas Department of Transportation (TxDOT), the Texas State Comptroller's Office, and the U.S. Department of Energy (DOE) Energy Information Administration's (EIA) National Energy Modeling System (NEMS), previous Center for Transportation Research (CTR) projects, other consultant reports, airline data, and the Texas Oil and Gas Association.

Current Transportation Use Data

Standard reports of VMT data are disaggregated by type of transportation facility, such as highways, airports, etc., and VMT data are more readily available by mode. However, for the purpose of this study, VMT must be disaggregated into the geographic categories discussed in Chapter 2. Next, VMT must reflect the modal split into modes such as automobile, public transit, airplane, and others. Finally, the fuel types utilized by each mode must be simulated in the model.

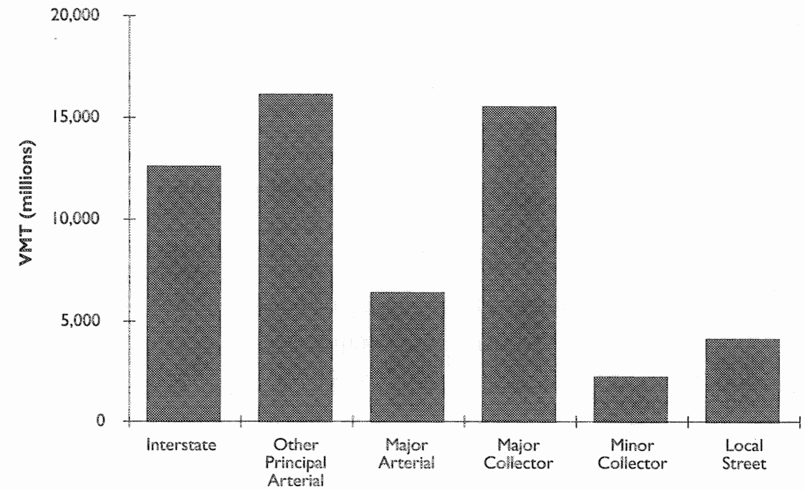
For each geographic category, data disaggregation into personal and freight by each mode was made based on locations of traffic counting sites used by TxDOT to estimate its VMT, complemented by literature on Texas metropolitan area transportation plans and recent transportation planning studies. VMT was converted to PMT using average vehicle occupancy rates also found in the literature. Projections of VMT, PMT and truck freight ton-miles into the near future are based on TxDOT's demand projections.

Given the difference between the levels of disaggregation of reported data and the levels of disaggregation required by our model structure (discussed in Chapter 2), some assumptions were necessary to disaggregate the statewide VMT. These assumptions relate either to road classes or to trip purpose (personal or commercial).

VMT Data. The approach to obtain vehicular (auto and truck) VMT by different vehicle classes was twofold. First, the statewide annual VMT on 12 different functional roads was estimated based on total annual VMT (Ref. 3). This information was coupled with the VMT distributions by different vehicle classes on different functional roads recorded by TxDOT, to obtain the statewide travel demand by different vehicle classes. For the first step, then, the functional road classes considered in the analysis were:

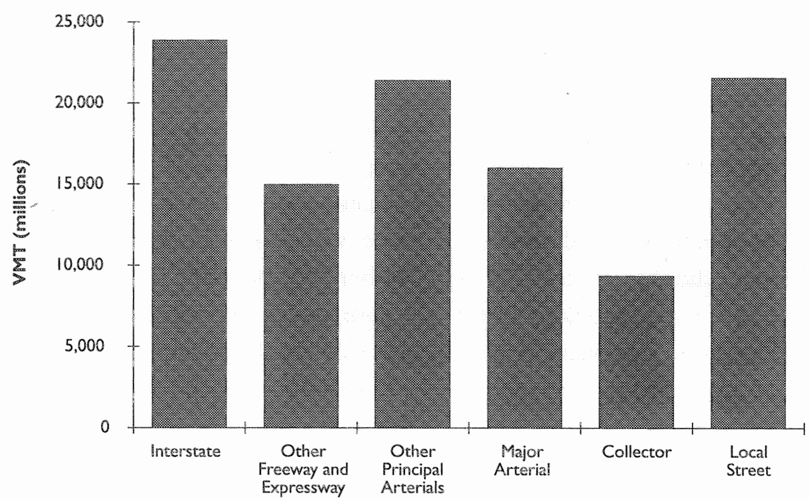
- Interstates in rural areas
- Other principal arterials in rural areas
- Major arterials in rural areas
- Major collectors in rural areas
- Minor collectors in rural areas
- Local streets in rural areas
- Interstates in urban areas
- Other freeways and expressways in urban areas
- Other principal arterials in urban areas
- Major arterials in urban areas
- Collectors in urban areas
- Local streets in urban areas

The estimated VMT on the six different rural functional roads, as well as on the six urban



Source: Texas Department of Transportation

Figure 3.1 Statewide Rural VMT by Functional System in 1992



Source: Texas Department of Transportation

Figure 3.2 Statewide Urban VMT by Functional System in 1992

Statewide Rural VMT by Functional System in 1992—Rural & Urban

The original 2-axle 4-tire truck VMT data (available from TxDOT) does not specify differences between commercial and personal trip purposes. In order to disaggregate this data into personal and commercial use, the historical data found in the "Truck Inventory and Use Survey" (TIUS) was used. TIUS reports that about 69.5 percent of the VMT by 2-axle 4-tire single-unit trucks is for personal use and the remaining use is for commercial purposes (Ref. 5). The truck VMT data for urban areas is depicted in Table 3.1. In the personal travel category, the VMT by passenger cars is about 5 times that of 2-axle 4-tire single-unit light trucks.

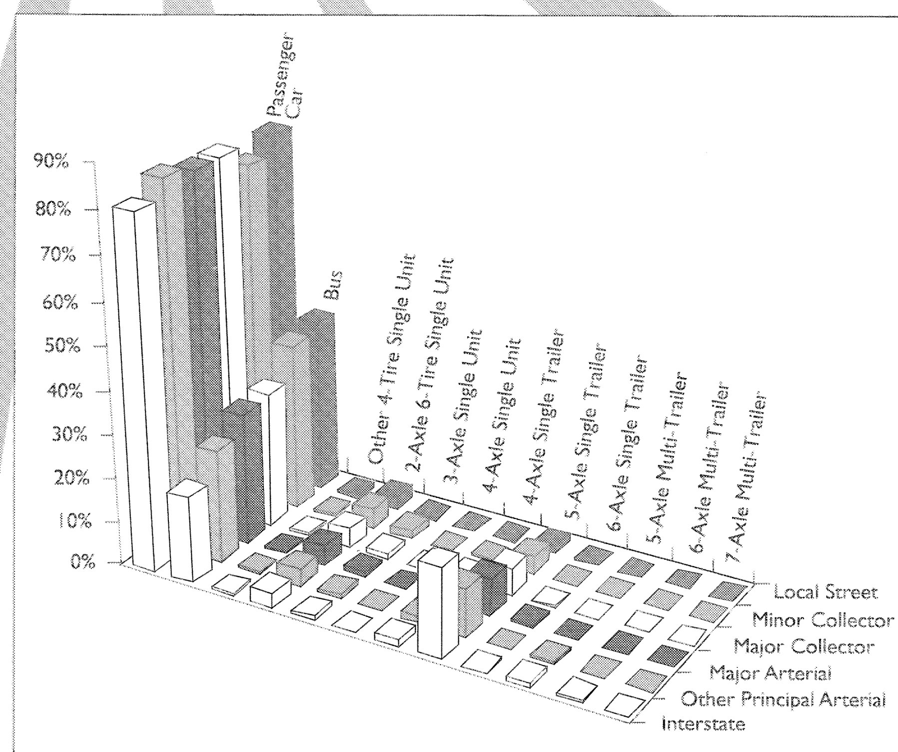


Figure 3.3 Travel Demand by Vehicle Class in Rural Areas

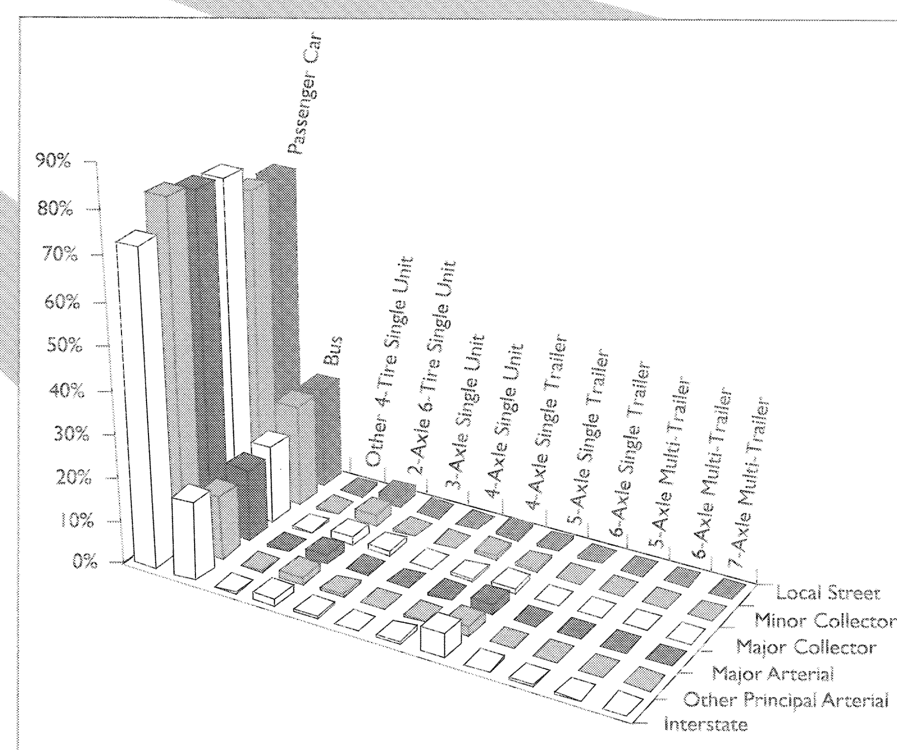


Figure 3.4 Travel Demand by Vehicle Class in Urban Areas

functional roads in Texas, is illustrated in Figures 3.1 and 3.2, respectively.

Then, for the second step to obtain auto and truck VMT, the different classes of vehicles traveling in the state were identified using information compiled by TxDOT. These classes are:

- Passenger car
- Other 4-tire single-unit vehicle
- Bus
- 2-axle 6-tire single-unit vehicle
- 3-axle single-unit vehicle
- 4-axle single trailer
- 5-axle single trailer
- 6-axle single trailer
- 5-axle multi-trailer
- 6-axle multi-trailer

The travel demand information by vehicle types on different functional road systems is depicted in Figures 3.3 and 3.4. In the original data recorded by TxDOT, the percentage of travel activities by the 10 vehicle types on urban local streets were not available. It was, therefore, assumed that the travel activities on an urban local street have the same distribution as those on an urban collector. Figures 3.3 and 3.4 indicate that passenger cars and other 4-tire single-unit vehicles dominate the travel activities in both urban and rural areas, trucks comprise only about 5 percent of total VMT, and the 5-axle single trailer, commonly known as the 18-wheeler, has the largest share of the total truck VMT.

Following our proposed model structure, it is necessary to further divide the urban area VMT data into VMT for large urban areas (population size greater than 200,000) and urban VMT for the remaining urban areas. In 1992, there were eight urban areas in Texas with population greater than 200,000 (Ref. 3): Dallas/Fort Worth, Houston, San Antonio, Longview, El Paso, Austin, Corpus Christi, and McAllen-Pharr-Edinburg. The average daily VMT in these cities (Ref. 3) was used to calculate the annual VMT for the large urban areas.

The model structure also requires intercity demand in the Texas Triangle area be input separately. This necessitated specific analysis of intercity personal travel activities. There are six major urban concentrations in the triangle area—Houston, Dallas/Fort Worth, San Antonio, Austin, Waco, and Bryan/College Station. Intercity auto personal trip

Travel Purpose	Vehicle Type	Urban		Intercity	
		Large Urban	Small Urban	Triangle Area	Other Intercity
Personal	Passenger Car	57,161	22,829	2,012	34,758
	2-Axle 4-Tire Light Truck	9,955	4,015	402	8,316
	Bus	174	76	0	183
Freight	2-Axle 4-Tire Light Truck	4,369	1,762	-	3,826
	2-Axle 6-Tire Light Truck	1,531	622	-	1,724
	3- or more Axle Single Unit Truck	383	155	-	466
	4- or less Axle Single-Trailer	433	170	-	512
	5-Axle Single-Trailer	1,781	544	-	4,697
	6- or more Axle Single-Trailer	52	16	-	76
	5-Axle Multi-Trailer	85	24	-	171
	6-Axle Multi-Trailer	20	4	-	25
Total		75,944	30,217	2,414	54,754

Source: Texas Department of Transportation

Table 3.1 Statewide VMT in 1992 (millions)

data in the triangle area is taken from a previous high speed rail (HSR) feasibility study for the triangle area (Ref. 6). Given the average distance between pairs of triangle cities, the VMT by passenger cars and 2-axle single-unit trucks is shown in Table 3.1. Unfortunately, the commercial intercity VMT in the triangle area is not recorded by any agency and could not be included in the analysis.

Motor Vehicle PMT Data. Having analyzed data compiled from the U.S. Department of Transportation's (DOT) 1990 Nationwide Personal Transportation Survey (Ref. 7), the Oak Ridge National Laboratory (ORNL) reported that 32.1 percent of VMT traveled each year are for working trips, while the remaining trips are devoted to other purposes (Ref. 8). In addition, ORNL noted that the average vehicle occupancy was 1.16 for working trips, and 1.87 for other-purpose urban trips. For the present study, this information was coupled with the vehicle occupancy for intercity trips (Ref. 6) to convert the personal VMT by auto and light trucks into the corresponding PMT. From Section 15 transit data (Ref. 9), the average bus occupancy in Texas is about 7.64 passengers per bus. The figures for statewide PMT in 1992 are shown in Table 3.1.

Airborne PMT Data. Historical data on annual origin-destination air travel volumes between Texas Triangle cities or "local" air demand (Ref. 6), was utilized in order to estimate the personal PMT carried by airlines in the triangle area (shown in Table

Category	Travel Mode	Avg. Vehicle	VMT in 1992	PMT in 1992
Large Urban	Auto-Work	1.161	18,349	21,303
	Auto-Other	1.869	38,812	72,540
	Light Truck-Work	1.161	3,196	3,711
	Light Truck-Other	1.869	6,759	12,633
	Transit-Work	7.640	56	428
	Transit-Other	7.640	118	902
	Non-Motorized-Work	0.000	0	0
	Non-Motorized-Other	0.000	0	0
Small Urban	Auto-Work	1.161	7,328	8,508
	Auto-Other	1.869	15,501	28,971
	Light Truck-Work	1.161	1,289	1,497
	Light Truck-Other	1.869	2,726	5,095
	Transit-Work	7.640	24	183
	Transit-Other	7.640	52	397
	Non-Motorized-Work	0.000	0	0
	Non-Motorized-Other	0.000	0	0
Intercity Triangle	Auto	1.700	2,012	3,420
	Light Truck	1.700	402	683
	Rail	-	-	-
	Air	90	16	1,440
Other Intercity	Auto	1.700	34,758	59,089
	Light Truck	1.700	8,316	14,137
	Transit	7.640	183	1,398
	Rail			44.8
	Air	90	713	64,170

Table 3.2 Personal VMT and PMT by Trip Purpose (millions)

TIUS	TxDOT	FEDERAL		LEAP Model
		Single	Combination	
< 6,000	≤6,000	< 26,000	<50,000	< 10,000
6,001-10,000	6,001-8,000			
10,001-14,000	8,001-10,000			10,001-19,500
14,001-16,000	10,001-17,000			
16,001-19,500	17,001-24,000			
19,501-26,000	24,001-31,000			> 19,500
26,001-33,000	> 31,000	> 26,000		
33,001-40,000				
40,001-50,000				
50,001-60,000			50,000-70,000	
60,001-80,000			70,000-75,000	
80,001-100,000				
100,001-130,000			> 75,000	
> 130,000				

Table 3.3 Truck Classification Criteria (lbs.)

	Light	Medium	Heavy
2-Axle 4-Tire (or 6-Tire) Single-Unit Truck	4.75 %	46.39 %	48.86 %
3-Axle Single-Unit Truck	0.16 %	11.95 %	87.89 %
All Single- or Multi-Trailers	0.00 %	0.00 %	100.00 %
Source: TTI, Texas A&M: WIM Data (Ref. 11).			

Table 3.4 Distribution of Light, Medium and Heavy Trucks

3.2). For intercity air travel outside of the triangle, PMT and VMT data are based upon an estimate made by the Texas Transportation Institute (TTI) (Ref. 10).

Rail PMT Data. Personal rail travel data is available only at the statewide level, and as such it is impossible to disaggregate to the triangle area. However, qualitative discussions from sources such as the *Independent Ridership and Passenger Revenue Projections for the Texas TGV Corporation High Speed Rail System in Texas* (Ref. 6) indicate that current levels of passenger travel by rail are very small compared to other modes. Since rail energy consumption is also very small with respect to other modes, the impact of personal rail trips in the triangle area is negligible in terms of overall transportation energy consumption, and the lack of data in this area will not undermine the Reference Scenario results.

Truck Freight Data. In Table 3.1, the VMT for commercial travel purposes is separated into the 8 different vehicle classes used by TxDOT. The proposed LEAP model, however, takes into account three truck categories only, according to the groupings provided in NEMS:

- Light-truck with gross weight less than 10,000 lbs.
- Medium-truck with gross weight between 10,000 lbs and 19,500 lbs.
- Heavy-truck with gross weight exceeding 19,500 lbs

Because NEMS was the main source for fuel consumption and other energy-related input data, it was necessary to utilize this method of truck classification in our analysis.

It is important to note the importance of developing and/or choosing truck classification criteria according to the study purposes. For example, TIUS classifies trucks into 14 categories because their objective is to provide data on the physical and operational characteristics of the truck population nationwide (Ref. 5). Industry, business, academia, and the general public utilize that dataset for planning road improvements, examining truck size and weight issues, evaluating user fees, determining truck involvement with intermodal use, and identifying other market issues. TxDOT uses different classifications for the purpose of registering commercial motor vehicles and truck-tractors. A federal highway cost allocation study uses even a third classification system (Ref. 16). Policies and energy consumption issues refer to the three categories used in this study. Table 3.3 presents a comparison among the TxDOT, federal, and LEAP/NEMS classifications with respect to the TIUS criteria.

The weight-in-motion (WIM) data in Texas indicate that all combination trucks, including both single-trailers and multi-trailers, belong to the heavy truck category. Only some of the two-axle single-unit trucks and three-axle single-unit trucks fall in the light- or medium-truck categories. The frequency of these trucks at WIM stations in Texas are reported in Table 3.4.

Truck Class	Weight Group	Gross Weight	Empty Weight	Cargo Weight
2-Axle Single Unit	Light	9,205	7,291	1,914
	Medium	13,896	11,007	2,889
	Heavy	22,084	17,490	4,594
3-Axle Single Unit	Light	9,097	7,873	1,224
	Medium	15,171	13,129	2,042
	Heavy	32,103	26,337	5,766
4-Axle Single Trailer	Heavy	34,021	30,000	4,021
5-Axle Single Trailer	Heavy	66,109	35,000	31,109
6-Axle Single Trailer	Heavy	59,126	38,000	21,126
5-Axle Multi-Trailer	Heavy	53,658	35,000	18,658
6-Axle Multi-Trailer	Heavy	56,799	38,000	18,799
Source: TTI, Texas A&M: WIM Data: (Ref. 11).				

Table 3.5 Average Vehicle Weights (lbs.)

One important element in calculating the freight hauled in Texas is the cargo weight carried by each truck. Vehicle class and gross vehicle weight limits have been combined with WIM data and information on standard empty truck weights to produce the gross weight by each vehicle class depicted in Table 3.5. It is important to note that the average gross weight of the vehicles includes some empty trucks, thus representing the average weight for all miles traveled in Texas. Using the estimated average cargo weight on trucks in Table 3.5 and traffic data in Table 3.1, it is possible to estimate annual freight-tonnage moved by trucks in the state. The results are reported in Table 3.6.

Rail Freight Data. Currently, there are 6 Class 1 railroads and 39 Class 2 and Class 3 railroads operating in Texas. Class 1 railroads are those with annual revenues exceeding $50 million, while Class 2 and 3 railroads have annual revenues less than $50 million and are characteristically regional railroads, short lines, or providers of terminal and switching services. From the available data, 80,512 million ton-miles of freight were hauled by all railroads in Texas in 1992. Out of these, 99.3 percent were accomplished by the six Class 1 railroads.

Waterway Freight Data. The waterborne freight transport data collected for Texas is for travel along the Gulf Intracoastal Waterway (GIWW) from the Sabine River to the Texas/Mexico border. Travel within the Galveston district and Texas inland waterways is also included. Data for waterborne freight transport is taken from TTI (Ref. 10) and from the U.S. Department of the Army (Ref. 17).

Category	Travel Mode	VMT in 1992	Ton-Mileage in 1992
Large Urban	Light Truck	281	243
	Medium Truck	2,783	3,628
	Heavy Truck	5,591	34,192
	Automobile	0	0
Small Urban	Light Truck	113	98
	Medium Truck	1,125	1,466
	Heavy Truck	2,060	11,159
	Automobile	0	0
Intercity	Light Truck	264	229
	Medium Truck	2,630	3,425
	Heavy Truck	8,604	76,057
	Rail	-	80,512
	Air	-	257
	Waterway	-	16,566
	Petroleum	-	77,100
	Natural Gas*	-	949,869
*The unit of natural gas is in billion cubic foot-miles.			

Table 3.6 Freight VMT and Ton-Mileage (millions*)

Pipeline Data. This study includes mainly petroleum and natural gas hauled through pipelines in Texas. Data for other commodities is either unavailable or aggregated with pipelines not covered by this study, such as urban pipelines transporting household utility gas. TTI reported 77,100 million ton-miles of petroleum transported in the state (Ref. 10). Natural Gas pipeline shipment data could not be obtained except for a rough estimate for the interstate (within Texas borders) transport of natural gas. Therefore, we have utilized the EIA natural gas pipeline fuel state consumption estimate (Ref. 1).

Intra- or Inter-State Categories

The model structure selected for this study, utilized in the Reference Scenario and in the analysis scenarios, includes the inter- and intra-state trip categories for each mode. It is important to clarify the definition of intra-state and inter-state as it is used in the model context. The data input in LEAP is in terms of VMT, PMT, and freight ton-mileage, for each transport mode. As such, the data has a distance component and a weight or vehicle component, and either component can be intra-state or inter-state. However, while the details of the distance component may be ascertained from the data sources, the person and weight components can be regarded as another name for passenger origin and destination data or commodity. Collection of origin and destination data is beyond the scope of this study, and such data is seldom reported in the literature, especially to the level of disaggregation required for this study. Commodity data are usually regarded as confidential by the freight companies, given the potential for use of the data by competitors. Nevertheless, the weight or person component can be safely assumed to include intra-state and inter-state movements unless the data specifies otherwise.

Figure 3.5 shows the trip origin-destination combinations of interest to this study. Trip Type 1 consists of both the origin and destination inside

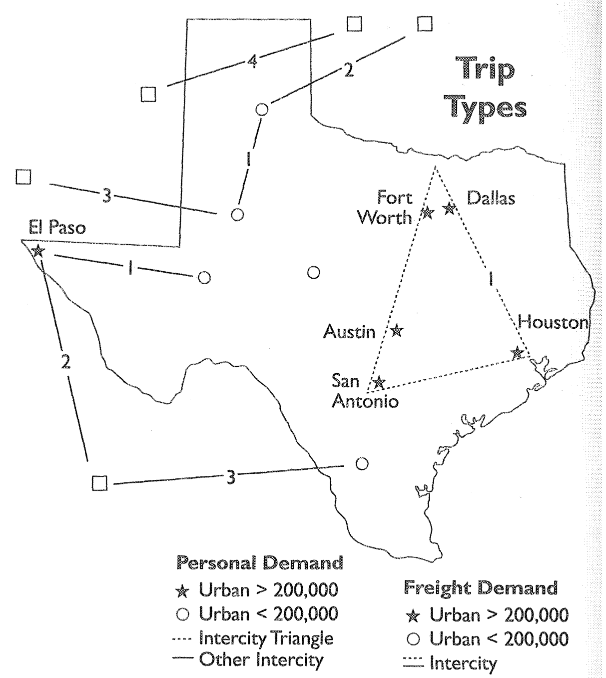


Table 3.5 Trip Types

Texas boundaries. Type 1 trips have both weight or person and distance components within the state. Trip Types 2 and 3 have either an origin or a destination inside Texas boundaries. Trip Type 4 pertains to "through" trips that neither originate from nor are destined to locations inside Texas.

Table 3.7 summarizes the trip types that are included in the data collected for each mode. Again, the data includes these trip types bu,t due to lack of specific information, is not disaggregated by these categories.

1994 Transportation Base

Utilizing the 1992 collected data and TxDOT's VMT projections, VMT has been estimated for the 1994 base study period. Figures 3.6 through 3.9 summarize the transportation demand data collected for the model. Figure 3.6 shows the current PMT by geographic designation. It can be seen that VMT for intercity trips in the Texas triangle are only about 2 percent of the statewide total PMT, while almost 40 percent of all PMT occurs within Texas large cities (those with 200,000 or more inhabitants). This is an interesting finding in terms of potential energy savings, since TCMs are generally cost-effective only when applied in large cities.

Figure 3.7 shows the same PMT data geographically aggregated for the entire state, but disaggregated by mode. Auto trips comprise 68 percent of the statewide VMT, while the more energy efficient modes such as transit and rail represent a small percentage. Air travel accounts for 18 percent of the statewide PMT. Since fuel is an important component in the cost of an air trip, these findings illustrate the potential for energy savings in a mode switch from auto and air to transit and rail.

Figure 3.8 depicts the freight ton-mileage by geographic designation. Over 80 percent of total statewide ton-mileage is in the intercity category, while the ton-mileage observed in the largest cities of Texas is more than three times that of all other cities combined. This is not surprising, since Texas population has become increasingly urban: the 1990 U.S. Census indicates that about 70 percent of Texans

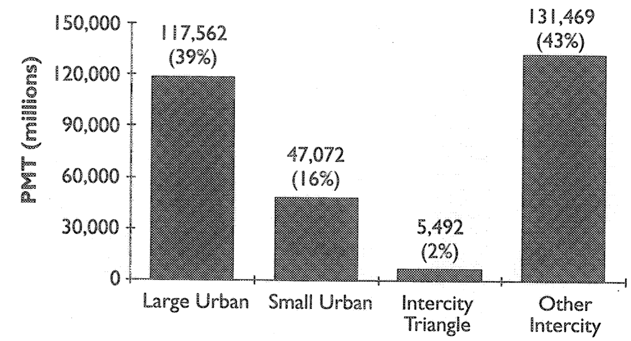


Figure 3.6 Current PMT by Geographic Designation

Category	Mode	Weight or Person Included				Distance Includes
		Type 1	Type 2	Type 3	Type 4	
Passenger	Roadway	Y	Y	Y	Y	TX Only
	Rail	Y	Y	Y	Y	TX Only
	Air	Y	Y	Y	Y	TX Only*
Freight	Roadway	Y	Y	Y	Y	TX Only
	Rail	Y	Y	Y	-	TX Only
	Air	Y	Y	Y	Y	TX Only*
	Waterway	Y	Y	Y	Y	TX Only
	Pipeline	N	Y	Y	N	TX Only

Y — Yes; N — No.
*averaged overall possible in-Texas portions.

Table 3.7 Reference Case Data by Trip Type

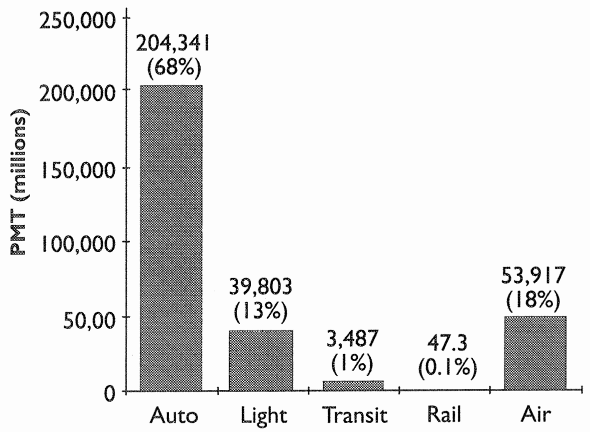


Figure 3.7 Current PMT by Mode

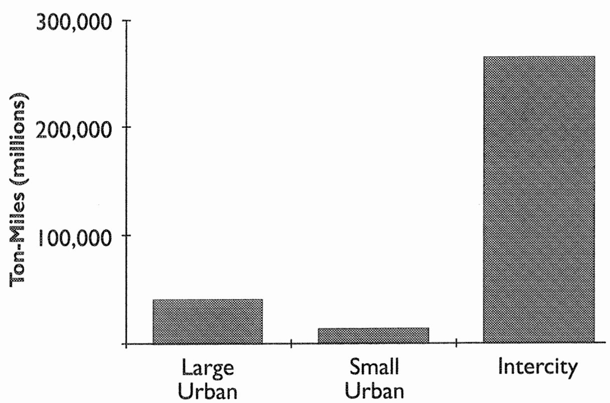


Figure 3.8 Current Freight Ton-Miles by Geographic Designation

now live in a city with 200,000 or more inhabitants.

Figure 3.9 presents the statewide freight ton-mileage disaggregated by transport mode. Heavy and medium trucks together are responsible for 43 percent of the freight ton-mileage in Texas, while rail's contribution is 26 percent. Pipelines contribute almost the same as rail, and the other modes show a fairly insignificant amount. This information would indicate that there is energy savings potential in Texas by encouraging mode shift from trucks to rail and/or water.

Equipment Mix, Fuel Mix and Energy Intensity

This section lays out the assumptions that are embodied in the LEAP Reference Case in terms of fuel shares and energy intensities. Energy intensity represents energy use per VMT (e.g., BTU/mile or gallons/mile), essentially the inverse of fuel efficiency (e.g., miles/gallon). The fuel share values are the fraction of each mode's energy consumption for a given fuel type.

The fuels included in the analysis are gasoline, diesel, compressed natural gas (CNG), liquefied petroleum gas (LPG), ethanol, methanol, biofuels, electricity, residual oil, jet fuel, and aviation gas. Most of these fuels are used in the personal transportation sector; residual oil is only used in water-borne transportation. All of these fuels are included in the model structure, but some of the more technologically-advanced alternative fuels do not gain significant fuel shares until included in the alternative scenarios.

Personal Transportation. Recall that the structure of the LEAP model is such that personal transportation is divided into four sectors: Large Urban, Small Urban, Intercity-Triangle, and Intercity-Other. The main sources for assumptions regarding fuel shares and energy intensity for personal transportation are ORNL (Ref. 12), NEMS model inputs, and a vehicle stock model developed by Tellus. (See Appendix 1 for a discussion of the Stock fleet turnover model.) From these sources, inputs were developed for fuel shares by mode and fuel type, and for energy intensity by mode and fuel type.

The EIA NEMS data was forecast to 2010, and then the values were extrapolated to coincide with our planning horizon of 2020. This was done by applying the annual growth rate from 2005-2010 to all years after 2010. The rate for 2005-2010 was consistently lower than the rate for 2000-2010 in the EIA projections, indicating a slowing of the growth rate that we maintained for the period following 2010.

- ***Bus Transit***. For the 1994 fuel share inputs for bus transit, it is assumed that 95 percent of the buses run on diesel and 5 percent run on CNG, based on conversations with major gas local distribution companies (LDCs) in Texas. We assume that these fuel shares will reverse over time, so that by the year 2010, 95 percent of the buses will run on CNG and 5 percent will run on diesel. This assumption is based on the current trend in Texas of converting bus fleets to CNG, in accordance with state policies that strongly encourage conversion to natural gas and federal initiatives.

The 1994 energy intensities of buses are 36,939 BTU/vehicle-mile for transit buses and 22,310 BTU/vehicle-mile for intercity buses. To obtain projected values for transit and intercity buses, the EIA growth rate for efficiency improvements in medium-sized trucks is applied to the energy intensity of buses. These projections of changes in energy intensity are based on national statistics.

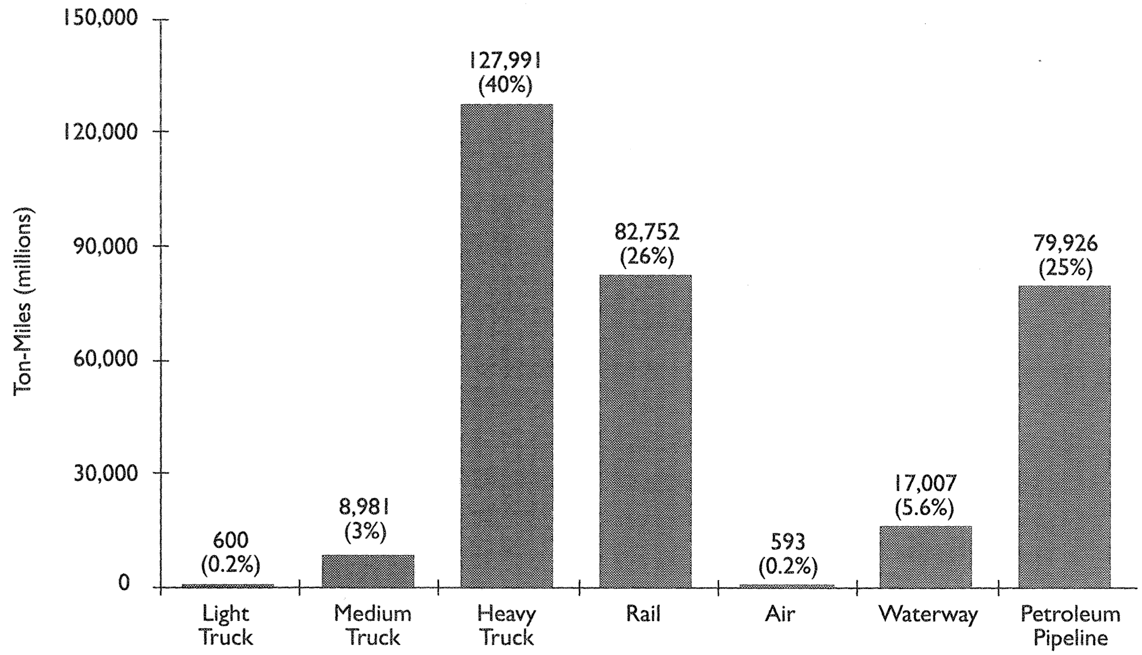


Figure 3.9 Current Freight Ton-Miles by Mode

■ ***Rail Travel.*** Passenger trains have a fuel distribution of 74.1 percent electric and 25.9 percent diesel. This distribution is assumed to remain constant over time. The 1994 energy intensity of passenger trains is taken from ORNL (Ref. 12). These values are assumed to be the same for diesel and electric powered trains, since the data source did not categorize energy intensity by fuel. The transit rail energy intensity is used for the two urban personal transport sectors, while the intercity energy intensity is used for the two intercity sectors. The energy intensities are 74,864 BTU/vehicle-mile for transit rail and 50,321 BTU/vehicle-mile for intercity rail. These energy intensities are assumed to remain constant over time.

■ ***Air Travel.*** The 1994 fuel shares for passenger air travel are assumed to remain constant over time at 97.8 percent for jet fuel and 2.2 percent for aviation gas. The 1994 energy intensity (401,145 BTU/vehicle-mile) is an average for all passenger commercial carrier air travel in 1991 and is assumed to remain constant over time in the Reference Scenario.

■ ***Automobiles and Light Trucks.*** Since automobiles and light trucks are the largest consumers of energy in the personal transportation sector, they have the most detailed modeling assumptions incorporated into their LEAP inputs. As is apparent in the breakdown of the PMT data, automobile and light-truck urban transport are divided into work and non-work categories. The main reasons for this disaggregation were to account for the different levels of congestion that occur for those two types of driving; to incorporate different levels of vehicle occupancy for each type of driving; and to allow for the application of different policies for each trip type.

The different energy intensity values entered into LEAP for automobiles and light trucks are based on the level of congestion (and average speed) for the particular type of driving: highway, city, and a non-work level. The highway factor is used for all intercity travel. The city factor is used for all work travel and the composite factor is used to scale all urban travel that is non-work related.

Much of the data for automobiles and light trucks and for alternative fuel vehicles was gathered from NEMS. The Tellus vehicle stock turnover model was used, which serves to identify the distribution of ages of vehicles within the on-road fleet. A supplemental spreadsheet model was developed to calculate the fleet average fuel efficiency, based on stock turnover. (See Appendix 2 for a discussion of the fleet average fuel economy calculations.) This model provided the energy intensity values for gasoline automobiles and light trucks.

Freight Transportation**.** The LEAP structure for freight transportation includes large urban, small urban, and intercity travel. The data for freight transportation is from two primary sources: ORNL (Ref. 12) and NEMS. The following sections describe the inputs for all modes within freight transportation.

- ***Light Trucks*****.** It is assumed that there is a major difference in the type of light trucks used in large urban freight travel versus travel in the other two freight sectors. The difference is that there are a large number of fleet vehicles in the larger cities. For this reason, light trucks have been modeled in a similar fashion to personal transport light trucks. That is, we have included a much more detailed breakdown by technology type. The technology shares are taken from the national fleet truck fuel shares found in NEMS.

  The energy intensity levels are equivalent to those in the urban-non-work category of personal travel. This allowed us to more explicitly model the conversion to alternative fuels, which will occur much faster in fleet vehicles than in other types of freight light trucks due to the Energy Policy Act of 1992 (EPACT).

  For the other two freight sectors, freight light trucks are modeled on a much less detailed basis. The technology shares and the energy intensity values are taken directly from the NEMS national light truck freight data. All light truck inputs are based on national data.

- ***Medium and Heavy Trucks*****.** The technology shares and energy intensity values for medium and heavy trucks are taken from the national average data in the NEMS model.

- ***Rail*****.** For the LEAP analysis, rail freight is powered solely by diesel fuel. The energy intensity value (384 BTU/ton-mile) is from ORNL (Ref. 13). It is assumed that the energy intensity for electric and diesel trains is the same and that both the technology shares and the energy intensities remain constant over time.

- ***Water*****.** The 1994 fuel shares for water freight are 70.6 percent for diesel fuel and 29.4 percent for residual oil with an energy intensity of 393 BTU/ton-mile (Ref. 13). Since ORNL does not categorize energy intensity by fuel, it is assumed that it is the same for diesel-powered and residual oil-powered water freight. The technology shares and the energy intensities are assumed to remain constant over time.

- ***Air***. The 1994 technology shares for air freight are 97.8 percent for jet fuel and 2.2 percent for aviation gas with an energy intensity of 401,145 BTU/mile. We apply the same energy intensity to both jet fuel-powered and aviation gas-powered planes. The technology shares and the energy intensities are assumed to remain constant over time in the Reference Scenario.

- ***Pipeline***. The transport of petroleum and natural gas through pipelines are included in the analysis. For the study, petroleum pipelines are powered solely by electric motors, and natural gas pipelines are powered by natural gas. The estimated energy intensity values are 95 BTU/ton-mile for petroleum pipelines and 5 BTU/ton-mile for natural gas pipelines (Ref. 13). Neither the technology shares nor the energy intensities are assumed to change over time.

Emission Factors

In order to calculate carbon dioxide (CO_2), carbon monoxide (CO), volatile organic compounds (VOCs), nitrogen oxides (NO_X), sulfur oxides (SO_X), and particulates (PM) emissions, the EDB feature of LEAP is used. The emissions are tracked from the end-use consumption only. The great uncertainty associated with upstream emissions prevented calculation of these values. Importantly, upstream energy use (energy consumed during extraction, production, and transport of fuels) is calculated for all the scenarios.

Emissions for the six pollutants are not all proportional to the amount of energy that a device consumes. CO_2 and SO_X do correspond to the amount of energy that a device consumes, the other four pollutants do not have the same relationship to energy consumption. Rather, these pollutants are tied more to the number of miles that a vehicle travels. For this reason, these four pollutants are treated differently within LEAP.

CO_2 and SO_X were linked directly to the portion of the LEAP structure that produced energy as the output. The other four pollutants were linked to the portion of the LEAP structure that produced miles traveled as an output.

Reference Case Calibration

Overview. EIA estimates annual energy consumption for four sectors: residential, commercial, industrial, and transportation (Ref. 1). We have compared our findings of current Texas energy consumption in the transportation sector with those of the EIA. This resulted in a critique of both our methodology and that of the EIA and has led to a better overall estimate of current state energy consumption in the transportation sector.

As described in Appendix A of the EIA's State Energy Data Report, many of the state consumption estimates of various fuel types are based upon proportioning total national consumption with state fuel sales data. In other words, the state energy consumption estimates made by EIA do not track end use of the particular fuel type. Given that Texas is a major oil refining state, tracking the end use (in-state versus out-of-state) of a particular fuel type is important when estimating state consumption.

Therefore, the state energy consumption data for the transportation sector reported by EIA is not necessarily the most accurate data available for each fuel type. As such, we have adjusted both our preliminary energy consumption estimates as well as the estimates reported by EIA.

The latest state data available from EIA is for 1992, compared with the 1994 energy consumption estimates prepared for LEAP. This discrepancy appears to be mitigated, at least for some of the fuel types, by the fact that the EIA consumption estimates have fluctuated between positive and negative annual growth in recent years. For instance, the last six years (1987–1992, inclusive) of EIA estimates of state motor gas consumption have fluctuated between a plus or minus 2 percent growth rate. This implies that the future 1994 EIA estimate of motor gas consumption may not be significantly different from its 1992 estimate.

Evaluation of Preliminary Energy Estimates. Our preliminary finding of current Texas energy consumption in the transportation sector was significantly different from the EIA estimate. Table 3.8 compares EIA consumption estimates by fuel type for Texas within the transportation sector (1992 being the latest available data) with our preliminary findings of current consumption (1994).

Fuel Type	EIA (1992)	CTR/TELLUS Preliminary Estimate (1994)
Natural Gas	84.9 (Pipeline Fuel)	7.7
Aviation Gas	4.0	2.7
Distillate Fuel	371.8	481.8
Jet Fuel	509.1	118.3
LPG	1.1	3.3
Lubricants	10.8	0.0
Motor Gas	1024.0	927.9
Residual Fuel	188.1	2.0
Other	0.0	3.6
TOTAL	2193.8	1547.3
DIFFERENCE	-	-646.5

Table 3.8 Comparison of EIA and CTR/TELLUS Texas Energy Consumption (trillion BTU)

Following is a description of the critique made of the current state transportation sector energy consumption estimates for each fuel type and the adjustments made to both the EIA reported values and our preliminary findings.

- ***Natural Gas***. Our preliminary finding of natural gas consumption is based primarily upon vehicle use, while the EIA data is based upon fuel used to operate natural gas pipelines. In addition, our preliminary estimate of fuel consumption in natural gas pipeline operations (0.10 trillion BTU) is based on a rough estimate of interstate natural gas transport by pipeline. Data to estimate pipeline fuel used to transport natural gas to residential and commercial locations within Texas could not be found.

  Therefore, we have used the EIA data of 84.9 trillion BTU as the current amount of total natural gas pipeline fuel consumption. The difference between the EIA's estimate of natural gas pipeline fuel of 84.9 trillion BTU and our preliminary estimate of 0.10 trillion BTU is added to the natural gas pipeline fuel category. We have assumed that 50 percent of the natural gas pipeline fuel (the fuel used to operate natural gas pipelines) is allocated to intercity transport, 25 percent to large urban and 25 percent to small urban.

- ***Aviation Gas and Jet Fuel***. The EIA estimate of current aviation gas and jet fuel consumption in Texas is 513.1 trillion BTU while our preliminary estimate is 121.0 trillion BTU. The EIA state estimate is based upon proportioning total U.S. consumption with state sales data.

  Texas has a significant oil refining capacity and there is a significant amount of petroleum products being imported and exported into and out of the Petroleum Administration for Defense (PAD) District III (Alabama, Arkansas, Louisiana, Mississippi, New Mexico, and Texas). Therefore, tracking end use of aviation gas and jet fuel, which the EIA State Energy Data Report does not do, is important. Furthermore, a significant amount of jet fuel (naphtha jet fuel) is used for military purposes and is included in the EIA data. In this study, we are only concerned with civilian transportation energy consumption and any military energy use included in the data should be netted out.

Our preliminary energy consumption finding is based upon estimating state commercial airline VMT. This estimate is made by proportioning total U.S. commercial air VMT with Texas' share of the national number of enplanements (Ref. 10). In addition, our preliminary energy intensity for air travel (amount of BTU per VMT) is based upon averaging general aviation fuel use with commercial fuel use. This averaging has the effect of reducing the air transport energy intensity to about half of that of commercial carriers alone (Ref. 12). The adjustments made to the EIA data follow.

Adjustment to State Jet Fuel Exports. The EIA jet fuel state consumption estimate is reduced to account for net jet fuel exports from Texas to other states. This amount is estimated to be 19.3 percent of the 509.1 trillion BTU. The percentage of net jet fuel exports leaving Texas is calculated by using a better estimate of jet fuel consumption within the Petroleum Administration for Defense (PAD) District III (Ref. 14).

The jet fuel data within the *Petroleum Supply Annual* is a better estimate of actual consumption than the data within the *State Energy Data Report* because it tracks various petroleum product production amounts and net import/export activity, internationally as well as between PAD districts. The difference between the *State Data Energy Data Report* estimate of 509.1 trillion BTU and the *Petroleum Supply Annual* estimate is assumed to be the amount of net state exports. This amount is 19.3 percent of the total, or 98.3 trillion BTU.

Adjustment to State Jet Fuel Military Use. The EIA jet fuel data includes both naphtha jet fuel and kerosene jet fuel. Based on Appendix A of the *State Energy Data Report* and on phone conversations with EIA personnel, naphtha jet fuel is primarily used for military purposes. We have estimated the percent of naphtha-jet fuel use to be 27.1 percent of the total jet fuel consumption in Texas or 111.4 trillion BTU (Ref. 14).

The combined effects of accounting for state jet fuel exports and military jet fuel use reduce the EIA state jet fuel consumption estimate from 509.1 trillion BTU to 299.4 trillion BTU. Concerning adjustments to the CTR/Tellus preliminary findings of state aviation energy consumption, the following changes are made:

Adjustment to Commercial Airline Energy Intensity: we have corrected the air energy intensity in order to accurately account for commercial airline travel energy use. The energy intensity is increased from 213,845 BTU per VMT to 401,145 BTU per VMT. This increases our estimate of state jet fuel consumption from 118.3 trillion BTU to 221.9 trillion BTU.

VMT Factor: using data from the *Petroleum Supply Annual* as the basis for actual jet fuel consumption in Texas, we applied a VMT factor of approximately 1.3 to our Texas air VMT estimate in order to increase the jet fuel consumption from 221.9 trillion BTU to 299.4 trillion BTU.

- ***Distillate and Diesel Fuel***. The EIA estimates 1992 state consumption of distillate fuel in the transportation sector

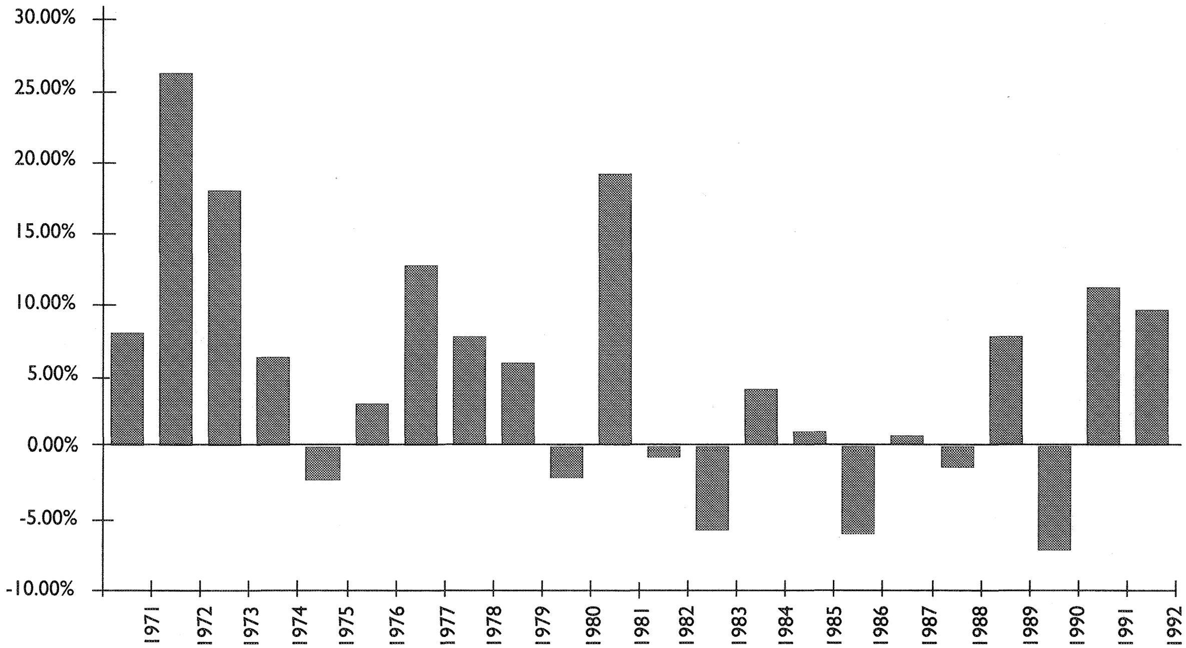


Figure 3.10 EIA State Distillate Fuel Consumption Estimates–Annual Growth Rates

to be 371.8 trillion BTU. While we were not able to estimate Texas net intra-national imports or exports of distillate fuel, we did estimate the amount of military use of distillate fuel within Texas to be 28.3 trillion BTU (Ref. 15). This amount was subtracted from the 371.8 trillion BTU figure for a revised distillate fuel consumption total of 343.5 trillion BTU.

Our preliminary diesel fuel consumption estimate of 481.8 trillion BTU (1994) is 138.3 trillion BTU, 40 percent greater than the revised EIA estimate of 343.5 trillion BTU (1992). However, given that we do not have enough detailed data (e.g., as for jet fuel) to explain this difference, we did not attempt to adjust our finding of the current state diesel fuel consumption of 481.8 trillion BTU. Figure 3.10 shows the annual growth rate fluctuations for EIA state distillate fuel consumption estimates. If the 10 percent growth rate of the last two years were to continue to 1994, this would reduce the difference between our estimate and that of the EIA from 138 trillion BTU to 66 trillion BTU.

- ***LPG*.** Because the current LPG consumption level is so small, we did not make any attempt to explain the difference between our estimate of state LPG fuel consumption in the transportation sector and that of the EIA.

- ***Lubricants*.** For purposes of this study, we did not include lubricants as part of our analysis. Therefore, we have "zeroed out" the EIA estimate of 10.8 trillion BTU for lubricants.

- ***Motor Gas*.** Our preliminary estimate of state motor gas consumption in the transportation sector is 927.9 trillion BTU, while the EIA estimates this consumption to be 1,024.0 trillion BTU. The EIA data for motor gas includes "marine" use (e.g., recreational boating) and we have subtracted that amount (8.9 trillion BTU) from their estimate. This results in a revised EIA state motor gas consumption estimate of 1,015.1 trillion BTU.

Our preliminary finding of current (1994) state motor gas consumption is 9.4 percent less than the revised EIA estimate (1992). Figure 3.11 shows the annual growth rate fluctuations for the EIA's estimates of state motor gas consumption. The annual fluctuation between positive and negative growth rates over the last six years of data indicates that the future EIA estimate of 1994 consumption may not be significantly different than the 1992 estimates. Given that we do not have enough detailed data to explain the difference between our estimate and that of the EIA's, we did not make any adjustment to our finding of 927.9 trillion BTU.

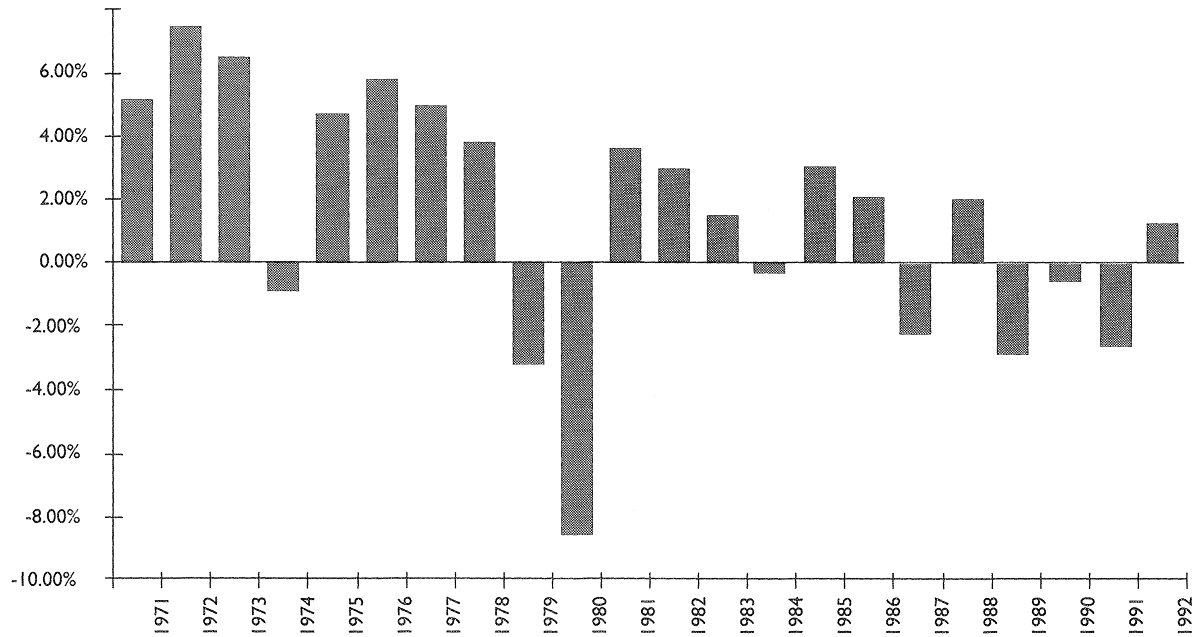


Figure 3.11 EIA State Motor Gas Consumption Estimates–Annual Growth Rates

Residual Fuel. Our preliminary finding of 2.0 trillion BTU for state residual fuel consumption reflects an estimation of current waterborne freight ton-mileage of 17 million ton-miles. Our total preliminary finding of waterborne freight of 6.7 trillion BTU is distributed among diesel fuel and residual fuel. The ton-mile data is based on tonnage hauled and miles traveled within the GIWW and does not reflect trans-gulf or trans-ocean transport of cargo.

The EIA estimate of 188.1 trillion BTU for state residual fuel consumption includes a category called "vessel bunkering,"—the fueling of vessels while in port. A certain amount of vessel bunkering fuel is also included in the EIA's distillate fuel consumption estimate. We determined that a total of 235 trillion BTU is consumed for vessel bunkering in Texas (Ref. 15). This amount of fuel stored in the vessels presumably would be for trans-gulf or trans-ocean transport and not just for travel inside the Texas GIWW.

Therefore, we multiplied our preliminary estimate of waterborne freight ton-miles by a factor of 35 to increase our preliminary energy consumption estimate of waterborne commerce from 6.7 trillion BTU to 235 trillion BTU. Two hundred thirty trillion BTU of this amount is allocated to the residual fuel category.

Revision of Energy Use Estimates. The major adjustment made to the EIA estimate of current Texas transportation sector energy consumption is to jet fuel, in order to take into account exports of jet fuel from Texas to other states (which the EIA does not consider). Also, "we netted" out that portion of jet fuel used by the military which the EIA State Energy Data Report includes in its energy consumption estimate.

The major adjustments made to our preliminary findings for state energy consumption in the transportation sector are to jet fuel, residual fuel and natural gas pipeline fuel. We were not able to obtain air carrier VMT data within the state, only and instead utilized a crude estimate of state air VMT which proportioned national air VMT with Texas' share of the national number of enplanements. Also, the air energy intensity was significantly increased when general aviation energy intensity data was factored out. Thus, our preliminary finding of state jet fuel consumption was increased from 118 trillion BTU to 298 trillion BTU.

The dramatic increase in residual fuel consumption from our preliminary finding of 2 trillion BTU to 230 trillion BTU reflects the fact that waterborne ton-mileage data does not include trans-gulf or trans-ocean mileage. Given that the EIA estimate of residual fuel consumption implicitly took this into account by including "vessel bunkering" in its estimate, we increased our preliminary estimate accordingly.

Finally, the data required to calculate the fuel used to power natural gas pipeline compressors was not available and as such, our preliminary finding of natural gas pipeline fuel was in effect zero. Therefore, we utilized the EIA figure (85 trillion BTU), since it

Fuel Type	EIA Revised	CTR/TELLUS Final Estimate
Natural Gas	84.9 (Pipeline Fuel)	87.2
Aviation Gas	4.0	2.7
Distillate Fuel	343.5	481.8
Jet Fuel	299.4	298.3
LPG	1.1	3.3
Lubricants	0.0	0.0
Motor Gas	1015.1	927.9
Residual Fuel	188.1	230.4
Other	0.0	9.2
TOTAL	1,936.1	2,040.8
DIFFERENCE		+104.7

Table 3.9 Revised Reference Scenario Texas Energy Consumption (trillion BTU)

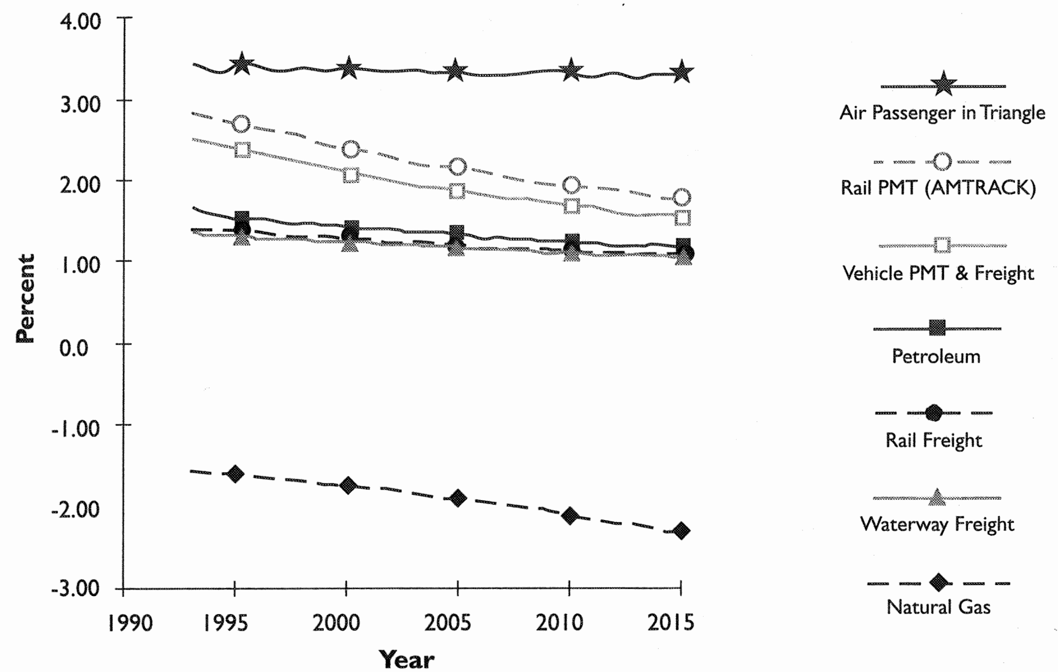


Figure 3.12 Growth Rates by Mode

contained this specific category of energy consumption in the transportation sector.

Table 3.9 displays the net effect of these adjustments to estimates of current consumption by the EIA and by the CTR/Tellus study team. Our estimate of current (1994) state transportation sector energy consumption is now 105 trillion BTU greater than the revised EIA (1992) estimate.

Transportation Demand Projections

In the previous section, we described the methodologies used to calculate current state energy consumption in the transportation sector. This final section discusses the projection of the adjusted estimates of current demand into the analysis period of this study. Whenever possible, we attempted to use official demand forecasts, such as those issued by TxDOT for roadway VMT growth.

For other modes (rail, air, waterway and pipeline), we used historical data and employed a simple regression technique on the observed growth rates. The growth rates through 2015 are shown in Figure 3.12. The projections, obtained by applying these growth rates to 1992 data, are listed in Tables 3.10 and 3.11.

Category	Travel Mode	PMT				
		1994	2000	2005	2010	2015
Large Urban	Auto-Work	22,458	25,924	28,812	31,701	34,589
	Auto-Other	76,473	88,274	98,108	107,944	117,779
	Light Truck-Work	3,912	4,515	5,018	5,522	6,025
	Light Truck-Other	13,318	15,373	17,085	18,798	20,511
	Transit-Work	451	521	579	637	695
	Transit-Other	950	1,097	1,219	1,342	1,464
	Non-Motorized-Work	0	0	0	0	0
	Non-Motorized-Other	0	0	0	0	0
Small Urban	Auto-Work	8,969	10,353	11,507	12,660	13,814
	Auto-Other	30,542	35,256	39,183	43,111	47,039
	Light Truck-Work	1,578	1,821	2,024	2,227	2,430
	Light Truck-Other	5,371	6,200	6,891	7,582	8,272
	Transit-Work	193	223	248	273	298
	Transit-Other	419	483	537	591	645
	Non-Motorized-Work	0	0	0	0	0
	Non-Motorized-Other	0	0	0	0	0
Intercity Triangle	Auto	3,606	4,162	4,626	5,090	5,554
	Light Truck	720	832	924	1,017	1,110
	Air	1,539	1,874	2,202	2,585	3,031
Other Intercity	Auto	62,293	71,905	79,916	87,928	95,939
	Light Truck	14,904	17,204	19,120	21,037	22,954
	Transit	1,474	1,701	1,891	2,080	2,270
	Rail	47.3	54.8	61.1	67.4	73.7
	Air	69,828	86,454	100,348	114,242	128,137

Table 3.10 Personal PMT Projections (millions)

Category	Travel Mode	PMT 1994	2000	2005	2010	2015
Large Urban	Light Truck	256	296	329	362	395
	Medium Truck	3,825	4,415	4,907	5,399	5,891
	Heavy Truck	36,046	41,609	46,244	50,880	55,516
	Automobile	0	0	0	0	0
Small Urban	Light Truck	103	119	133	146	159
	Medium Truck	1,545	1,784	1,983	2,182	2,380
	Heavy Truck	11,764	13,579	15,092	16,605	18,118
	Automobile	0	0	0	0	0
Intercity	Light Truck	241	279	310	341	372
	Medium Truck	3,611	4,168	4,632	5,097	5,561
	Heavy Truck	80,181	92,554	102,865	113,178	123,490
	Rail	82,752	89,470	95,068	100,667	106,265
	Air *	274	317	353	389	424
	Waterway	596,780	643,818	683,016	722,215	761,413
	Petroleum	79,926	87,285	93,417	99,549	105,681
	Natural Gas **	920,737	833,343	760,514	687,685	614,857

* Includes freight-only carriers

** The unit of natural gas is in trillion cubic foot-miles.

Table 3.11 Commercial Ton-Mileage Projections (millions)

FOUR: SCENARIOS FOR ENERGY SAVINGS IN THE TRANSPORTATION SECTOR

INTRODUCTION

For the most part, current efforts to reduce energy consumption in the transportation sector are a by-product of policies aimed at reducing urban roadway congestion and air pollution. The major objective of this project is to identify and evaluate measures to reduce energy consumption and associated pollutant emissions in the Texas transportation sector. The Reference Scenario, presented previously, provides the baseline for comparing the other four alternative scenarios. That Reference Scenario reflects the current situation in Texas, as well as the near-term trends with no additional policy measures.

In this chapter, we discuss four future scenarios–the Moderate, Aggressive, Visionary, and Rollback. The first three consist of increasingly aggressive policies and measures to reduce energy consumption and emissions in the Texas transportation sector. The Rollback Scenario is presented to estimate the consequences of revoking the current alternative fuels program.

The energy analysis was completed using the LEAP system, as outlined previously. It includes energy consumption by transport mode and geographic region, as well as an estimate of emissions. In addition, we also estimated the implementation costs (incremental with respect to the Reference Scenario), for the Moderate and the Aggressive scenarios.

The proposed scenarios include a number of alternative transportation policies, pricing strategies to modify travel behavior, and new technologies on both the vehicle and the infrastructure side. Table 4.1 depicts a summary of the five analysis scenarios examined in this study.

Scenario	Objective
Reference	Provides a transportation sector baseline to potential impacts of alternative scenarios
Rollback	Estimates the consequences of a reversal of the current national and state alternative fuels programs.
Moderate	Examines measures that require moderate changes in current travel behavior, modal distribution, and vehicle choice in the short-term.
Aggressive	Examines measures that produce more substantial changes in current travel behavior and modal distribution, and technologies for the intermediate term.
Visionary	Investigates more radical modal shifts and behavioral changes, significant land use changes, and visionary technological innovations that are realistic for the future.

Table 4.1 Summary of the Analysis Scenarios

Development of the Study Scenarios

The Moderate, Aggressive, and Visionary scenarios consist of increasingly effective energy reduction policies. The specific policies for the three scenarios were selected based on their potential effectiveness for the various transportation sectors, and their feasibility in the short and intermediate terms, as well as in the future. The descriptions of these policies and their area of influence are illustrated in Table 4.2. Most of the policies target the surface transportation system. The details of the alternative scenarios and their policy components are discussed in the remainder of this chapter. However, before these scenarios are examined, we begin with an assessment of current alternative fuels mandates.

<table>
<tr><th rowspan="2">Scenario</th><th colspan="2">Passenger</th><th colspan="2">Freight</th></tr>
<tr><th>Urban</th><th>Intercity</th><th>Urban</th><th>Intercity</th></tr>
<tr><td rowspan="2">Moderate
Incentives only
No pricing strategies</td><td colspan="2">1. Revenue-neutral feebates
2. Accelerated retirement of vehicles</td><td rowspan="2"></td><td rowspan="2">1. Truck size & weight increases</td></tr>
<tr><td>1. ETRP
2. System optimization (ΔSpeed)–TSMs
3 Telecommuting
4. Improved public transit</td><td></td></tr>
<tr><td rowspan="3">Aggressive
Pricing strategies utilized</td><td colspan="4">1. More aggressive feebates, not necessarily revenue neutral, applied only to gasoline and diesel vehicles
2. Other pricing strategies
3. Technology options, including alternative fuels</td></tr>
<tr><td colspan="2">1. Mode shift to HOVs
2. Teletransporting</td><td colspan="2">1. Telefreight</td></tr>
<tr><td>1. ETRP
2. Improved public transit</td><td></td><td>1. Alternative fuels requirements to private fleets in large urban</td><td>1. Mode shift truck to rail</td></tr>
<tr><td rowspan="3">Visionary
Full-cost pricing</td><td colspan="4">1. Technology options, including ZEVs and fuel cells</td></tr>
<tr><td colspan="2">1. Larger mode shift to HOVs than in Aggressive Scenario
2. More significant teletransporting</td><td rowspan="2"></td><td>1. Higher mode shift truck to rail</td></tr>
<tr><td>1. Land use
2. ETRP
3. Intensive public transit</td><td>1. Mode shift to HOVs, including high speed rail</td><td>1. Alternative rail fuels</td></tr>
</table>

Table 4.2 Description of the Study Scenarios

Rollback Scenario

As described in Chapter 1, the U.S. is a major energy consumer and the world's largest consumer of petroleum. Much of the world's oil supplies are located in politically and economically unstable regions, and the U.S. is heavily dependent on these areas for its energy supply. Texas is the nation's largest consumer of petroleum and, for transportation, petroleum remains the principal energy source.

Because of the importance of transportation in developing sound policies for energy security, much attention has been directed to non-petroleum-based, clean-burning alternative fuels for motor vehicles. A number of federal and Texas initiatives have been developed in the last six years that promote the use of alternative transportation fuels. (These are discussed in more detail in Appendix 3.)

Rollback Scenario Analysis and Results. The Rollback Scenario simulates the energy and pollutant emissions outlook under the assumption of a reversal of current policies to encourage increasing use of alternative fuels. It also assumes that no additional policies to save energy and/or control pollution would be implemented in the near future. In short, this scenario consists of a permanence in time of all current transportation policies and practices (Reference Scenario) except the alternative fuels program.

The analysis was made using the LEAP system discussed in Chapter 2, with only one modification in the Reference Scenario data: that the use of alternative fuels will decrease. The results of the analysis include:

1. Energy consumption by transport mode and geographic region.
2. Pollutant emissions by transport mode and geographic region.

The analysis of implementation costs with respect to the Reference Scenario baseline is not applicable in this scenario, since the only costs involved with the elimination of this program are externalities–that is, increased pollution and dependence on fossil fuels.

The consequences of revoking the current alternative fuels policies in Texas would be felt in the mid- to long term, affecting primarily the dependence on fossil fuels. In the year 2020, emissions increases, relative to the Reference Scenario, range from 1.5 percent to 17.0 percent for sulfur oxides (SOx) and particulates (PM), respectively. Eliminating current alternative fuels policies results in about a 1.4 percent increase relative to the Reference Scenario in overall transportation energy use by the year 2020. Figure 4.1

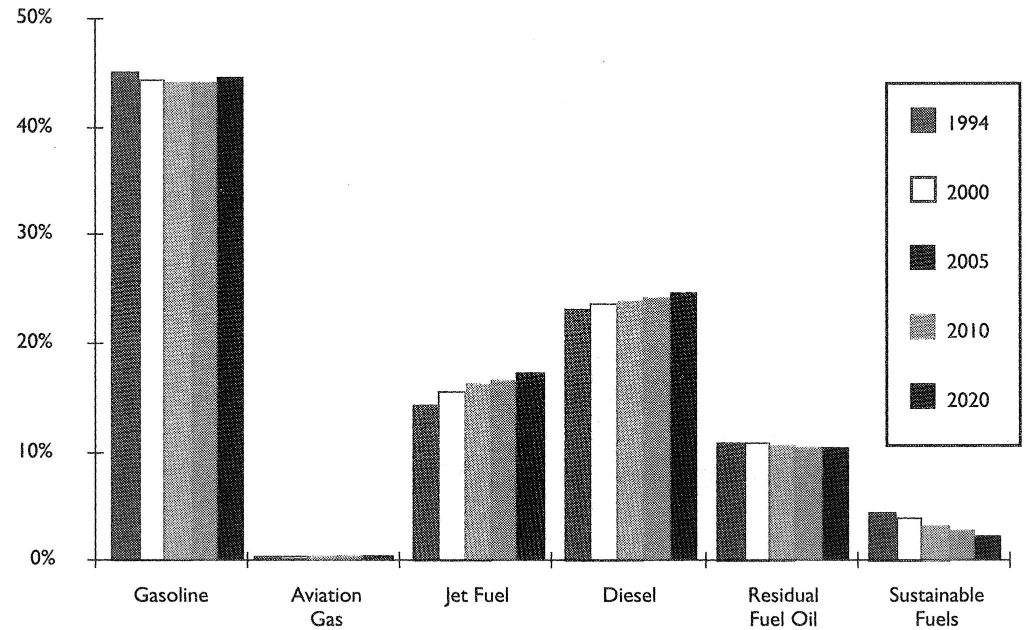


Figure 4.1 Percent Energy Use by Fuel Type (Rollback Scenario)

shows the projected shares of sustainable energy use under the Rollback Scenario. The percent energy shares for each of the petroleum-based fuels (gasoline, aviation gas, jet fuel, diesel, and residual fuel oil) do not decrease over time, while those for the sustainable fuels (electricity, natural gas, LPG, ethanol, and methanol), already in the lowest percentages of use, show a clear decline in usage over the same time frame.

As expected, elimination of alternative fuels results in a slightly higher urban share of energy use. The urban automotive passenger trip is the most affected group. Their energy use increases relative to the Reference Scenario by nearly 3 percent in 2020. Losses would be even greater if it were not for the steady improvement in vehicle fuel efficiency. There are no significant effects in the freight transportation sector energy use as evidenced by total state transportation energy use by mode. Alternative fuels are primarily utilized in the passenger transportation market and thus do not affect freight activity significantly.

The increasing dependence on fossil fuels created by revoking the alternative fuels programs is more clearly depicted in Figure 4.2. While the immediate impact of revoking these polices would be very small, this impact increases over time, and amounts to a more than twofold decrease in the expected shares of sustainable fuels in Texas. It is also worth observing that, although our analysis period ends in the year 2020, the trends clearly indicate that the long-term decline in transportation sustainability would accelerate in the future. (Detailed energy use tables for the Rollback Scenario are listed in Appendix 5, Tables A5.6 to A5.10.)

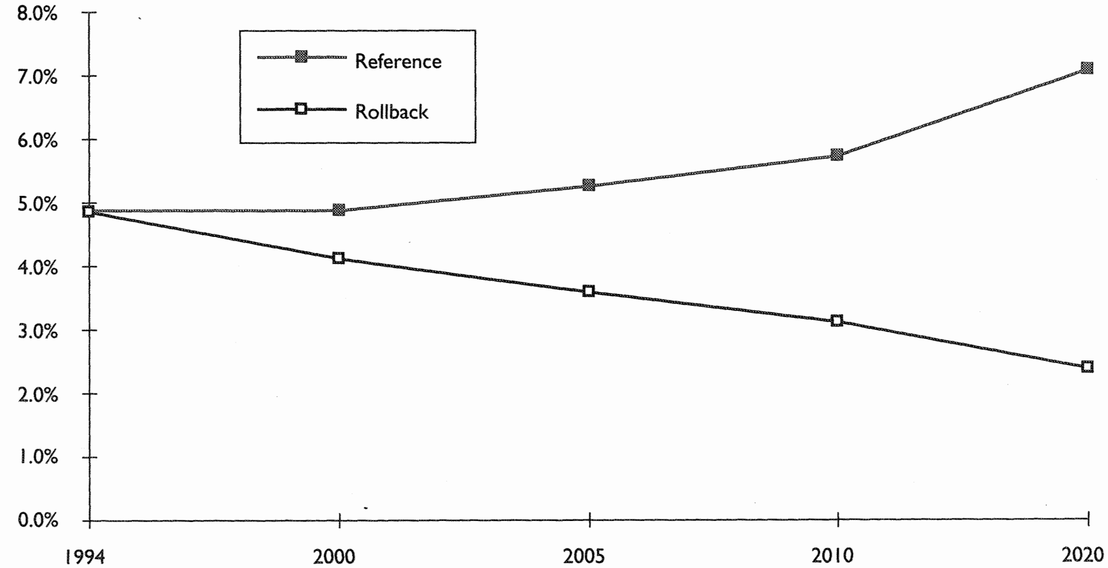


Figure 4.2 Share of Sustainable Fuels for Rollback and Reference Scenarios

Moderate Scenario

The objective of the Moderate Scenario is to investigate the potential impact of policies consisting primarily of transportation control measures (TCMs), financial incentives, and resulting technological innovations that do not require drastic changes in established travel behaviors (and as such are suitable for short-term implementation). The scenario assumes a moderate but steady increase in fuel efficiency for passenger vehicles and light trucks, but not for heavy-trucks and other modes. This fuel efficiency improvement is a product of revenue-neutral financial incentives. The five policies in the Moderate Scenario are:

1. Feebates (revenue neutral)
2. Accelerated retirement of poor fuel-efficient vehicles

3. Employer trip reduction (ETR) for cities with populations over 200,000
4. Roadway system optimization
5. Increased truck size and weight limits

As described in the first report of this study, feebates are a system of sales taxes and rebates on new vehicle purchases. For this scenario, a program of feebates are developed for automobiles and light-trucks used for passenger transportation that yields no additional revenues. (The feebate program is not be extended to commercial freight vehicles.) The feebate program results in a steady improvement in vehicle fuel efficiency resulting in energy savings in the passenger transportation sector.

Accelerated vehicle retirement (AVR) programs offer a payment to owners of old, low fuel economy vehicles in order to induce them to scrap their vehicles in favor of newer, more fuel efficient vehicles. Similar to, and in conjunction with, feebates AVR should yield a steady improvement in overall fuel efficiency for passenger transportation and a larger fleet of low-emission vehicles.

ETR programs are required for all large urban areas in Texas. The TCMs applicable to ETR programs include work schedule changes, telecommunication, car- and van-pooling or other ridersharing, and greater utilization of public transportation. Energy consumption and pollution reductions are achieved through reductions in vehicle work trips, i.e., lower peak period vehicle miles of travel (VMT). Incidental to a program of ETR are speed improvements due to reduced congestion. The speed improvements will also yield some gains in vehicle fuel economy.

Roadway system optimization, focusing on the supply rather than the demand for transportation, attempts to improve transportation flows. These flow improvements yield higher speeds by allowing less accelerations and decelerations that are more fuel efficient and less polluting. Specific optimization policies in this scenario include traffic management systems and improvements in traffic signalization and traffic operations. The energy and emissions benefits to optimization will occur principally during urban (intra-city) peak periods. We are assuming that the optimization improvements will not be offset by latent demand.

This scenario highlights the effect of increases in size and weight limits for intercity commercial trucks. Higher size and weight limits should improve economies of scale for the truck industry and result in fewer truck trips. This will be partially offset by reduced fuel economy, since truck weight is a major determinant of truck fuel consumption. However, these fuel economy losses should be more than offset by productivity improvements in the industry.

An important assumption in this policy is that the resulting decrease in operating costs for the trucking industry will not encourage a rail-to-truck mode shift. The additional infrastructure costs required by increases in truck size and weight limits (such as stronger pavements and bridges, and safer facilities) are discussed later in the cost analysis.

Moderate Scenario Analysis and Results. As discussed above, the Moderate Scenario comprises alternative policies that affect the following data categories:

- All categories of personal-auto trips, through the feebate and accelerated retirement of vehicles programs
- The metropolitan personal transport demand, with the expansion of the ETR programs and the roadway system optimization policies
- The intercity freight category, with the increased truck efficiency program

The feebates and AVR policies are directed toward all forms of automobile passenger transportation, i.e., urban and intercity trips. The ETR program targets peak-period urban trips. The roadway optimization measures, while benefiting all vehicular urban trips, will produce energy savings and emissions reductions for passenger and freight vehicles especially those operating during peak periods. Energy consumption reduction in the freight industry will be achieved by productivity improvements in intercity traffic operations. Policies such as feebates, AVR, and roadway optimization are assumed not to have an impact on demand, i.e., they affect only the fuel efficiency level of LEAP. The other policies decrease VMT (or ton-miles), and are recorded as such in the LEAP analysis.

The analysis consisted of energy use and

Closely linked to the pricing policies are the expanded use of feebates. In the Aggressive Scenario, feebates are constructed to provide additional revenues for funding other high occupancy vehicle transportation improvements. The Aggressive Scenario feebates include all motor vehicles, not just passenger cars. This yields additional efficiency improvements in urban freight transport through changes in freight fleet and logistics management.

Alternative fuels are required for all large urban freight transportation movements. The direct effect of this measure is more energy efficient freight vehicles. Because of higher transport costs, the freight sector will also implement measures to optimize fleet movements in order to remain competitive.

***Aggressive Scenario Analysis And Results*.** Implementation of the strategies in the Aggressive Scenario will lead to a 15.2 percent increase in overall energy use from 1994 to 2020 (from 2,044 trillion BTU to 2,355 trillion BTU). Petroleum-based fuels will remain the major fuel of choice, however at a much lower overall rate. Intercity transportation's share of energy use increases significantly from 53.5 percent in 1994 to 58.9 percent in 2020.

The annual energy consumption by auto and light truck passenger travel actually decreases between 1994 and 2010, from 847 trillion BTU to 793 trillion BTU. This is due to a combination of the policies implemented under this scenario, including a 10 to 12 percent increase in vehicle fuel efficiency. By 2020, the growth rate in passenger travel overtakes these improvements and the auto and light truck passenger travel energy use increases to 848 trillion BTU. All the details of the energy consumption are listed in Table A5.16 through Table A5.20 in Appendix Five.

Visionary Scenario

The Visionary Scenario represents a fundamental change in the way we see our communities. The operative element of the transportation system is a shift from mobility to access. A community planned around the principal of access is more conducive to an energy efficient and environmentally sensitive transportation system.

The Visionary Scenario represents what can be accomplished in Texas with fundamental changes in the urban transportation environment and utilization of anticipated technological changes. The policies that would foster such a change include:

- Large-scale utilization of fuel-cell powered vehicles and electric vehicles
- Ambitious fuel economy standards
- Land use changes
- Teletravel
- High speed rail
- Full cost pricing

Given the nature of the Visionary Scenario, it is more appropriate to discuss the potential impacts of these measures than the individual policies. Central to this scenario is a fundamental change in the urban perspective. Given the long-term nature of this scenario, we assume that urban sprawl can be reduced and replaced with more dense communities. Individuals would be able to work, shop and recreate within these communities. Nearly all transportation in the urban environment can be provided by public transportation utilizing zero-emission vehicles and/or high efficiency vehicles including non-motorized transport. Teletravel–i.e., telecommunication, teleshopping, etc.–would be widely used. Intercity travel would see less reliance on the automobile and more reliance on high speed rail and intercity buses. Business passenger travel via air would be less frequent through expanded use of teleconferencing. Freight operations would become much more efficient through full-cost pricing mechanisms, an extension of the aggressive pricing policies (full-cost pricing is a method of charging that includes all external costs). The economic value of energy savings, lower emissions, opportunity costs of land use, and other externalities would be more accurately priced, leading shippers to select the most efficient low-cost alternative.

***Visionary Scenario Analysis and Results*.** As shown in Table A5.21 through A5.25 in Appendix 5, total annual state transportation sector energy use decreases steadily during the period 1994-2010 (from 2,044 trillion BTU to 1,917 trillion BTU), and increases slightly in the following ten years (to

1,961 trillion BTU in 2020) as growth in passenger and freight travel eventually overtake the energy saving policies implemented. Petroleum-based fuels continue to dominate the total transportation energy use in the state but there are significant increases in alternative fuel use.

The area distribution of total state transportation energy use changes over the study period from 1994 to 2020. Intercity transport's portion of energy use increases from 53.5 percent in 1994 to 64.1 percent in 2020, while urban travel's portion decreases from 46.5 percent to 35.9 percent.

A similar result is found when comparing total state transportation energy use between passenger and freight activity. Passenger transport's share of energy use decreases from 56.8 percent in 1994 to 52.8 percent in 2020, while freight's share increases from 43.2 percent in 1994 to 47.2 percent in 2020.

Modal comparison of state transportation energy use shows auto and light truck passenger transport energy use decreasing by 34.5 percent from 1994 to 2020, while annual truck freight transport energy use decreases by 6.8 percent during the same period.

Summary

In this chapter, we analyzed four possible alternatives and associated the energy use. The Moderate Scenario aims at the short-term and gradual changes, while Aggressive and Visionary scenarios consist of increasingly aggressive policies and measures to reduce energy consumption and emissions in the Texas' transportation sector. On the other hand, the Rollback Scenario is presented to estimate the consequences of revoking the current alternative fuels program.

As expected, the Visionary Scenario shows the most significant energy drop among all the scenarios, while the Rollback Scenario makes things worse. Some dramatic measures are needed to achieve the necessary energy decrease during the next 25 years.

In the next chapter we will compare the four scenarios with the Reference Scenario, and discuss the results further.

FIVE: CONCLUSIONS AND RECOMMENDATIONS

INTRODUCTION

To meet Texas' mobility and accessibility needs, a vast transportation network has developed. It consists of corridors and facilities that link the state's cities and towns to each other and to the rest of the nation and world. This transportation system includes the largest rail network in the U.S. with 11,370 miles of rail line, 26 primary commercial airports, 369 general aviation airports, 172,000 miles of pipeline carrying crude oil and refined petroleum products, and 196,000 miles of natural gas pipeline. This transportation system is dominated by 294,152 miles of public roads, utilized daily by vehicles whose state-wide average occupancy is close to one.

The emphasis on highways and individual transportation has led to high public and user costs, worsening of air quality, increased dependence on imported petroleum, and more rapid depletion of non-renewable resources. These are major social concerns and the impetus behind this study is to explore alternative scenarios aimed at promoting greater efficiency in the transportation sector.

Overview of the Transportation Scenarios

As discussed in the previous chapters, the underlying objective of this project is to identify and evaluate measures to reduce energy consumption and associated pollutant emissions in the Texas transportation sector. A comprehensive energy model developed by the Tellus Institute was calibrated to examine modal energy consumption from 1994 to 2020. The initial model calibration represents the Reference Scenario, or base case. A second scenario–the Rollback Scenario–represents what might occur if current policies promoting the use of alternative fuels are terminated. The Moderate Scenario represents changes in energy consumption based on policies that have a modest impact on transportation travel behavior and incentives that promote the purchase of newer, more energy-efficient technologies. The fourth, or, Aggressive Scenario is guided by transportation pricing measures, aggressive feebates, and alternative fuels mandates for urban freight transportation. The final scenario–the Visionary Scenario–represents what could be accomplished in Texas with fundamental changes in the transportation environment and widespread utilization of advanced technologies.

This chapter present a comparative discussion of the energy consumption and pollutant emissions that are expected under each of these scenarios. The Reference Scenario represents the expected trends if no changes are made to current transportation policies and technologies. As such, it provides the baseline for comparing alternative scenarios.

Energy Consumption Results

Based on current practices and policies, the Texas transportation sector consumed 2,044 trillion BTU in 1994. The Reference Scenario projects a steady increase in energy use through the year 2020 owing primarily to population growth and associated increases in personal driving and economic activity. By 2020, energy use in the transportation sector will have increased by 44.2 percent to 2,948 trillion BTU. Energy consumption is dominated by petroleum-based fuels, although alternative fuels increase steadily during this period. By location, energy use begins to increase at a higher rate for intercity transportation than in the state's urban areas. The intercity share of energy use increases from 53.5 percent in 1994 to 55.6 percent in 2020. Most of this growth is driven by the passenger sector. Intercity passenger transportation's share of energy

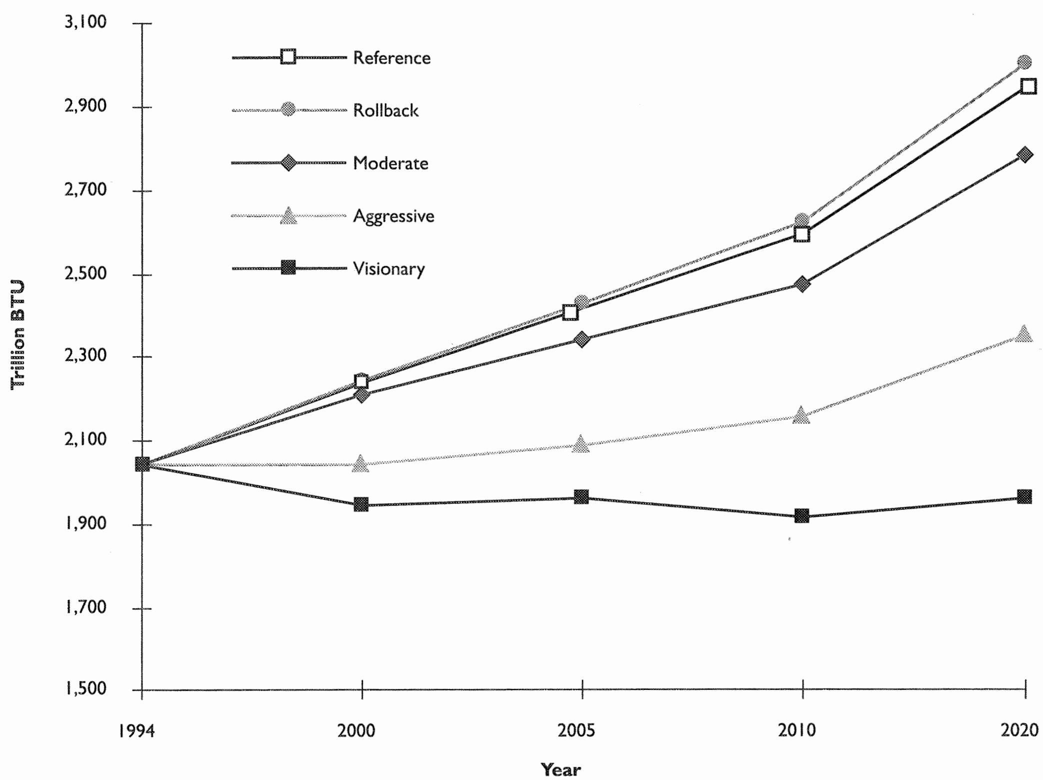


Figure 5.1 Statewide Transportation Energy Consumption

Scenario	1994	2000	2005	2010	2020
Rollback	0.00 %	0.28 %	0.62 %	1.04 %	1.94 %
Moderate	0.00 %	-1.32 %	-3.10 %	-4.77 %	-5.46 %
Aggressive	0.00 %	-8.66 %	-13.44 %	-16.99 %	-20.13 %
Visionary	0.00 %	-13.15 %	-18.81 %	-26.21 %	-33.51 %

Table 5.1 Change in Total Energy Consumption Relative to the Reference Scenario

consumption increases from just above 25.3 percent in 1994 to over 28.5 percent in 2020. Actual energy consumption increases for all modes. The highway surface transportation system remains the major mode of operation for passenger and freight transportation in terms of energy use. As a percentage of total consumption, however, the highway sector's share of energy use remains steady around 67.5 percent during the period from 1994 through 2020, as improvements in vehicle fuel economy and greater utilization of alternative fuels are offset by the increase in personal and freight transport in highway sector. (The direct impact of alternative fuels was discussed in Chapter 4 in the Rollback Scenario.)

Total Transportation Energy Use. Figure 5.1 shows the relative impacts of the various scenarios on total energy consumption in the Texas transportation sector relative to the Reference Scenario. By the end of the analysis period, the energy consumption under the Rollback Scenario is 1 percent higher than the Reference Scenario, due to the cancellation of the alternative fuel policies. The Moderate, Aggressive, and Visionary scenarios progressively reduce energy consumption in the state's transportation sector. By the year 2020, the energy consumption decreases 5.5 percent under the Moderate Scenario, over 20.1 percent under the Aggressive Scenario, and over 33.5 percent in the Visionary Scenario. Table 5.1 summarizes the percent reductions with respect to the Reference Scenario.

Petroleum-Based Energy Use. Another important issue examined in our analysis is the dependence on petroleum-derived fuels under the different scenarios. Figure 5.2 illustrates the decline in petroleum-based fuels (gasoline, diesel, jet fuel, aviation gas, and residual fuel oil) as a percent of total transportation energy consumption between the scenarios.

Under the Reference Scenario, petroleum-based fuels are providing approximately 2,740 trillion BTU, which corresponds to almost 92.9 percent of the state's transportation energy needs in the year 2020. The year 2020's petroleum-based energy use increases to 2,917 trillion BTU in the Rollback Scenario, bringing the petroleum-based energy share to over 97.6 percent. The 92.9 percent Reference Scenario share is maintained in the Moderate Scenario, though actual petroleum use is less (2,590 trillion BTU for the Moderate Scenario).

The Aggressive and Visionary scenarios show the most significant change. In the year 2020, total petroleum-based energy use drops to 2,104 trillion BTU in the Aggressive Scenario, and to 1,662 trillion BTU in the Visionary. This corresponds, respectively, to petroleum-based fuel shares of 89.4 percent and 84.8 percent. Unlike in the Aggressive Scenario, the petroleum-based fuel energy consumption in Visionary Scenario has a continuous downward trend after the year 2005. This is primarily due to the increase of electric vehicles.

As already discussed, the Rollback Scenario effects would be felt primarily in the mid- to long

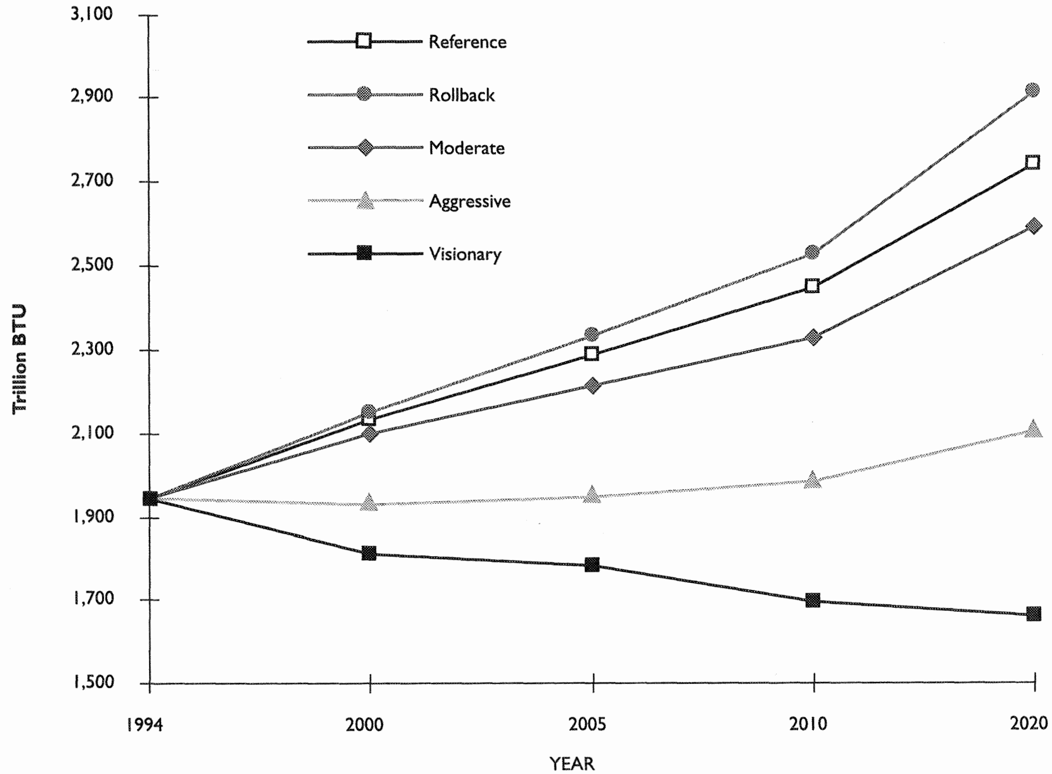


Figure 5.2 Petroleum-Based Energy Use

Scenario	1994	2000	2005	2010	2020
Rollback	0.00 %	0.85 %	2.05 %	3.42 %	6.46 %
Moderate	0.00 %	-1.41 %	-3.25 %	-4.92 %	-5.447 %
Aggressive	0.00 %	-9.33 %	-14.81 %	-19.1.%	-23.19 %
Visionary	0.00 %	-14.88 %	-22.00 %	-30.69 %	-39.35 %

Table 5.2 Change in Petroleum-Based Energy Use Relative to the Reference Scenario

trillion BTU under the Aggressive Scenario, and 554 trillion BTU under the Visionary Scenario. The category share of energy use also decreases to 36.6 percent, 36.0 percent, and 28.2 percent, respectively, for the Moderate, Aggressive, and Visionary scenarios.

Table 5.3 summarizes the changes in energy use of the passenger travel by auto and light truck with respect to the Reference Scenario. By the year 2020, over a 3 percent increase occurs in the Rollback Scenario, due to the elimination of the alternative fuels. The Moderate Scenario provides almost a 13.0 percent decrease in the energy use of this category, while the Aggressive and Visionary scenarios have more significant effects—decreases of almost 27.7 percent and over 52.7 percent, respectively.

Energy consumption by truck freight transport shows similar but less significant trends. The lesser impact is due to the fact that the policies included in the various scenarios have less effect on truck freight energy use than on auto and light truck passenger travel.

By the year 2020, energy consumption by truck freight transport is just under 802 trillion BTU in the Reference Scenario, corresponding to just under 27.2 percent of the total energy use. Both the energy use and the share of freight by truck category are increased in the Rollback Scenario. About 806 trillion BTU are used in this category, corresponding to over 26.8 percent of total energy use in this scenario–representing a one-half percent increase in energy use with respect to the Reference Scenario, as shown in Table 5.4.

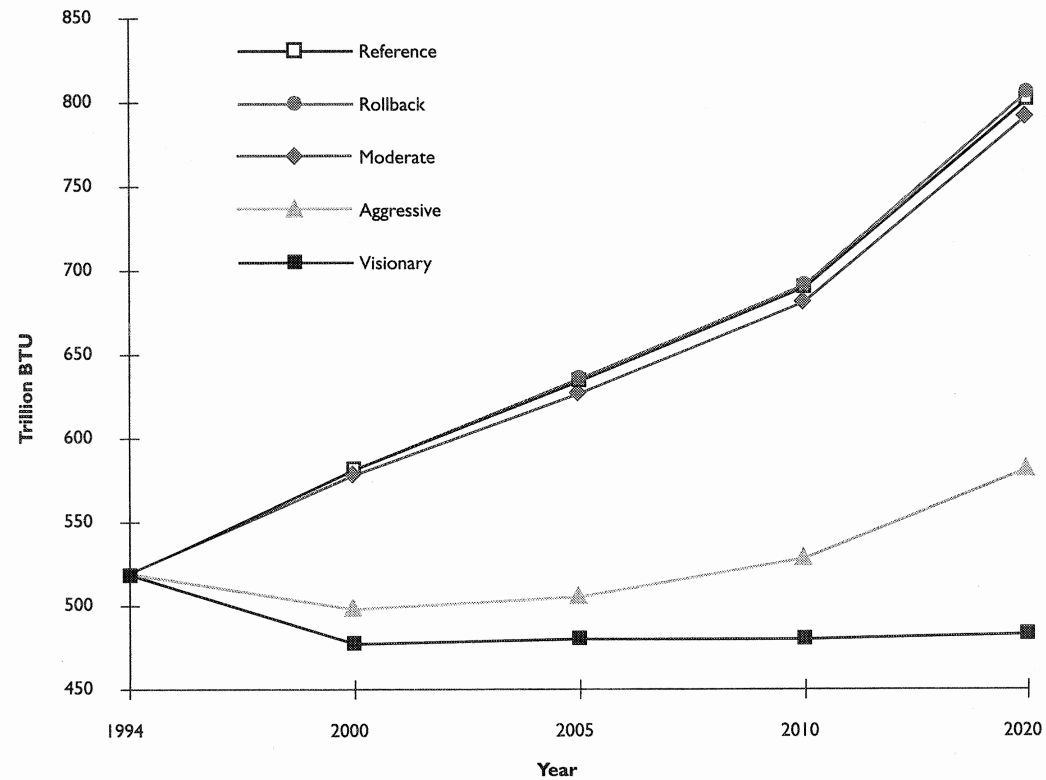


Figure 5.4 Energy Use—Freight Transport by Truck

Scenario	1994	2000	2005	2010	2020
Rollback	0.00 %	0.09 %	0.18 %	0.28 %	0.47 %
Moderate	0.00 %	-0.73 %	-1.46 %	-1.47 %	-1.48 %
Aggressive	0.00 %	-14.41 %	-20.51 %	-23.63 %	-27.65 %
Visionary	0.00 %	-17.96 %	-24.29 %	-30.39 %	-39.78 %

Table 5.4 Freight Transport by Truck—Change in Energy Use Relative to the Reference Scenario

Scenario	1994	2000	2005	2010	2020
Rollback	0.00 %	0.05 %	0.08 %	0.22 %	0.64 %
Moderate	0.00 %	-1.39 %	-3.25%	-5.00 %	-5.68%
Aggressive	0.00 %	-8.91 %	-13.65%	-16.95 %	-19.62%
Visionary	0.00 %	-13.61 %	-19.08%	-26.00 %	-31.90%

Table 5.5 Change in Primary Energy Use Relative to the Reference Scenario

Relative to the Reference Scenario, the energy use of the truck freight category decreases progressively in the Moderate, Aggressive, and Visionary scenarios. However, changes in shares of total energy use remain within the 2 percent to 3 percent range. By the year 2020, freight transport by truck amounts to just over 790 trillion BTU under the Moderate Scenario, 580 trillion BTU under the Aggressive Scenario, and 483 trillion BTU under the Visionary Scenario. This corresponds to decreases of, respectively, less than 1.5 percent, 27.7 percent, and almost 39.8 percent with respect to the Reference Scenario. The share of energy use of this category is 28.4 percent for the Moderate Scenario, and 24.6 percent for the Aggressive Scenario, and 24.5 percent for the Visionary scenarios. Table 5.4 depicts the changes in energy use with respect to the Reference Scenario. It suffices to say that, pricing policies, as represented in the Aggressive and Visionary scenarios, have a more dramatic effect on freight transportation than do increases in vehicle size and weights (Moderate Scenario).

Primary Energy Consumption. In addition to end-use energy consumption, the LEAP/EDB system has the capability to calculate upstream consumption. Upstream consumption represents the energy required during extraction, production, and transportation of energy to its final source. Primary energy consumption is the total consumption of the primary resource (coal, natural gas, crude oil, etc.) including final consumption at the end use (e.g., gasoline use for motor vehicles) and upstream energy consumption. Total primary energy consumption is about 25 percent higher than end-use consumption; for example, in the Reference Scenario end-use consumption is 2,044 trillion BTU in 1994, while primary energy consumption is 2,433 trillion BTU. Overall, changes in upstream energy use track closely to the changes in end use. Table 5.5 compares the change in energy consumption relative to the Reference Scenario for each of the alternative scenarios.

Emissions

The primary focus of this study is energy use, but we also developed estimates of emissions under each scenario. Since most policies that have the potential to decrease energy consumption are used today almost exclusively for air quality purposes, these emissions estimates can assist in future discussions about implementation of the policy scenarios. It is also important to note that, while the social costs associated with poor air quality are still rather controversial, they are nevertheless always present; these emissions estimates can serve as a basis for estimating these external costs, if needed.

The transportation sector air pollutant emissions that we have estimated for the five scenarios are total suspended particulates (TSP), carbon monoxide (CO), volatile organic compounds (VOCs), nitrogen oxides (NO_X), and sulfur dioxide (SO_2). These are among the criteria pollutants for which EPA has promulgated standards for point sources, mobile sources, and ambient concentrations, primarily to reduce the deleterious human health effects of these emissions. In addition, we have estimated emissions for carbon dioxide (CO_2)–the most important greenhouse gas contributed by the transportation sector.

Increased ambient concentrations of the criteria pollutants can have deleterious health effects, both directly and indirectly (e.g., through the reaction of VOCs, NOx and sunlight to form ozone), including increased mortality and incidence of chronic and acute symptoms, especially of the respiratory and cardiovascular systems. These are especially problematic in congested urban areas such as the Houston region. Increases in these pollutants can also cause damages to aquatic and terrestrial ecosystems, including crop loss. They can reduce visibility and damage soil materials in built environments. CO_2, released to the atmosphere from anthropogenic sources such as fossil fuel combustion generally and in transportation in particular, is the most important of the "greenhouse gases" that could lead to global and regional climate disruption. The consequences could be drastic, including sea level rise, more severe weather patterns, changes in the location and production of vegetation, including forests and agriculture, and a variety of ecological, physical, economic, and demographic impacts with serious political consequences.

Our estimates are comprised of emissions from vehicle tailpipes and other energy combustion processes for the propulsion of the transportation modes. While they are important, we were unable to estimate emissions from upstream sources. Emissions to the air and ground of other pollutants and from other aspects of the whole transportation system can also have important health and environmental effects, and associated social costs. Some of these are evaporative emissions and spills of toxic materials including lubricants and solvents at filling stations and runoff of tire materials left on the road. These additional impacts have not been included in this analysis, but if included, would have less of an impact in the Moderate, Aggressive, and Visionary scenarios because of reductions in VMT and energy use.

According to our estimates, an energy efficient transportation scenario should lead to a decrease in emissions, and bring non-attainment areas into attainment status. Table 5.6 summarizes the Reference Scenario emissions.

The Reference Scenario reflects the current clean air policies, and as such the general trend of emissions is to decrease with time. Nevertheless, the Reference Scenario has the potential to generate over 235 million metric tons of greenhouse gas CO_2, as well as significant quantities of other pollutants, in the year 2020.

This situation gets worse under the Rollback Scenario, but better under the Moderate, Aggressive and Visionary scenarios. Figures 5.5 and 5.6 show a comparison of year 2020 emissions under the five scenarios for CO_2 and for all the other pollutants, respectively. In addition, Table 5.7 shows the percent changes in emissions with respect to the Reference Scenario.The air quality implications of a reversal in the alternative fuels program (Rollback Scenario) are clearly reflected in the emissions estimates. In the year 2020, CO_2 emissions increase over 2.5 percent with respect to the Reference Scenario, while emissions of CO—a highly toxic gas—and HC increase about 17.0 percent and 9.7 percent respectively. Particulate material (TSP) increases by over 8,700 metric tons, almost 9.0 percent

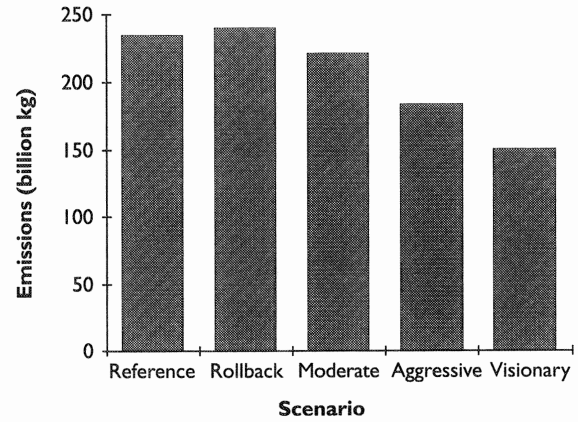


Figure 5.5 Year 2020 CO_2 Emissions

Scenario	1994	2000	2005	2010	2020
CO_2 (billion kg)	160	177	192	207	235
CO (million kg)	2182	1707	1494	1397	1489
HC (million kg)	501	425	382	354	374
NO_X (million kg)	759	728	734	760	875
SO_2 (million kg)	273	280	298	316	355
TSP (million kg)	121	101	92	89	97

Table 5.6 Emissions Estimates for the Reference Scenario

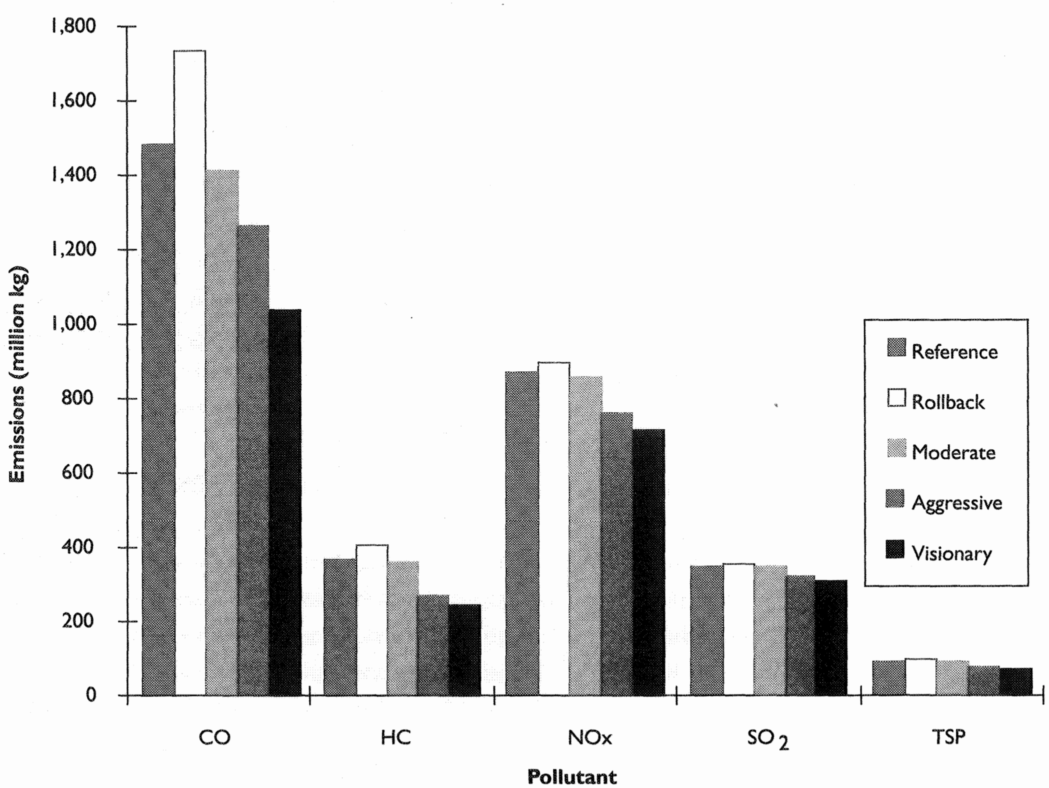


Figure 5.6 Year 2020 Emissions

higher than the Reference Scenario. SO_2 and NO_X increase 1.5 percent and 3.1 percent, respectively.

The Moderate Scenario has the potential to decrease CO_2 emissions by almost 13 million metric tons by the year 2020. This corresponds to over a 5.4 percent decrease in this greenhouse gas emission. All other pollutants also decrease, although at a lesser level.

The Aggressive Scenario indicates a stronger potential for significantly improved air quality as an added benefit of an energy-efficient transportation system. With respect to the Reference Scenario, HC emissions decrease by about 25.4 percent by the end of the analysis period, while CO_2 emissions decrease over 21.5 percent. There are two types of pollutant showing a one-decimal place percent decrease, namely the SOx at almost 6.9 percent and TSP at 9.3 percent.

The Visionary Scenario represents the potential changes that are possible with full use of advanced technologies and rational pricing policies in the transportation sector. The results indicate a considerable potential for improvement. In the year 2020, CO_2 emissions are 36.0 percent less than the Reference Scenario, closely followed by HC and CO at 33.2 percent and 30.0 percent decreases, respectively. TSPs decrease almost 20.0 percent, SOx over 10.0 percent, and NOx by 17.6 percent.

While some of the numbers discussed above may seem rather small, it is worth noting that our results represent total statewide emissions. For example, the 4.6 percent decrease in CO under the Moderate Scenario may not seem overwhelming, and could be regarded as so if these 68,410 metric tons were uniformly emitted over the entire state. In practice, however, these thousands of additional tons of CO are concentrated in urban areas, especially in large cities, many of which have already been classified as non-attainment areas for several years. Analogous reasoning is applicable to other pollutants considered in our analysis.

Conclusions and Recommendations

The analysis of the four transportation energy scenarios developed in this study indicate that there is the potential for a 33.5 percent decrease in total energy use by the year 2020, which is captured in the Visionary Scenario. This percent decrease is relative to

2020 Reference Scenario energy use and not to current energy use. Moderate polices can decrease such energy use by almost 5.5 percent in the year 2020, while a more aggressive perspective can improve such potential decreases to over 20.0 percent.

One way of appreciating the energy impacts of the various scenarios analyzed is to state each scenario's energy use in terms of the year in which the equivalent amount of energy was consumed in the Reference Scenario. For example, in the year 2020 under the Aggressive Scenario 2,354 trillion BTU are projected to be consumed, while under the Reference Scenario this amount of energy would have already been consumed by year 2005. In other words, the Aggressive Scenario would not consume the year 2005 Reference Scenario's amount of energy until 15 years later. Table 5.8 shows the equivalent Reference Scenario year for each scenario analyzed.

On the average, the effects of a reversal in the alternative fuels programs correspond to a two-year acceleration in the energy use. In other words, the Rollback Scenario would mean that the levels of energy use expected for the year 2022 under the Reference Scenario would occur in 2020. The Moderate Scenario shows a modest deceleration of energy growth. On the average, the policies included in the Moderate Scenario have the potential to decelerate the energy use level by two years in the beginning, with progressive improvement (three years lag in 2010, five in 2020).

This deceleration becomes more significant for the Aggressive Scenario, which already decelerates

Scenario	Pollutant	1994	2000	2005	2010	2020
Rollback	CO_2	0.00 %	-0.01 %	0.40 %	0.92 %	2.53 %
	CO	0.00 %	3.55 %	7.33 %	10.88 %	16.96 %
	HC	0.00 %	1.58 %	3.42 %	5.19 %	9.72 %
	NOx	0.00 %	0.51 %	1.20 %	1.85 %	3.08 %
	SO_2	0.00 %	0.48 %	0.96 %	1.50 %	1.46 %
	TSP	0.00 %	1.76 %	3.72 %	5.59 %	9.00 %
Moderate	CO_2	0.00 %	-1.35 %	-3.14 %	-4.78 %	-5.44 %
	CO	0.00 %	-5.37 %	-5.49 %	-5.74 %	-4.59 %
	HC	0.00 %	-2.34 %	-2.29 %	-2.74 %	-2.07 %
	NOx	0.00 %	-0.92 %	-1.25 %	-1.44 %	-1.46 %
	SO_2	0.00 %	-0.10 %	-0.51 %	-0.76 %	-0.83 %
	TSP	0.00 %	-1.86 %	-2.49 %	-1.92 %	-1.54 %
Aggressive	CO_2	0.00 %	-8.99 %	-13.98 %	-17.89 %	-21.51 %
	CO	0.00 %	-13.33 %	-13.79 %	-14.63 %	-14.79 %
	HC	0.00 %	-17.18 %	-17.67 %	-21.65 %	-25.42 %
	NOx	0.00 %	-9.39 %	-8.46 %	-8.14 %	-12.55 %
	SO_2	0.00 %	-2.51 %	-4.34 %	-5.58 %	-6.85 %
	TSP	0.00 %	-15.18 %	-12.28 %	-10.17 %	-9.27 %
Visionary	CO_2	0.00 %	-13.61 %	-19.41 %	-27.23 %	-36.02 %
	CO	0.00 %	-22.07 %	-23.43 %	-27.13 %	-30.01 %
	HC	0.00 %	-24.24 %	-24.78 %	-29.24 %	-33.15 %
	NOx	0.00 %	-12.36 %	-11.85 %	-13.10 %	-17.61 %
	SO_2	0.00 %	-0.63 %	-3.94 %	-7.46 %	-10.13 %
	TSP	0.00 %	-20.37 %	-18.39 %	-18.54 %	-19.66 %

Table 5.7 Change in Emissions Relative to the Reference Scenario

Scenario	Analysis Year				
	1994	2000	2005	2010	2020
Reference	1994	2000	2005	2010	2020
Rollback	1994	2000	2006	2012	2022
Moderate	1994	1998	2003	2007	2015
Aggressive	1994	1995	1996	1997	2005
Visionary	1994	1990	before 1990	before 1990	before 1990

Table 5.8 Year of Reference Scenario with Same Energy Use as Analysis Year

the energy levels by 5 years in the year 2000, increasing to 15 years in the year 2020. In other words, implementation of the Aggressive Scenario would maintain the 2020 energy use at the level expected for 2005 under the Reference Scenario. Finally, the Visionary Scenario indicates that there is the potential to bring energy use levels down to what they were before 1990, even for the year 2020.

Another important point to observe is that the trends shown in Table 5.8 accelerate with time. In other words, this potential to bring future energy consumption down to past levels will improve even more in the long term. For example, if we extrapolate these trends into the year 2030, the Visionary Scenario would be at the energy use levels of 1992, the Aggressive of 2013, and the Moderate of 2025. Analogous effects are observed in the Rollback Scenario: in 2030, it would be at the energy levels only expected for 2035 under the Reference Scenario.

The U.S. transportation system has been dominated by choices that are energy-consuming as well as polluting. Personal surface transportation is dominated by single-occupant vehicles, freight transport has a very high level of truck use, and the use of energy efficient modes such as rail and water is almost non-existent for passengers, and secondary for freight. In Texas, this situation has reached such levels as to make the state the fifth highest energy consumer in the entire world as a political entity.

Our study proposes and analyzes alternative scenarios that promote more efficient use of energy sources as well as a decreased reliance on non-sustainable fuels. The analysis indicates that, while rather aggressive policies are needed to affect considerable energy savings, benefits other than energy savings are also obtained, specifically improved air quality.

Depletion of petroleum-based energy sources and energy extraction from renewable sources are both practices aggressive to the environment, and this aggression increases as the transport demand increases. Pollution from mobile sources is a very important cause of non-attainment of clean air standards, as well as a health and an ecological hazard. The study clearly demonstrates that an energy-efficient transportation scenario has considerable potential to improve air quality, and, consequently, both public and environmental health.

We recommend further studies to improve the understanding of the relationship between energy efficiency and environmental issues. We also recommend studies to carefully monitor and analyze the impacts of energy-efficient and/or environmentally friendly transportation initiatives, such as TCM implementation in non-attainment areas. We hope that this study will serve the ultimate purpose of drawing more attention to the need for a sustainable, efficient, and environmentally friendly transportation system.

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