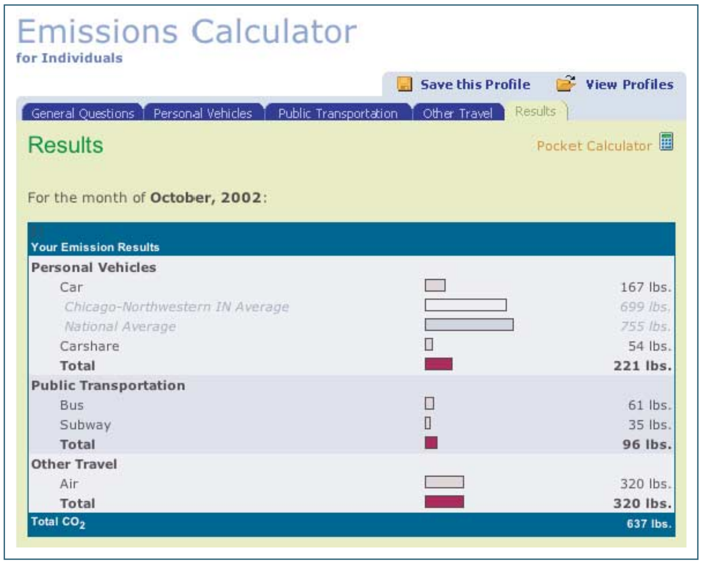
TCRP

REPORT 93

TRANSIT COOPERATIVE RESEARCH PROGRAM

Sponsored by the Federal Transit Administration

Travel Matters: Mitigating Climate Change with Sustainable Surface Transportation



TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

TRANSIT COOPERATIVE RESEARCH PROGRAM

TCRP REPORT 93

Travel Matters: Mitigating Climate Change with Sustainable Surface Transportation

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SUBJECT AREAS
Planning and Administration • Public Transit

Research Sponsored by the Federal Transit Administration in Cooperation with the Transit Development Corporation

TRANSPORTATION RESEARCH BOARD

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TRANSIT COOPERATIVE RESEARCH PROGRAM

The nation's growth and the need to meet mobility, environmental, and energy objectives place demands on public transit systems. Current systems, some of which are old and in need of upgrading, must expand service area, increase service frequency, and improve efficiency to serve these demands. Research is necessary to solve operating problems, to adapt appropriate new technologies from other industries, and to introduce innovations into the transit industry. The Transit Cooperative Research Program (TCRP) serves as one of the principal means by which the transit industry can develop innovative near-term solutions to meet demands placed on it.

The need for TCRP was originally identified in *TRB Special Report 213—Research for Public Transit: New Directions*, published in 1987 and based on a study sponsored by the Urban Mass Transportation Administration—now the Federal Transit Administration (FTA). A report by the American Public Transportation Association (APTA), *Transportation 2000*, also recognized the need for local, problem-solving research. TCRP, modeled after the longstanding and successful National Cooperative Highway Research Program, undertakes research and other technical activities in response to the needs of transit service providers. The scope of TCRP includes a variety of transit research fields including planning, service configuration, equipment, facilities, operations, human resources, maintenance, policy, and administrative practices.

TCRP was established under FTA sponsorship in July 1992. Proposed by the U.S. Department of Transportation, TCRP was authorized as part of the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA). On May 13, 1992, a memorandum agreement outlining TCRP operating procedures was executed by the three cooperating organizations: FTA, The National Academies, acting through the Transportation Research Board (TRB); and the Transit Development Corporation, Inc. (TDC), a nonprofit educational and research organization established by APTA. TDC is responsible for forming the independent governing board, designated as the TCRP Oversight and Project Selection (TOPS) Committee.

Research problem statements for TCRP are solicited periodically but may be submitted to TRB by anyone at any time. It is the responsibility of the TOPS Committee to formulate the research program by identifying the highest priority projects. As part of the evaluation, the TOPS Committee defines funding levels and expected products.

Once selected, each project is assigned to an expert panel, appointed by the Transportation Research Board. The panels prepare project statements (requests for proposals), select contractors, and provide technical guidance and counsel throughout the life of the project. The process for developing research problem statements and selecting research agencies has been used by TRB in managing cooperative research programs since 1962. As in other TRB activities, TCRP project panels serve voluntarily without compensation.

Because research cannot have the desired impact if products fail to reach the intended audience, special emphasis is placed on disseminating TCRP results to the intended end users of the research: transit agencies, service providers, and suppliers. TRB provides a series of research reports, syntheses of transit practice, and other supporting material developed by TCRP research. APTA will arrange for workshops, training aids, field visits, and other activities to ensure that results are implemented by urban and rural transit industry practitioners.

The TCRP provides a forum where transit agencies can cooperatively address common operational problems. The TCRP results support and complement other ongoing transit research and training programs.

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The members of the technical advisory panel selected to monitor this project and to review this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. The opinions and conclusions expressed or implied are those of the research agency that performed the research, and while they have been accepted as appropriate by the technical panel, they are not necessarily those of the Transportation Research Board, the National Research Council, the Transit Development Corporation, or the Federal Transit Administration of the U.S. Department of Transportation.

Each report is reviewed and accepted for publication by the technical panel according to procedures established and monitored by the Transportation Research Board Executive Committee and the Governing Board of the National Research Council.

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Sharon Feigon, Manager of the Research and Development Division at CNT, was the principal investigator. The other authors of this report are Ryan Mooney-Bullock, Research Analyst, CNT; David Hoyt, Research Analyst, CNT; and Lisa McNally, Research Analyst, CNT. Research assistance was provided by William Eyring, Senior Engineer, CNT; Jessica Drenth, Research Analyst, CNT; and Jen McGraw, Coordinator, Community Energy Division. Information technology and additional data analysis were conducted by Peter Haas, Technical Information Manager, CNT; Timothy Lang, Website Developer, CNT; Paul Smith, Information Technology Designer, CNT; and Larry Holish, Database Consultant. Review and consulting services were performed by Sarah Campbell, President, TransManagement; and Dennis Leach, Senior Associate, TransManagement.

Staff at CNT would like to thank the members of the TCRP H-21 supervisory panel for their encouragement, and the many useful suggestions offered during the preparation of this report.

FOREWORD

By Dianne S. Schwager
Staff Officer
Transportation Research Board

TCRP Report 93: Travel Matters: Mitigating Climate Change with Sustainable Surface Transportation will be of interest to transportation agencies, environmental organizations, and communities concerned about greenhouse gas emissions. The report and the TravelMatters website (developed as part of this project) are designed to present information on climate change and to examine how greenhouse gas emissions from transportation may be reduced. Both the print and web-based research products review the capacity of public transportation to mitigate greenhouse gas emissions and present this information in a format accessible to transportation professionals and the general public.

Under TCRP Project H-21, "Combating Global Warming through Sustainable Surface Transportation Policy," the Center for Neighborhood Technology and TransManagement produced the report, *Travel Matters: Mitigating Climate Change with Sustainable Surface Transportation* and the website, *www.TravelMatters.org*. In both formats, key strategies for reducing transportation emissions—increasing the use of transit, changing land-use patterns, and adopting energy-efficient technologies and fuels in transit fleets—are discussed.

The TravelMatters website includes two on-line calculators that track greenhouse gas emissions for individuals or transit fleets and a series of geographic information systems maps illustrating the correlation between land use, auto use, and carbon dioxide emissions. Both the print and website products present information on land-use factors that generate demand for travel; ways transit agencies can modify current operating systems to maximize potential ridership; and the potential emissions benefits of alternative, low-emissions technologies available to transit agencies.

In October 2002, the TCRP Oversight and Project Selection (TOPS) Committee allocated funding for TCRP Project H-21A,which will enhance the capacity of the TravelMatters website to calculate transportation emissions regulated by the Clean Air Act. The second phase of the project will be completed in 2004 and will then be integrated into the two existing on-line calculators and website content. Completed research on local transportation decisions as they relate to mobile source criteria pollutants, together with curricular materials and a prototype transit trip planning emissions calculator, will be available through TRB.

TCRP Project H-21A will also be used to expand the TravelMatters website to include an on-line instructional resource for teachers and students that will provide interactive lesson plans and activities drawing from TravelMatters web content. Instructional materials will be made downloadable, for access from the classroom and home. Project funds will also be used to develop a calculator for use in conjunction with on-line transit agency trip planners. The tool will calculate greenhouse gas and criteria emissions corresponding to selected transit routes and the emissions avoided by any auto trip replaced by transit.

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TRAVEL MATTERS: MITIGATING CLIMATE CHANGE WITH SUSTAINABLE SURFACE TRANSPORTATION

SUMMARY

THE CHALLENGE OF GLOBAL CLIMATE CHANGE

A majority of scientists now agree that the Earth's climate is warming, as indicated by a rise in the average surface temperature of the earth. Positive climate change (warming) is thought to be the result of human-generated emissions, principally of carbon dioxide (CO_2). Carbon dioxide, like the greenhouse gases methane (CH_4) and nitrous oxide (N_2O), allows solar radiation to pass through the atmosphere, but prevents surface radiation from escaping to outer space, effectively "trapping" it. This process leads to an overall increase in surface temperature. The observational evidence for positive climate change is circumstantial but extensive: direct measurement has established that atmospheric carbon dioxide levels have increased since the industrial revolution and the related surge in fossil fuel consumption. The gas physics behind the "heat-trapping" greenhouse effect is not disputed, and the man-made exacerbation of the greenhouse effect is considered to be very likely. The ultimate effects, however, remain uncertain. The premise of the report, based on a review of climate change science summarized in Chapter 2, is that enough is now known, despite the uncertainties of measurement and forecasting, to warrant prudent actions to moderate or reduce emissions of greenhouse gases (GHGs). Much of what can be done in this regard will have the multiple effects of improving air quality and human physical health, as well as increasing fuel efficiency. Although improving personal and transit vehicle fuel efficiency is one tactic in any future GHG reduction strategy, another equally important tactic involves expanding the overall share of transit in U.S. transportation. This report concentrates on such transit-related strategies.

THE TRANSPORTATION SECTOR AND GREENHOUSE GASES

The United States produces one-quarter of the world's global GHG emissions. (see U.S. Department of Transportation, *Energy Data Book,* ed. 22 (2000) [http://www.cta.ornl.gov/data/Index.html]). As described in Chapter 1, the transportation sector accounts for one-third of U.S. emissions. This makes American transportation a substantial factor in the global climate change equation and, as such, one of the primary targets of any comprehensive emissions reduction strategy. The strategy outlined in the chapters that follow is composed of three elements: (1) identifying ways to reduce per capita miles driven by encouraging transit use and promoting transit-supportive land use patterns, (2) implementing energy-efficient transit fuels and technologies, and (3) developing tools to educate individuals, planners, and transit agencies regarding the climatological consequences of travel decisions.

TRANSIT-SUPPORTIVE POLICIES AND CLIMATE CHANGE

In many places, people drive not because they want to, but because there are few practical alternatives. Where transit options do exist, poor service, management, and marketing often fail to attract potential riders. Enhancing transit usage means addressing both short-term operational problems and broad, long-term issues of transit-supportive urban planning, zoning, and land use. In the short term, there are many low-cost actions open to transit agencies to make the transit experience more pleasant for the public, whether this means maintaining the interior and exterior cleanliness of a vehicle, providing customer service training for personnel, or offering efficient and comfortable means of access and egress to vehicles at transit stops. Chapter 3 presents selected examples of such operational, service, and marketing programs.

Beyond the aspects of transit service and performance, demand for transit is even more significantly affected by the physical characteristics of a place, such as residential density, street layout, land use mix, transit accessibility, and an area's friendliness to pedestrians and bicyclists. Together, these aspects of an urban location determine the most efficient mode of transportation available to an individual. Where these local characteristics work together to encourage automobile use, GHG emissions will be high. Where these local characteristics support mass transit and nonmotorized forms of transportation, GHG emissions will be low—as can be seen in the maps of household GHG emissions in Chapter 3. This link, visually represented, shows how local land use patterns can have global consequences. It also opens the door to a range of local actions (surveyed in Chapter 3) that are available to regional planners, developers, community groups, and transportation agencies and can make public transportation a more viable mobility option.

FUEL-EFFICIENT AND LOW-EMISSIONS TRANSIT TECHNOLOGY

Transit agencies in large urban areas often are constrained by regulations on exhaust gases known to cause smog and acid rain. In order to meet emissions requirements, agencies have invested millions of dollars to convert from diesel to cleaner-burning technologies, such as compressed natural gas (CNG). Although currently there is no regulatory requirement to reduce GHG emissions from transit vehicles, increasing the fuel efficiency of transit vehicles effectively reduces CO_2 while cutting operating costs and regulated pollutants. Based on a review of the existing literature, interviews with practitioners, and consultation with developers of Argonne National Laboratory's Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Model, the research team compiled the comparative CO_2 benefits of alternative fuels and has presented them in a chart in Appendix A. Appendix C includes a tabulation of the hypothesized costs or savings per ton of CO_2 for each alternative fuel type.

Chapter 4 synthesizes the largely theoretical results of GREET modeling with other, more empirical evidence from simulated road-tests. While all alternative fuels, with the exception of methanol, show modest-to-large CO_2 benefits in the GREET model, this is contradicted in empirical testing of natural gas. However, 100% biodiesel, eliminates virtually all regulated and GHG emissions, as does hydrogen manufactured with a renewable energy source. GREET and empirical tests are in agreement that virtually any of the alternative fuels, and even petroleum diesel, achieve dramatic GHG reductions when used in a hybrid electric or a fuel cell engine. Using available fuels and technologies (e.g., a hybrid–electric powered bus), it is possible to cut operating costs and to lower regulated and GHG emissions dramatically. Using technologies and fuels still in development (e.g., hydrogen fuel cells), it will be possible to reduce regulated and GHG emissions even further.

EDUCATIONAL TOOLS

In the United States, most people are unaware of how much carbon dioxide and other GHGs their daily activities emit into the atmosphere. The emissions calculators designed for this project and hosted at the website, www.TravelMatters.org, are intended to educate people about the emissions that their transportation choices generate, and to encourage them to consider shifting to lower-emissions modes. The calculators, described in Chapter 5, provide user-friendly tools for quantifying GHG emissions generated by an individual's travel choices, or the operation of an entire transit fleet. Both calculators use estimates of fuel consumption by type of vehicle to calculate the resulting GHG emissions. Ridership on a transit system is used to calculate the emissions that a system is offsetting by providing transit service. The calculators allow transit agencies to measure their GHGs and provide information comparing alternative technologies and fuels.

In October 2002, TCRP allocated funding to enhance the capacity of TravelMatters to calculate transportation emissions regulated by the Clean Air Act. The enhanced emissions calculators will also be designed to function as part of an on-line transit trip planner, allowing transit users to determine emissions savings stemming from use of transit along specified routes. Project extension funds will also be used to develop online curricular materials dealing with climate change, available for use by high-school students and teachers. Included in the module will be a version of the emissions calculators adapted especially for classroom use.

CHAPTER 1

INTRODUCTION AND RESEARCH APPROACH

ROLE OF TRANSPORTATION IN GLOBAL CLIMATE CHANGE

Greenhouse gases absorb and reradiate low-level radiation in the atmosphere and therefore have a heat-trapping effect. Although the presence of carbon dioxide and water vapor, the two most common greenhouse gases (GHGs), in the atmosphere keep the Earth's temperature warm enough for life to survive, rapid burning of fossil fuels over the last century has released GHGs (mostly carbon dioxide) into the atmosphere at a rate higher than at any time in at least the last 20,000 years (see U.N. Intergovernmental Panel on Climate Change, *Third Assessment Report. Climate Change 2001: The Scientific Basis*, "Technical Summary," (2001), C.1 [http://www.grida.no/climate/ipcc_tar/wg1/016.htm#co2]). Currently, around 8% of the world's annual carbon emissions originate in the U.S. transportation sector. Mounting levels of GHGs are absorbing heat and causing the Earth's average surface temperatures to rise. Scientists hypothesize that global warming could cause significant changes in ocean level, weather, and precipitation patterns, all of which could dramatically impact human populations and the natural environment.

If properly understood, the potential benefits of reducing GHGs are substantial enough to induce municipal, regional, and state authorities to take action on climate change independently of a large federal initiative. For example, any tactic for reducing GHGs from transportation will also reduce emissions of pollutants regulated by the Environmental Protection Agency, currently a significant challenge for many municipalities. Sustainable surface transportation can be implemented locally and regionally with the collaboration of citizens' groups, transit agencies, governments, and metropolitan planning organizations. Although currently there are few initiatives that specifically target GHG mitigation on a local level, the fact that carbon emissions are so closely tied to energy efficiency means that strategies for controlling GHGs can be based on already existing transportation efficiency programs, such as improved transit service and transit-oriented land use. Lower GHGs, essentially, are a collateral benefit of sustainability and smart growth strategies. These can include everything from the individual choice to commute by bicycle rather than automobile, to the municipal construction of new rapid transit or commuter rail, or community development of affordable housing or employment near transit. All of these items have the potential to reduce carbon emissions by dropping the demand for automobile use.

PROJECT OBJECTIVE

The objective of TCRP Project H-21, "Combating Global Warming Through Sustainable Surface Transportation Policy," together with its companion website, www.TravelMatters.org, is to present educational materials on the subject of climate change and to examine how GHGs from transportation may be reduced. Both the print and web-based versions of the project review the capacity of public transportation to mitigate GHGs and present this material in a format that is accessible to both lay individuals and transit professionals. Three strategies for reducing transportation emissions are identified in the report as follows:

1. Increasing the use of public transit (Chapter 3),
2. Reforming corresponding land-use practices (Chapter 3), and
3. Adopting energy-efficient technologies and fuels for transit fleets (Chapter 4).

The project website includes two online calculators that track travel emissions for individuals or transit fleets and a series of geographic information system (GIS) maps illustrating the positive correlation between land use, auto use, and carbon dioxide emissions. Both versions of the project present information on the land use factors that generate demand for travel; strategies that transit agencies can use to modify current operating systems to maximize potential ridership and potential emissions benefits of alternative, low-emissions technologies available to transit agencies.

RESEARCH APPROACH

"Combating Global Warming Through Sustainable Surface Transportation Policy" encompasses secondary research on the science of global climate change, case studies on local sustainable transportation systems, analysis of alternative transit vehicle technologies, and web-based tools that can be used to calculate the GHG emissions of transit service or individual travel choices.

Research carried out in the preparation of the report began with a synthesis of the state of scientific knowledge on the subject of global climate change, an analysis of the sources of total U.S. carbon emissions, and the emissions contribution of the surface transportation sector. To understand the factors that shape the substantial automobile use (and resultant high emissions) that is characteristic of the American urban landscape, the research team reviewed the ways in which land use and urban form condition travel demand. Like the authors of several other recent studies on transportation and emissions (discussed in Chapters 2 and 3), the research team found that strategies for smart growth in urban areas and increased use of public transportation emerged as feasible ways to lower transportation sector emissions. The research team then conducted case studies of three locations that combine exemplary transit service with economic development strategies that reduce vehicle travel. Chattanooga, Tennessee, was selected for its forward-looking adoption of new electric vehicle technology to serve its downtown shopping district, which also contributed to the revitalization of a struggling city center. Santa Monica, California, was studied for its celebrated and heavily used bus system. Arlington County, Virginia, was chosen as an example of effective and prosperous transit-oriented development in a suburban location, which has been guided over decades by transit-supportive regional planning.

After reviewing the literature on climate change, travel demand, and land use, the research team surveyed the field of alternative transit fuels and technologies. This entailed interviews with transit practitioners and alternative fuels researchers, as well as a synthesis of the latest data on emissions testing, to determine which of the fuels and technologies currently available and/or in development are most likely to reduce GHGs. The result of this research is both a narrative and tabular comparison of the emissions reduction potential of various transit fuels and technologies, as well as their associated implementation costs. (See Chapter 4 and Appendix G.)

On the basis of the above research, the report includes a model that estimates GHG transit emissions for a timeframe that is between 20 and 40 years in the future (See Appendix B). The model is designed to illustrate total transit emissions based on several different scenarios reflecting the adoption of alternative technologies and fuels. The model scenarios demonstrate the impact that alternative fuel and technology adoption can have on total emissions from the transit industry.

The most labor-intensive aspect of the project involved the design and testing of a website to host the results of the project research and various decision-support tools provided exclusively online and intended to help individuals, transit agencies, and municipal planners understand how GHGs are generated (by both individuals and transit systems) and provide options for minimizing emissions from the transportation sector. The tools, hosted on www.TravelMatters.org, consist of two emissions calculators, one of which is intended for transit agencies and the other for individuals. The calculators provide an easy-to-understand way to measure the emissions resulting from individual travel choices or from the operation of a particular transit fleet. GIS maps accompanying the calculators illustrate national carbon emissions from vehicle travel at both the county and household level. GIS maps of regional and household carbon emissions for Chicago, Los Angeles, and San Francisco also are provided in this report and on the website. All of these maps show that comparatively low household carbon emissions are associated with high-density urban areas and that, in contrast, high household emissions are found in sprawling or rural areas.

The final task of the project concerned disseminating the results and marketing the decision-support tools to target audiences.

Climate Change: Background, Evidence, and Debate

For a century, scientists have known that carbon dioxide (CO_2) has the capacity to absorb and reradiate low-level radiation. In and of itself, this is not a cause for concern. The heat-trapping property of CO_2 has the beneficial effect of keeping the Earth's climate relatively warm. Unlike the gaseous and particulate pollutants tracked by environmental regulators, CO_2 is not a harmful gas, but moves through the air, water, and terrestrial ecosystems in large quantities as part of the global carbon cycle upon which life depends. The flow of carbon through the various stages of the cycle typically attains equilibrium—a balance between the carbon produced and absorbed—that endures for centuries and contributes to the stability of the Earth's climate.

Over the last several hundred years, a new element has been introduced into the carbon cycle: human activity. The economic activities of growing and industrializing societies have increased the amount of carbon being released into the atmosphere, primarily through deforestation and the combustion of fossil fuels. Until roughly 50 years ago, the consensus was that this increase in atmospheric carbon could be absorbed by the oceans and taken up by terrestrial vegetation. However, as scientists have learned more about the sensitivity of the Earth's climate to various perturbations, a consensus has emerged that the equilibrium of the carbon cycle is being distorted—that more carbon is being introduced into the atmosphere than is being absorbed by either land or ocean—and carbon is therefore remaining in the atmosphere to absorb radiation. Other gases, some man-made, were found to have heat-trapping properties as well and were classified as GHGs. The primary GHGs are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and chlorofluorocarbons (CFC-11, -12, -113, CCl_4).

Although GHGs are emitted locally, they distribute rapidly and evenly throughout the atmosphere. Concentrated emissions in one geographic region, therefore, will eventually affect the atmosphere globally. Although the consequences of climate change affect everyone, the fact that a few regions produce large amounts of carbon dioxide and other gases means that reducing emissions in these areas can go far toward an overall reduction of GHGs. The United States, for example, is responsible for a quarter of all annual worldwide carbon dioxide emissions. Any substantial emissions reduction measures taken by the United States would have significant global consequences.

A Sector-Based View of Carbon Dioxide Emissions

Each of the four sectors of the U.S. economy—industrial, commercial, residential, and transportation—is responsible for a significant share of national emissions. All of these sectors are heavily reliant on energy derived from fossil fuels, which emit CO_2. The surface transportation sector alone accounts for a third of all U.S. carbon dioxide emissions. Surface transportation includes cars, trucks, buses, trains, and boats, all of which rely predominately on fossil fuels. With growth in the economy overall, activity in the transportation sector has grown as well, resulting in a steady increase in the number of vehicle miles traveled in passenger and freight vehicles over the past two decades. As the number of light trucks and SUVs in use has risen precipitously, the average fuel efficiency of vehicles on the road has dropped, despite technological advances over the last 20 years. Because they make up such a relatively large single source of global emissions, systematically addressing U.S. transportation emissions by increasing transit use, encouraging the adoption of alternative fuels and technologies, and lowering travel demand by planning for high-density, mixed-use urban development, can have a mitigating effect at the global level.

A Place-Based View of Carbon Dioxide Emissions

The physical characteristics of a place, or urban form, influence how often, how far, and by what means people travel. Characteristics such as the density of households in a given area, the mixture of land uses, access to public transportation, and pedestrian friendliness can determine the range of travel options available to local residents. A person living in a residential subdivision with cul-de-sac streets and few sidewalks has little choice but to drive to the grocery store and to a job. A person living in an area laid out in a grid of interconnecting streets with a mixture of land uses supported by a comprehensive transit system can choose to walk, bicycle, use transit, or drive. Even with the option to drive, the physical layout of the latter community is likely to generate fewer vehicle trips, and shorter trip lengths overall, and will produce fewer CO_2 emissions than the former community.

Despite the many ways in which emissions reductions can be approached, there are few substantive local or regional initiatives that address global warming directly. While this is changing gradually at the local and state levels, an optimal short-term strategy for GHG reduction would be based on existing programs, such that reductions in GHGs would come as collateral benefits of efforts to improve air quality, reduce pollution in nonattainment areas, and avoid suburban sprawl. Sustainability organizations tend to focus on the environmental, social, and economic problems that are directly experienced in their communities. Such initiatives address local problems in ways that involve transportation policy—making them an excellent resource to build upon for the purpose of reducing CO_2 emissions. By taking up issues such as improved transit service and infrastructure, affordable housing close to employment, retail development near transit stops, and the development of vacant urban land instead of open land outside the city, these organizations are helping to reduce GHGs by decreasing individuals' needs to drive a car. Sustainability and smart growth initiatives recognize that America's current model of development, its limited range of transportation choices, and the quantities of fossil fuels consumed cannot be sustained indefinitely.

Low-Emission Transit Technologies

Reducing personal vehicle travel, particularly single-occupancy trips, is a primary goal for many air quality and smart growth initiatives. It is also, indirectly, the goal of most transit agencies, as they try to increase their ridership by attracting new transit riders. Public buses and trains produce fewer emissions per person than the equivalent number of auto trips. Even so, transit vehicles are operating with the fuels and technologies of 30 years ago. A number of alternative fuels and technologies have been developed for public transportation, but not widely implemented. Much still can be done to make low GHG emissions fleets affordable and practical for transit agencies and to create incentives for transit agencies to convert their fleets. Fortunately, mitigating climate change is not the sole incentive for transit systems to adopt advanced technology. Rapidly developing technologies, such as diesel hybrid engines, not only reduce regulated and GHG emissions, but save money on fuel, while delivering performance on a par with diesel. As discussed further in Chapter 4, not only do such fuel-efficient vehicles benefit air quality and human health, they also work for the financial bottom line.

SUMMARY

This report examines the ways in which individuals, communities, transportation planners, and transit systems can locally reduce GHG emissions from transportation. Even in the absence of federal policy that regulates GHG emissions, the benefits of the actions that reduce GHGs are so great that implementing them presents a win–win situation for communities. When individuals replace driving trips by walking, biking, or taking transit, they not only decrease GHGs, but also improve air quality. When transit agencies replace old diesel buses with efficient vehicles burning low-emissions fuels, they save money by decreasing fuel consumption, improve air quality, and reduce their emissions of regulated pollutants. When transit systems and planners commit to expanding investment in transit infrastructure and improving transit access and frequency, they give more individuals the opportunity to drive less and commit to improving air quality. In all, actions that reduce GHG emissions also can work toward federal, state, and local air quality requirements; improve the health of communities and their residents; and encourage people to spend time and money in their neighborhood business districts. Sustainable surface transportation is a key strategy for lowering the U.S. contribution to global warming, while achieving other critical goals, such as clean air and the physical and economic health of communities, to name only a few.

CHAPTER **2**

CLIMATE CHANGE RESEARCH

INTRODUCTION

It is now widely accepted within the scientific community that the quantity of CO_2 and other GHGs present in the atmosphere has increased steadily since the Industrial Revolution, and particularly since the mid-twentieth-century. Current levels of atmospheric CO_2 are higher now than at any point during the past 420,000 years (see U.N. Intergovernmental Panel on Climate Change, *Third Assessment Report. Climate Change 2001: The Scientific Basis*, "Summary for Policymakers," (2001). [http://www.grida.no/climate/ipcc_tar/wg1/index.htm]). It is also widely accepted that the average surface temperature of the Earth has increased by a significant fraction of one degree Celsius over the last century. Determining the causal relation between these two sets of empirical observations—increasing concentrations of GHGs and rising global average surface temperatures—is the crux of climate change science. Until quite recently, uncertainty existed as to whether the observed changes in temperature were significant, or simply natural fluctuations of climate. Through close monitoring of climatological indicators such as ocean and atmospheric temperatures, the functioning of clouds and moisture in trapping and dispersing heat, and the behavior of oceans in absorbing CO_2 and regulating global surface temperatures, climate researchers have determined with greater certainty than only a decade before, that most warming of the last 50 years is a result of human, GHG-generating activities (as will be shown in the following sections).

Our understanding of climate change is based on two sets of evidence: direct and proxy climate measurements and computer simulations of future climate behavior. The set of direct observational data consists of surface temperature measurements, atmospheric samplings, and various environmental observations, such as the retreat of alpine glaciers, earlier-than-usual migration of seasonal waterfowl, and the rising temperature of ocean surface waters. To this body of data also belong so-called proxy, or *paleoclimatological*, data, which includes evidence of past climatic conditions used to reconstruct major long-term fluctuations of the Earth's climate, such as ice ages. Evidence from ice core samples, tree rings, and sea floor sediments are the basis for this extension of the climatological record back in time. Computer-generated models, making up the second major body of evidence in the study of climate, are calibrated against the record of past climate variation, in order to reliably predict the likely effect of natural and external forcings of the Earth's climate. The accuracy of computer simulations is directly dependent upon the extent and accuracy of the climate data fed into the computers used to create simulations. Although less well established than the observational evidence, computer-simulated climate projections have improved tremendously over the last 15 years. Advances in computing power have made it possible not only to improve forecasting capability, but also to better test for the statistical significance of any number of potential factors in the climate-change equation.

The evidence in support of human-induced climate change is evaluated in terms of probability. Any credible demonstration must take into account the sum weight of many different indicators, and the degree to which these indicators contradict or reinforce one another. Significantly, in the time between the First and Third IPCC Assessments of the United Nations Intergovernmental Panel on Climate Change (1990 and 2001), research has strengthened agreement between various fundamental data sets, partly in response to criticisms leveled at the integrity of long-term temperature records. The well-publicized possibility of sampling errors in surface temperature measurements, arising from such distortions as urban heat islands, has been reduced substantially. Similar improvements in reliability apply to most observational measurements. Increasingly, scientific uncertainty is concentrated on the detection and measurement of climate system feedbacks, or the way in which dynamic processes such as cloud formation or ocean circulation act to accelerate or dampen changes in global temperatures. While knowledge in these areas is still evolving, the United Nations Intergovernmental Panel on Climate Change (U.N. IPCC) concluded in 2001 that "the effect of anthropogenic greenhouse gases is detected," thus shifting the focus of uncertainty from the reality of human influence on climate change to the question of the intensity and timing of that influence. (U.N. Intergovernmental Panel on Climate Change, *Third Assessment Report. Climate Change 2001: The Scientific Basis*, "Technical Summary" (2001), 12.6, "Detection of Climate Change and Attribution of Causes. Concluding Remarks." [http://www.grida.no/climate/ipcc_tar/wg1/467.htm]) A subsequent report issued by the U.S. Environmental Protection Agency, in fulfillment of U.S. treaty obligations under the U. N. Framework Convention on Climate Change, did not dispute the analyses or findings of the IPCC report, although it emphasized the provisional state of scientific knowledge in the field (*2*). The IPCC report was reviewed by the the National Academy of Sciences in 2001, which found "the body of the WGI [Working Group I] report is scientifically credible and is not unlike what would be produced by a comparable group of only U.S. scientists working with a similar set of emissions scenarios, with perhaps some normal differences in scientific tone and emphasis"(*3*, p. 22). The IPCC's third report forms the basis for the synthesis that follows.

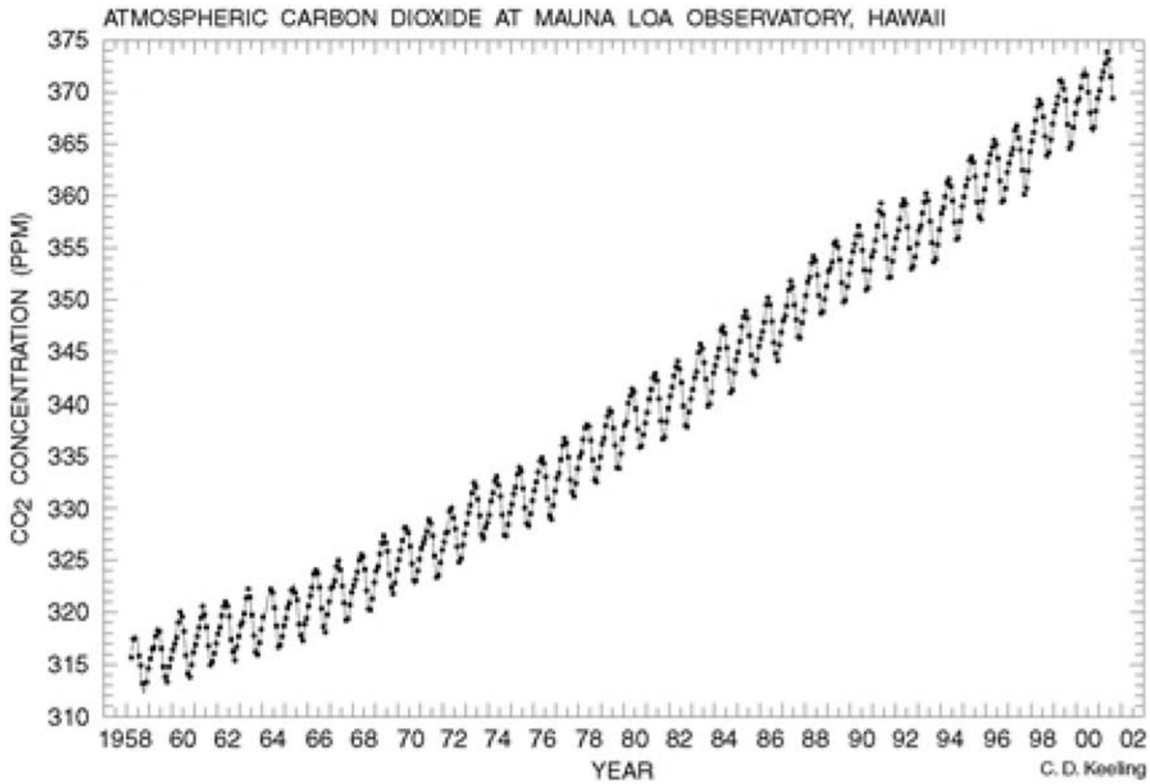
CLIMATE CHANGE: HISTORICAL BACKGROUND

The theory behind global warming—or, as it is referred to in the technical literature, global climate change—is over a century old. It arose in the context of the growing consumption of fossil fuels, particularly coal, that was transforming European economies at the end of the nineteenth and the beginning of the twentieth centuries. As early as the 1850s, such industrial centers as Manchester, England, were notorious for surrounding themselves and the nearby countryside in a shadow of coal smoke. Across the Atlantic, travelers wrote of the great banner of haze that announced the approach to Chicago from across the prairies in the 1880s. In 1896, the Swedish chemist Svante Arrhenius saw such sights as proof of modern industry's bottomless appetite for fuel. In order to meet industrial needs, he argued, tons of carbon, buried in the earth for millions of years, were being rapidly dissolved directly into the atmosphere. The rate at which this was occurring, Arrhenius observed, was historically unprecedented (*4*, *5*). When this observation was linked to the well-established heat trapping property of CO_2 and other atmospheric gases, the prospect of human, gas-generating activity leading to a warming of the Earth's atmosphere announced itself as a disturbing possibility (*6*, pp. 488–491). Over time, this simple theory, and the uncontroversial gas physics that underlie it, have become so compelling that they are now the backbone of an international research effort to untangle the much more complex patterns of global atmospheric behavior (*7*).

Despite the fact that the bulk of measured warming in global mean temperatures occurred before 1940, scientists during this period were confident that the carbon being released into the atmosphere was maintained at equilibrium by the ability of the Earth's oceans to absorb it in vast amounts (*8*). It was not until the 1950s, a period of innovation in the geophysical and atmospheric sciences, that concerted research began on the subject of GHGs. The tide of scientific opinion began to turn when Roger Revelle, working at the Scripps Institution of Oceanography at the University of California, San Diego, proposed that the volume of CO_2 in the Earth's atmosphere was out of equilibrium with the capacity of the oceans and landmasses to absorb it. Revelle was able to prove this by performing a number of experiments measuring the carbon content of the air, and in seafloor sediments (*9*). It was under his supervision that the CO_2 monitoring station on Mauna Loa, Hawaii, was established. Readings from this station and a station in Antarctica established that atmospheric CO_2 has increased steadily since 1957 (Figure 2–1). Since carbon that is a byproduct of human activities (i.e., fossil fuel combustion or slash and burn deforestation) is identifiable on the basis of a chemical structure distinct from that of naturally occurring carbon, Revelle further established that this is the result of human activities.

Focused research on climate science gathered momentum in the 1970s, when world population growth (*8*) and the oil-related energy crisis became issues of primary concern for both the public and policy makers (*6*, p. ix–xii). The latter sought to understand the likely consequences of a world increasingly dependent on energy derived from fossil fuels, especially a potential surge in the use of coal. The first reports commissioned by the U.S. government dealing with CO_2 emissions addressed the economic, political, and environmental impacts of increased fossil fuel consumption both in the developed and developing worlds (*6*, *10*). Although awareness of the role of GHG emissions in climate change was increasing at this time, the energy and environmental legislation of the 1970s and 1980s was motivated largely by an interest in reducing U.S. dependency on foreign oil and in cutting emissions from cars and power plants that caused acid rain.

The upsurge of interest in fossil fuel combustion and climate change during the 1980s prompted both governmental and nongovernmental organizations to begin sponsoring research in climate science. Central to this effort was the United Nations' establishment of the IPCC in 1988, which laid the groundwork for an international research program. Since the science of climate change involves many gases—some natural, some synthetic—and their impact on a very complex system, the greatest challenge to climate researchers has been to isolate precise linkages of cause and effect. The instrumental measurements required must be assembled from a number of heterogeneous data sets from around the world and reconstructed from the historical record. Such comprehensive amassing of information, together with direct experimentation, is fundamental to differentiating between important changes that indicate climate warming from natural climate variability. One of the founding purposes of the IPCC was to organize the coordinated, international effort that would be necessary to advance scientific understanding of the atmosphere and its response to human-induced emissions. At the time of the first IPCC report, monitoring climate change was a task for which scientific infrastructure was undeveloped. Because of the paucity of existing data, the IPCC called in each of its three reports for improvements in computer simulation capabilities, an increase in the range and accuracy of observational evidence, and further international efforts to monitor climate. [The first IPCC assessment report was published in three separate volumes. For the first and most general of



Source: Scripps Institution of Oceanography, UCSD.

Figure 2-1. Atmospheric carbon dioxide at Mauna Loa Observatory, Hawaii.

these, see: *Scientific Assessment of Climate Change—Report of Working Group I,* J.T. Houghton, G.J. Jenkins and J.J. Ephraums, eds. (Cambridge, UK: Cambridge University Press, 1990). For the second, 1995, assessment, see: *Climate Change 1995. The Science of Climate Change,* J.T. Houghton, L.G. Meira Filho, B.A. Callander, N. Harris, A. Kattenberg and K. Maskell (Cambridge, UK: Cambridge University Press, 1996). Of the several documents composing the IPCC Third Assessment Report, this research has drawn most from the *Third Assessment Report. Climate Change 2001: The Scientific Basis,* J.T. Houghton, Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden and D. Xiaosu, eds. (Cambridge, UK: Cambridge University Press, 2001).] The resources required to do all this (particularly the need for supercomputing capacity) puts climate science research beyond the range of almost all but nationally and internationally funded organizations.

By the 1990s, the prospect of climate change emerged as an issue in its own right, sufficient to justify consideration of certain energy- and technology-related policy measures. The 1997 Kyoto Protocol is the most well known example of this, but there exist a number of much more focused investigations that explore ways to mitigate GHG emissions. One report, produced by several different energy policy initiatives sponsored by the Clinton Administration and known informally as the 1997 "Five Labs Report" (*11*), relates global climate change directly to emissions from specific economic sectors, including transportation (second only to industry as a source of CO_2). Based on the collaborative research of laboratories such as Argonne, Lawrence Berkeley, Oak Ridge, Pacific Northwest National, and the National Renewable Energy Laboratory, the Five Labs Report framed its research in terms of the costs and benefits of carbon emissions reduction strategies. It concluded that, with a heightened private and public commitment to alternative technology research and development (R&D) across a number of economic sectors, it would indeed be possible for the United States to reduce carbon emissions significantly, more than making up for the expense through increased energy efficiency. The need for R&D investment was cited as especially great in the transportation sector.

The 2002 National Research Council (NRC) report, "Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards," was the next significant statement to follow the Five Labs Report. Its authors likewise were convinced that global climate change provides sufficient motivation to turn attention once again to automotive fuel efficiency: "The most important [reason for taking up the issue], the committee believes, is concern about the accumulation in the atmosphere of so-called greenhouse gases, principally carbon dioxide. Continued increases in CO_2 emissions are likely to further global warming."(*12*)

CLIMATE CHANGE SCIENCE: STATE OF THE FIELD

Roger Revelle suggested in 1982 that, despite all the uncertainty of climate forecasts, “Almost any reasonable estimate of how much fossil fuel will be burned in the coming years suggests that if CO_2 is indeed altering the climate, an unmistakable warming trend should appear in the 1990s.”(*8*, p. 38) Such has indeed been the case. Long-term temperature data establish the 1990s as the warmest decade, and 1998 as the warmest year since reliable records were begun to be kept in 1861 (see *Third Assessment Report. Climate Change 2001: The Scientific Basis,* B.1, “Technical Summary” (2001). [http://www.grida.no / climate / ipcc_tar / wg1 / 012.htm # b1].) Paleoclimatological data go further and establish the 1990s as most likely the warmest decade in 1,000 years. Most of this warming has occurred in far northern Canada and Siberia, and at night—representing what scientists refer to as a decline in the daily temperature range. From an anthropomorphic perspective, such trends might not appear to be immediate cause for concern. But the long-term, secondary effects of such warming in the northern latitudes—primarily the release of water from melting polar ice and geographical shifts in agricultural fertility—may be ecologically and socially disruptive on a global level. There is also the danger of unforeseen regional atmospheric changes, such as “a sudden large change in response to accumulated climate forcing” (*3*, p. 7) on the scale of the sudden appearance of the ozone hole over Antarctica in the 1980s.

Positive climate change—or global “warming” of the climate—is an extremely complex phenomenon, about which knowledge is constantly evolving. Scientific doubt as to the existence of a warming trend itself, however, is no longer tenable. Regarding the causes of this warming, the IPCC’s Third Assessment reports an improved degree of confidence over the previous review, presenting between 66 to 90% likelihood that “most of the observed warming over the last 50 years is likely to have been due to the increase in greenhouse gas concentrations.” (See *Third Assessment Report. Climate Change 2001: The Scientific Basis,* E.8, “Technical Summary” (2001). [http://www.grida.no/climate/ipcc_tar/wg1/028.htm#e8].) Although knowledge of short- and long-term variability in climate change is still imperfect, paleoclimatological data make it clear that the rate of increase in temperatures on a global (not just regional) scale, as well as the magnitude of the increase, is unmatched over a period of more than 20,000 years. (See *Third Assessment Report. Climate Change 2001: The Scientific Basis,* “Technical Summary” (2001), 12.6, “Detection of Climate Change and Attribution of Causes. Concluding Remarks.” [http://www.grida.no/climate/ipcc_tar/wg1/467.htm]). Conversely, efforts to explain recent warming with recourse to natural causes alone are less and less promising. The IPCC suggests that this is “bordering on unlikely” (just under 90% certainty) that human activity has played no role in the general warming of the climate. (See *Third Assessment Report. Climate Change 2001: The Scientific Basis,* “Technical Summary” (2001), 12.6, “Detection of Climate Change and Attribution of Causes. Concluding Remarks.” [http://www.grida.no/climate/ipcc_tar/wg1/467.htm].) Most computer models, in fact, fail to replicate the recent warming trends without the inclusion of some kind of human-induced influence within the simulation parameters.

As was concluded in the IPCC’s second assessment on global climate change, “Detection of a human-induced change in Earth’s climate will be an evolutionary and not a revolutionary process. It is the gradual accumulation of evidence that will implicate anthropogenic emissions as the cause of some part of observed climate change, not the results from a single study.”(*14*, p. 438; *15*) It is unlikely that a single argument will tip the balance in either direction, given the complexity of the problem and the statistical nature of the evidence. Scientific certainty will increase incrementally, as data time series are lengthened, but the present incompleteness of such data in no way invalidates the “strong theoretical basis for enhanced greenhouse warming,” (*1*, p. 256) which is in fact the justification for sustained, internationally coordinated research. What is crucial to any scientific explanation is that the many different lines of evidence not be at variance.

The recent controversy surrounding climate change has had to do primarily with the internal consistency of various data series, or the possibility that certain natural agents of climate change, such as fluctuating levels of solar radiation, were not taken into consideration. As of the IPCC’s *Third Assessment Report*, most of these concerns have been addressed, resulting in an overall increase in certainty regarding the human causes of a warming climate since the “impact of observational sampling errors has been estimated for the global and hemispheric mean surface temperature record, and found to be small relative to the warming observed over the twentieth century.” (*1*) The exceptionally consistent global warming observed during the years between the IPCC’s second and third assessments (including 1998, the warmest year of the century) further substantiate the general warming trend observed over the last 50 years. (See *Third Assessment Report. Climate Change 2001: The Scientific Basis*, “Technical Summary” (2001), Chapter 12 Executive Summary.” [http://www.grida.no/climate/ipcc_tar/wg1/440.htm].)

Evidence: Carbon Dioxide Emissions

The primary GHGs in the Earth’s atmosphere are water vapor (H_2O), carbon dioxide (CO_2), [CO_2 left in expanded form because it is part of a list of similar objects]methane (CH_4), chlorofluorocarbons (CFC-11, -12, -113, CCl_4), nitrous oxide (N_2O), ozone (O_3), and aerosols. After water vapor, which is not directly affected by human activities, CO_2 is the GHG most prevalent in the atmosphere. Because CO_2 circulates throughout the biosphere in such large volumes, it plays a primary role in the thermal regulation of the Earth's atmosphere. Methane, although it is the second most prevalent gas by volume, is four times as powerful as a heat-trapping gas, has more than doubled its pre-industrial concentration, has a shorter residence time in the atmosphere, and is generated in much smaller quantities than CO_2 (*16*). Scientific interest in climate change has therefore focused primarily on CO_2, its behavior in the atmosphere, its past and present concentrations, and its relation to human industrial activity.

Records of relative atmospheric CO_2 concentrations constitute one of the most basic building blocks of climate change science. Evidence for the increase of anthropogenic (human-made) CO_2 in the atmosphere is well established. Because carbon derived from the combustion of fossil fuels and organic matter (associated with deforestation) contains fewer carbon isotopes than would be found in carbon normally circulating through the carbon cycle, it is possible to determine the ratio of anthropogenic to naturally produced carbon (*17*). Measurements to this effect, drawn from atmospheric samplings at the research station at Mauna Loa, Hawaii, where readings have been taken continuously since 1957, and the U.S. research station at Point Barrow, Antarctica, establish a trend of rising CO_2 emissions due to human activity during the second half of the twentieth century.

When brought into relation with the next most substantial body of instrumental data—gas concentrations frozen in air bubbles taken from the Greenland and Antarctic ice sheets—researchers have been able to make long-term, historical comparisons of CO_2 levels. This paleoclimatological evidence, corroborated by ice cores drilled at a number of sites around the world, establishes that the present concentrations of CO_2 in the atmosphere are the highest in nearly half a million years (much longer than any individual cycle of glaciation and deglaciation), up 31% since the approximate beginning of the industrial revolution in 1750. Further, the "rate of increase over the past century is unprecedented, at least during the past 20,000 years." (See *Third Assessment Report. Climate Change 2001: The Scientific Basis*, "Technical Summary" (2001), C.1. [http://www.grida.no/climate/ipcc_tar/wg1/016.htm#co2].) Similar evidence has been obtained for the other GHGs (though some, such as CFCs, have actually begun to diminish at global levels). Thus, based on historical evidence and given the known properties of CO_2 as a heat-trapping gas, steadily rising levels of CO_2 should lead to a detectable rise in average global temperature over a long enough time span.

Evidence: Temperature Increases

The direct evidence for positive climate change does not, contrary to popular opinion, equate to something as straightforward as perceptibly warmer summers. Rather, the empirical basis for a warming of the Earth's climate rests upon a global average of surface temperature readings, or *mean surface temperature.* Mean temperatures are derived from aggregate data collected from measuring stations around the world. The earliest consistent record began in 1861. Determination of temperature prior to this period is obtained from the measurement of certain trace elements recovered from ice cores that are known to correlate to surface temperature. The range of such average temperatures is very small—only a fraction of a degree Celsius—but it is known that major climatic events of the past, such as glaciation, were accompanied by only incremental changes in the global mean temperature.

Records of global temperature are well established for the last century and a half, since consistent measurements have been taken. As the record is pushed further back in time, scarcity of data raises the degree of uncertainty, but temperature trends reconstructed from proxy evidence are largely uncontroversial. For temperatures prior to the mid-nineteenth century, scientists make inferences on the basis of other variables known to correlate with temperature. Analysis of tree rings from exceptionally long-lived species or from dead trees that have been preserved, can extend the temperature record several thousand years into the past (*18*). Gas concentrations and trace elements frozen in the Antarctic and Greenland ice caps provide a record of atmospheric conditions extending back nearly a quarter of a million years. Beyond this, seabed sediments and fossilized coral provide temperature indicators for climatic conditions that existed millions of years ago. Such long-term evidence is essential to determine the relative significance of a more recent and comparatively brief period of warming. On this basis, paleoclimatic data suggest that "the present CO_2 concentration has not been exceeded during the past 20 million years." (See *Third Assessment Report. Climate Change 2001: The Scientific Basis*, "Summary for Policymakers" (2001). [http://www.grida.no/climate/ipcc?tar/wg1/oog.htm].)

It is acknowledged, however, that mean temperatures alone are insufficient for the attribution of human-induced climate changes (*1*, p. 246). To bridge the inferential gap, throughout the 1990s researchers called for a wide array of experimental measurements of such phenomena as heat absorption by the oceans and the cooling potential of ocean cloud cover and atmospheric aerosols (*19*, *20*). Better knowledge of these processes would simultaneously reduce the speculative aspects of climate modeling (a controversial issue) and provide more direct evidence for the mechanics of climate change. A call by NASA Goddard Institute researcher James Hansen for closer study of oceanic temperatures was recently answered by a project at the National Oceanic and Atmospheric Association (NOAA) to establish a database of ocean temperature measurements from 1948 to 1998 (*21*). Analysis of these data demonstrated an average increase in ocean temperatures between depths of 0 to 300 meters. Still another data set was recently compiled by researchers studying subsurface ground temperature measurements from "boreholes" on six continents. Again, these data indicate a twentieth century warming trend that is the greatest in 500 years (*22*, *23*).

In addition to enlarging the climate change database, much recent work has been devoted to refining one or another of the data sets that provide evidence for an abrupt warming during the last 50 years. For example, questions arose in the 1990s as to whether thermometer readings used to calculate the global mean temperature are elevated by their location in urban areas, or *heat islands*, known to be hotter than the surrounding countryside. The temperature difference between cities and their surroundings is most notable at night—which would seem to offer one possible explanation for the observed global rise in nighttime minimum temperatures. Several considerations, however, have eliminated the possibility that urban areas are giving the illusion of a general warming trend. Studies carried out since the IPCC *Second Assessment Report* separate urban from rural temperature series in order to isolate any statistically significant difference between the two trends, and found that "there is little difference in the long-term (1880 to 1998) rural . . . and full set of station temperature trends." Even without separating urban from rural temperature readings, the average surface temperature record fits well with warming trends unaffected by urbanization such as borehole temperatures, reduced terrestrial snow and ice cover, and changes in temperature of the ocean. (See *Third Assessment Report. Climate Change 2001: The Scientific Basis,* "Technical Summary" (2001), Chapter 2.2.2.1. [http://www.grida.no/climate/ipcc_tar/wg1/052.htm#2221].)

Other Evidence of Positive Climate Change

Several trends continue to positively correlate with the temperature measurements described above. Most conspicuous is the overall reduction in area of surface snow cover, a trend documented in some places since the mid-nineteenth century (and with satellite data since the late 1960s). The recent National Academy of Sciences assessment reviews this evidence succinctly.

> The warming trend is spatially widespread and is consistent with the global retreat of mountain glaciers, reduction in snow cover extent, the earlier spring melting of ice on rivers and lakes, the accelerated rate of rise of sea level during the twentieth century relative to the past few thousand years, and the increase in upper-air water vapor and rainfall rates over most regions. A lengthening of the growing season also has been documented in many areas, along with an earlier plant flowering season and earlier arrival and breeding of migratory birds. Some species of plants, insects, birds, and fish have shifted towards higher latitudes and higher elevations (*3*, p. 16).

Measurements from submarines and satellites both suggest that the thickness and extent of Arctic sea ice have diminished since these readings first became available in the 1970s. The IPCC *Third Assessment Report* documents the retreat of five ice shelves in Antarctica over the course of the twentieth century; the National Snow and Ice Data Center put the number at seven since 1974. Less than a year after the *Third Assessment Report* appeared, Antarctica experienced the dramatic collapse of the Larsen B ice shelf in the late winter and spring of 2002. Attributed by scientists to "a strong climate warming in the region," the collapse of Larsen B lasted 31 days, during which a volume of ice larger than the state of Rhode Island—(3250 km^2) and 220 m thick disintegrated into the sea.(*24*)

The range of evidence described above is entirely circumstantial but its cumulative weight is considerable, and has done much to establish beyond question the fact, disputed in the late 1980s and early 1990s, that the Earth's atmosphere is indeed warming. The IPCC concluded in its *Third Assessment Report,* "The effect of anthropogenic greenhouse gases is detected." (See *Third Assessment Report. Climate Change 2001: The Scientific Basis,* "Technical Summary," (2001), Chapter 12. [http://www.grida.no/climate/ipcc_tar/wg1/467.htm].) The IPCC also suggests the sort of dramatic and rapid ecological changes that further warming might accentuate.

Cloud Cover and Atmospheric Feedbacks

The two fundamental elements of climate change science—GHGs, primarily CO_2, and global average temperatures—are relatively easy to track and correlate. Although CO_2 is the principal agent of climate change, this is mostly as a trigger, one that raises atmospheric temperatures sufficiently to vaporize the most powerful greenhouse agent, water. A rise in temperature would, it is argued, results in higher rates of ocean evaporation and cloud formation that would, in turn, trap even more heat. The predicted operation of the greenhouse effect is based on such feedbacks accentuating the heat-trapping properties of CO_2 and other greenhouse gases. However, increased cloud cover would also result in a greater *albedo,* or amount of solar radiation reflected by clouds back into space without penetrating the lower atmosphere. Clouds therefore have potentially positive (warming) and negative (cooling) feedback effects. Since the atmosphere is such a complex and variable system, it is challenging to observe and measure the operation of such atmospheric feedback effects. The role of clouds and atmospheric moisture in particular have been at the center of recent controversy over climate change, and remain the least understood of all the possibly significant feedback mechanisms (*3*, p. 7).

The most highly regarded critic of the IPCC consensus statements, Richard Lindzen of MIT's Earth, Atmospheric, and Planetary Sciences Department, has undertaken hydrological research to understand how clouds regulate the temperature of the Earth's atmosphere. In a model he has advanced since 1989, Lindzen and colleagues argue that high-level tropical clouds over the Pacific operate as a sort of enormous heat valve, allowing the release of heat into space and so bringing temperatures to equilibrium (*25*, *26*). He further argues that thermal equilibrium is achieved primarily through the heat loss accompanying atmospheric convection and the transport of moisture from warmer to cooler latitudes, rather than through infrared radiation of the sort trapped by GHGs. Other climate researchers, however, point to evidence contradicting Lindzen's convection model such as "satellite and balloon observations showing that water in the upper troposphere increases, not decreases, whenever and wherever the lower troposphere is warmer." They also argue that, although Lindzen is the only scientist to develop a full, alternative model of climate systems, the bulk of circumstantial evidence still points toward the probability of positive climate change (*27*).

Computer-Simulated Climate Forecasts

Climate science research in the 1980s and 1990s devoted considerable attention to developing computer models capable of forecasting general climate trends on the basis of the information then known. Computer-generated scenarios have been used to suggest specific global and regional effects of positive climate change, such as increased or decreased local precipitation, longer or drier growing seasons, and coastal inundation. At the time of the ICPP's *Second Assessment Report,* the authors of that document were cautious regarding the accuracy of global climate forecasts, especially at the regional level. Such caution was based, in part, on the difficulties of modeling the complex atmospheric feedbacks associated with water vapor, clouds, ocean circulation, and the albedo effect. At the time of the *Second Assessment,* most simulations were unable to replicate short-term climatic variations, such as el Niño, without being manipulated. Since then, computing power has improved, as have the models themselves and the instrumental data fed into them. When tested against current and past climate observations, current models earn a higher degree of confidence than did their forerunners less than a decade ago. The IPCC now considers climate models capable of providing "credible simulations of both present annual mean climate and the climatological cycle," as well as "stable, multi-century simulations." (See *Third Assessment Report. Climate Change 2001: The Scientific Basis,* "Technical Summary" (2001), Chapter 8. [http://www.grida.no/climate/ipcc_tar/wg1/309.htm].) If a simulation that incorporates all known atmospheric feedbacks can faithfully reproduce several centuries of recorded climate variation, then the odds increase for the same simulation to create an accurate forecast well into the future.

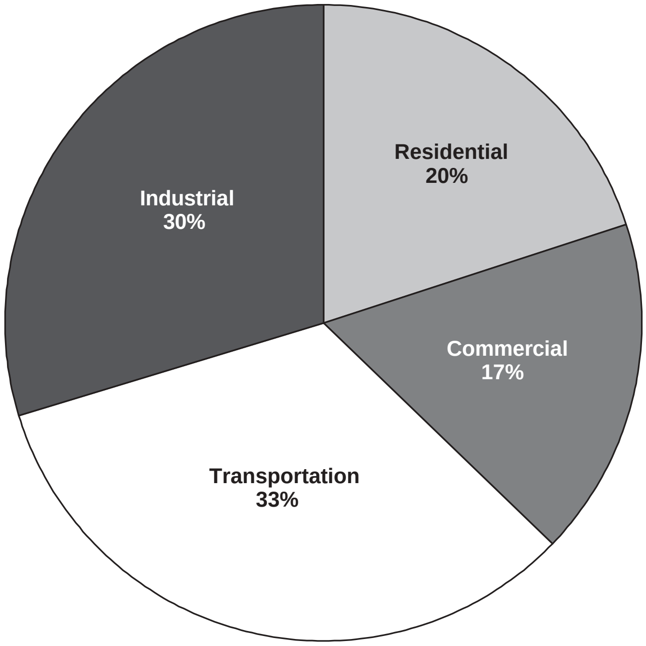
CARBON EMISSIONS FROM SURFACE TRANSPORTATION

The "emission of a greenhouse gas," concludes the IPCC, "that has a long atmospheric residence time is a quasi-irreversible commitment to sustained radiative forcing over decades, centuries, or millennia, before natural processes can remove the quantities emitted." (See *Third Assessment Report. Climate Change 2001: The Scientific Basis,* "Technical Summary" (2001), C.1. [http://www.grida.no/climate/ipcc_tar/wg1/016.htm].) Environmental issues of such long duration and consequence are unprecedented, and might seem at first to exceed the range of known scientific, technological, and policy resolutions. Yet, effective responses have been identified, and tend to focus on improved energy efficiency in all economic sectors. The principal conclusion of the Five Labs Report, for example, is that any risk-reducing strategy for carbon reduction would necessarily be tied to implementation of energy-efficient technologies, especially in the transportation sector. "Technology can be deployed to achieve major reductions in carbon emissions by 2010 at low or no net direct costs to the economy" (*11*). Although the report acknowledges that such an initiative would require a major federal and private R&D commitment, it nonetheless emphasizes that potentially effective mitigation strategies do exist. With atmospheric carbon levels affecting climate, and global emissions of the gas trending upwards, it is only prudent to further pursue efficiencies in the U.S. transportation sector, which is a substantial global GHG emissions producer. We now know that there are both feasible technological means, and sound economic reasons, for doing so.

Although the effects of increasing CO_2 emissions are dispersed throughout the Earth's atmosphere, the sources of CO_2 and other GHGs vary according to geographic region and economic sector. Therefore, CO_2 emissions can be traced to specific, regional economic and social practices that help us understand how the complex mechanics of climate change relates to on-the-ground activities in particular areas. The amount of fossil fuel consumed in a given sector of the U.S. economy, for example, is well known, and allows us to make a fairly accurate estimation of the corresponding amount of CO_2 produced.

According to the U.S. Department of Transportation, the United States contributes roughly a quarter of the global quantity of CO_2 emissions (*28*). The transportation sector is a major contributor to the total U.S. volume of CO_2 emissions, at 33% (as with all measurements of aggregate emissions, however, it should be noted that numbers vary slightly according to different sources and the 33% figure from DOT is 27% according to EPA.) of the total (*28*, *29*). Thus, emissions from the U.S. transportation sector make up 8% of world CO_2 emissions. For the decade of the 1990s, transportation sector emissions averaged the greatest rate of growth, at 1.8%, outpacing an average 1.25% growth in all other sectors (*30*). "Transportation," reports the Energy Information Administration in its 2000 U.S. inventory of GHG emissions, "is the largest contributing sector to total emissions" (Figure 2-2). (See U.S. Department of Energy, *Emissions of Greenhouse Gases in the U.S. 2000,* "Carbon Dioxide." http://www.eia.doe.gov/oiaf/1605/gg01rpt/index.html].)

Of the various modes of transportation that generate emissions, by far the largest segment consist of the combined



Source: U.S. Department of Energy, *Emissions of Greenhouse Gases in the U.S. 2000,* "Carbon Dioxide."

Figure 2-2. U.S. greenhouse gas emissions by economic sector.

emissions of both automobiles and light trucks; almost 60% of transportation-related carbon emissions come from motor fuel consumed by these two classes of vehicle. For year 2000, U.S. transportation sector CO_2 emissions generated by category were as follows:

- Cars generated 38.6%,
- Light trucks generated 20.6%, and
- Buses generated 13.7%.

The bulk of growth between 1990 and 2000 in transportation emissions was due to growth in the use of light-trucks—vans, pickups, minivans, and sports utility vehicles (*29*).

From a purely statistical point of view, then, a strategy for reducing global CO_2 emissions would do well to reduce emissions originating in the use of automobiles and light trucks in the United States (*31*). One way of accomplishing this, (in addition to increasing the fuel efficiency of new vehicles) would be to encourage people who would normally drive on any given occasion to use mass transit, ride bicycles, or walk instead. With such a large proportion of GHG emissions originating in the transportation sector, and the largest proportion of those emissions originating in personal automobiles, improving the competitiveness of transit vis-à-vis the automobile could directly and significantly reduce collective CO_2 emissions.

The goal of reducing GHG emissions from the transportation sector overlaps with the aims of various programs in urban planning and public policy, as well as within federal, state, and municipal transit agencies, all of which are directed toward increasing public use of mass transit. In the following chapters, various local strategies for encouraging the use of mass transit will be examined, including, most importantly, the land use practices most supportive of transit use; effective market incentives, and transit agency policies. The case of alternative transit technologies will illustrate a large principle on a small scale: how multiple goals can be achieved through programs of energy efficiency. For example, reducing transportation sector GHG emissions by increasing transit use has the positive consequence of reducing regulated pollutants and reducing transit agency operating costs.

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CHAPTER 3

LOCAL STRATEGIES FOR REDUCING CARBON DIOXIDE EMISSIONS

BACKGROUND

Because the transportation sector is such a sizeable contributor to total national GHG emissions, reducing transportation emissions will be a primary objective for any comprehensive national GHG mitigation policy. Of the three strategies for reducing GHG emissions outlined in Chapter 1, this chapter focuses on (1) promoting policies that may increase the use or expand the service of already existing transit systems and (2) reforming corresponding land use practices so they are more transit-supportive. Although the reform of land use practices prevailing in the United States is the more challenging of the two approaches, it is perhaps the more important for the long-term stabilization of CO_2 and other GHG emissions from the transportation sector. As the emissions maps presented in this chapter will make clear, there is a direct correlation between low CO_2 emissions and the reductions in auto use that accompany transit-friendly neighborhoods with high residential densities. It is not necessary to cross Manhattan- or Tokyo-level thresholds of density for this relationship to become apparent. Much of the County of Los Angeles, for example, displays significantly lower household carbon emissions than surrounding, less dense counties. Neighborhoods with lower rates of auto use, themselves reflections of lower household auto ownership, are neighborhoods that generate fewer GHGs. How we build cities, therefore, has atmospheric consequences; those consequences also have an economic impact on the budget of typical urban households. Households in high-density neighborhoods coupled with frequent and accessible transit incur low transportation expenses because they are freed of the costs of auto ownership—the second greatest expense for American households. For example, "The availability of public transit [in the Chicago region] reduces the regional average for household transportation spending by $876 per year, when compared to the national average." (*34*, p. 4) Were this efficiency extended to a greater percentage of urban inhabitants, the wealth freed at the household level would be enormous, on the order of $2.8 billion in the city of Chicago alone. (The average rate of auto ownership in Chicago is one vehicle per household, with 1,025,174 households in the city of Chicago. With an average annual cost of auto ownership of $5,678, aggregate household expenditure on automobiles comes to $5,676,847,366. Assuming aggregate auto ownership is reduced by 0.5 vehicles per household, this amount would be reduced by half, giving the figure of $2,838,423,683. Figures are based on 1994 VMT data and 1990 Household and Vehicle Data. The Federal Highway Administration's 1991 formula for calculating auto expenses, $2,207 per car per year plus 12.7 cents per mile driven, was used to derive an annual cost per household.) The lower levels of auto ownership that accompany high-density land uses lead to lower vehicle miles traveled (VMT, a measure of the total distance driven by automobiles in a given region), fewer GHGs, and—ultimately—lower transportation expenses per household. Reduction of transportation sector CO_2 from changes in land use is therefore an efficiency that has a measurable economic benefit.

TRAVEL DEMAND AND URBAN FORM

Transportation planners, and developers of transit and real estate, have been interested in the relationship between transit services and the markets that support them since the early days of public transportation. Formal modeling of travel demand, or of the concrete conditions that influence individual decisions of whether, where, and how to travel, however, began with the large-scale transportation construction of the 1950s. Until quite recently, one of the greatest barriers to studies attempting to isolate the causes of "trip generation"—a technical term referring to the factors that encourage local travel—has been the reliance of such modeling upon data of regional or city-wide resolution. Large-scale modeling techniques based on regional aggregates, however, were initially enough to suggest that effective transit and high-density land use were closely related. A benchmark study (*35*) of transit travel demand carried out by Boris S. Pushkarev and Jeffrey M. Zupan in the 1970s used aggregate density measures to determine density thresholds for effective transit demand; these measures, summarized below, still operate as rules of thumb in transit planning today. Pushkarev and Zupan's study, discussed in detail below, is the starting point for a brief review of the travel demand research leading up to the most recent, neighborhood-scaled studies of transit and location efficiency.

Pushkarev and Zupan began their study of travel demand with the observation that, today, transit functions in competition with the automobile. With the exception of neighborhoods in a handful of American cities, the percentage of trips carried by any given mode of transit—or mode share—is a small fraction of the total number of trips made. This has not always been the case. Before the expansion of the automobile market in the 1920s, and even into the early days of the 1950s suburban boom, transit was the most efficient way to travel distances longer than those easily traveled by foot. During the heyday of mechanized urban transit, from roughly 1880 to 1920, transit modes competed chiefly between themselves in a free market. Because rail transport was so basic to economic activity at this time, it functioned as a spur to development (*35*, p. 5). The functional design of the built environment was premised on the near and frequent operation of rail transport to serve the needs of inhabitants, merchants, and industry. This close relationship between rail transport and land use shaped the skeletons of the great American cities that came to maturity in the decades before World War I.

The expansion of the automobile market from the 1920s onward broke the monopoly relationship of rail transport and urban development. No other mode of travel could match the efficiencies of the automobile, primarily in terms of shorter trips and greater trip flexibility. Considered the travel mode of the future, new urban and suburban development began to orient itself towards the automobile, a trend that has continued to this day. As the auto-oriented sections of urban and suburban areas have grown dramatically since World War II, transit has been compelled to extend its operations into areas not laid out to maximize transit ridership, but rather to facilitate efficient automobile circulation. Transit during this time labored under the further financial burden, inherited from the free-market years of the early twentieth century, of financing itself in the absence of comparable levels of municipal and federal assistance available for the creation and maintenance of auto infrastructure (*36*). This led to a considerable reduction in transit service as early as the 1940s. Urban regions that experienced the bulk of their development after the auto revolution tend to have segregated land uses separated by barriers to anything but automobile circulation. Development around the automobile has resulted in a type of urban form that now makes other mobility options inconvenient and often uneconomical.

It was in this context that Pushkarev and Zupan produced their founding text of modern travel demand theory in the 1970s. The most effective way to restrain auto use, they argued, is to design urban environments that make the cost and inconvenience of using a car prohibitive. Such environments already exist in the hearts of older American cities built before the advent of the automobile, where the density of land uses reduces dependence on automobiles, while increasing the relative cost of their operation. "Only as auto access becomes difficult do riders by choice begin to switch to transit" (*36*, p. 37). A simple and very reliable way of determining the suitability of an urban area for transit, and the likelihood of residents to opt for transit over autos, is to measure the residential density of an area. As Pushkarev and Zupan summarize:

> Higher density of urban development acts both to restrain auto use and to encourage the use of public transit . . . Average figures from a number of urban areas in the United States suggest that:
>
> At densities between one and seven dwellings per acre, transit use is minimal. . . . A density of seven dwellings per acre appears to be a threshold above which transit use increases sharply. . . . At densities above 60 dwellings per acre, more than half the trips tend to be made by public transportation. (*36*, pp. 172–173)

Several of the indicators of transit effectiveness arrived at by Pushkarev and Zupan, in addition to those above, have become standard in the transportation planning literature. The most important underlying factor supporting transit use, according to Pushkarev and Zupan, is reduced auto ownership. Increasing residential density by a factor of 10, for example, is found to drop the level of auto ownership by 0.4 percent (*36*, p. 173). In fact, density correlates extremely closely with auto ownership, such that residential density offers a basis for predicting household auto ownership with 86 to 99% accuracy. Still more important, they argue, is the density of nonresidential floor space in a downtown area served by transit. High-densities of nonresidential, downtown floor space have the effect of suppressing auto use, and allowing the economy of scale for effective transit service to residential areas. As Pushkarev and Zupan conclude: "The land use policies which will do most for public transportation are those which will help cluster nonresidential floor space in downtowns and other compact development patterns" (*36*, p. 174). Rutgers University transportation researcher Reid Ewing remarks that Australia and Canada, with comparable levels of auto ownership and gross densities, nonetheless sustain transit ridership more than three times the U.S. level. The difference, Reid points out, is that "Canadian and Australian cities . . . have managed to create conditions favorable to transit," primarily by clustering uses in central areas and linking development to transit infrastructure (*37*, p. 43). Recent research by Apogee/Hagler Bailly gives further evidence of the strong correlation between employment density at trip origins and destinations with mode choice for both work and nonwork trips: where there is a high concentration of jobs (a less precise way of referring to "nonresidential floor space") more trips will show up on transit (*38*).

Although earlier studies of travel demand were revealing, they were limited by the lack of data on transportation choices made at the household level. Later studies have therefore gone to great lengths to closely scrutinize the same relationships with fine-grained, neighborhood-level data. This has necessarily involved the laborious compilation of new information. In 1994, John Holtzclaw developed a methodology for predicting household automobile travel from density and transit access in 28 California communities (*39*). His work later became part of an analysis conducted collaboratively by the National Resources Defense Council, the Center for Neighborhood Technology, and the Surface Transportation Policy

Project, which was designed to calculate the transportation value, or "location efficiency," of a given place (*40*). The Center for Neighborhood Technology, in cooperation with the Natural Resources Defense Council and the Surface Transportation Policy Project, developed a model to predict VMT in the Chicago, San Francisco, and Los Angeles metropolitan areas in 1997. Although earlier work, such as that carried out by Pushkarev and Zupan, looked at metropolitan regions on a citywide scale, the location efficiency model (LEM) and subsequent modeling was able to predict VMT for small geographies, in this case, traffic analysis zones in San Francisco and Los Angeles, and quarter sections in Chicago. Such a focus on small scales allowed as many variables as possible to be accounted for, thus removing suspicions that factors other than density (such as income level, geography, or culture) influenced travel choices. According to Holtzclaw, "Direct comparison of neighborhoods is necessary to determine if neighborhood characteristics like density, transit service, and pedestrian and bicycle friendliness—characteristics that can be influenced by public policy—truly influence auto ownership and driving" (*40*, p. 2). The model by Holtzclaw and colleagues predicts household vehicle ownership and use based on household income and size, vehicle ownership, residential density, block size (used as a surrogate for pedestrian accessibility), VMT, transit routes, and frequency of transit service. These factors are brought together in a statistical model to describe the transportation efficiency attributable to a location (i.e., the degree to which any trip can be made quickly and efficiently). High levels of efficiency indicate conditions favorable to transit and to high levels of pedestrian activity. Not surprisingly, in such circumstances, people consistently own fewer cars, drive less, and therefore produce fewer emissions.

LEM predicted household vehicle ownership and VMT by means of a regression analysis that incorporated residential density, transit access, availability of local amenities (a land-use mix indicator), and pedestrian friendliness. The LEM study marked an advance in three respects as follows:

1. Geographic information systems (GIS) unavailable prior to the 1980s allowed land use patterns and their effects to be made plainly visible;
2. The massive collection of household data in three cities allowed for trip origins (rather than total trips) per household to be tightly correlated to residential density; and
3. The relative cost to households having to make more trips was able to be calculated.

By incorporating the travel habits of different income groups into statistical analysis, as well as neighborhood-level data from geographically and historically distinct cities (Chicago, San Francisco, and Los Angeles), the 2000 location efficiency study found that the strong inverse correlation of residential density with auto ownership held true across three distinct urban environments (Figure 3–1). "Urban design and transportation infrastructure," concludes the location efficiency study, "have a highly significant influence on auto ownership and distance driven for neighborhoods" (*40*, p. 25), thus refining the 25-year-old insight of Pushkarev and Zupan, and moving beyond it with the introduction of the concept of location efficiency into discourse on travel demand.

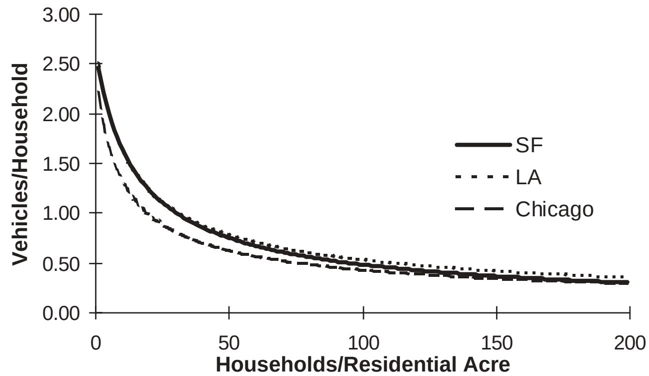


Figure 3-1. Auto ownership versus residential density: San Francisco, Los Angeles, and Chicago. (40)

In a later study, Pushkarev and Zupan quantify the ratio of transit trips to suppressed auto trips, illustrating the dramatic effect that a high-density, transit-supportive environment can have on auto use. In a study of six metropolitan areas served by rail transit, they found that "the reduction of auto travel . . . is much grater than that attributable to the direct replacement of auto travel by rail travel," on the order of a reduction of four auto trips for every one trip by transit (*41*, p. 25). In further research on "transit leverage," Holtzclaw found a reduction of VMT in San Francisco of 9 miles for every passenger mile of service (*42*, *43*). If a single passenger mile on transit equals multiple passenger miles in an automobile, then increasing transit use emerges as a substantial tool for GHG reduction. Recognizing this, the APTA calculates that, if only 7% of daily trips in the United States were shifted to transit, CO_2 emissions equivalent to more than 20% those of the commercial sector would be eliminated (*44*, p. 3). Taking the 1999 CO_2 emissions from transit, APTA calculates what the equivalent emissions would have been had those trips occurred on other modes (see Table 3–1), and obtains a figure representing a near doubling of the transit value (*44*, p. 9). For the APTA methodology as applied to case studies included in this chapter, see Appendix A and Table A-1.

SEGREGATED LAND USE, VEHICLE MILES TRAVELED, AND GREENHOUSE GAS EMISSIONS

Trends characteristic of the post-World War II period, such the absence of coordination between local land use and federal transportation planning, various subsidies and

TABLE 3-1 Comparative emissions from public transit and replacement use of private vehicles

Mode of Travel	Metric Tons of CO_2 in 1999
Public Transit	9,120,489
Private Vehicles	16,526,345
Environmental Savings	7,405,856

Source: Robert J. Shapiro, Kevin A. Hassett and Frank S. Arnold, "Conserving Energy and Preserving the Environment: The Role of Public Transportation," (APTA: July 2002), 9. [http://www.apta.com/info/online/shapiro.pdf]

economic incentives to suburban development, all accentuated the tendency toward what is now commonly called *sprawl*. The idea behind early zoning, and one of the reasons modern suburban development takes up so much land, is that planners felt the need to separate land uses based on the compatibility of their functions: industrial, commercial, residential, and the like. Although this was done for a variety of reasons, some still justifiable, it is increasingly clear that the extreme segregation of land uses leads to greater VMT and, by extension, higher levels of GHG emissions. Other factors have produced similar effects, for example, uncontrolled development, just as much a part of sprawl as the segregation of land uses, often follows transportation infrastructure designed to accommodate the automobile, thus locking high VMT into development itself.

While segregated land use patterns generate more automobile trips, and, in turn, higher GHG emissions, they also impose greater financial burdens on area inhabitants. Transportation costs for those living in areas of decentralized urban development are consistently higher than for those living in dense, mixed-use areas. Low transportation costs and low GHG emissions are linked together, a correlation that highlights the economic benefits of transportation efficiency. To use Chicago as an example, in studying the high transportation costs of decentralized urban development, the Surface Transportation Policy Project (STPP) and the Center for Neighborhood Technology (CNT) gathered data on household travel patterns in Chicago area suburbs. The study found that households in those suburbs closer to Chicago, and therefore better served by transit, spend noticeably less on transportation annually (Table 3–2) than households in more distant, transit-poor communities (*34*, p. 4).

The emissions maps in Figures 3–2 to 3–7 provide a geographic illustration of this relationship—on a per household basis, central Chicago, Los Angeles, and San Francisco generate fewer emissions than do outlying areas. Rather than imposing a financial burden to urban residents, greater transportation efficiencies would release significant funds on a per household basis. In the old, densely developed parts of cities (including notoriously sprawling Los Angeles), such efficiencies are already in place. Even when public spending on existing transit is factored into household transportation expenses, residents of sprawling cities such as Houston, Atlanta, and

TABLE 3-2 Highest and lowest average household auto costs by suburban Chicago municipality for 1990

Lowest Average Auto Costs Chicago's Inner Suburbs	
Oak Park	5,232
Evanston	5,407
Cicero	5,444
Berwyn	5,501
Harwood Heights	5,573
Elmwood Park	5,618
Highwood	5,693
Blue Island	5,793
Maywood	5,740
Forest Park	5,727

Highest Average Auto Costs Chicago's Outer Suburbs	
Old Mill Creek	7,068
Mettawa	7,049
Bull Valley	7,041
Barrington Hills	7,0343
Prairie Grove	7,000
Wayne	6,987
Wadsworth	6,968
Long Grove	6,958
Spring Grove	6,955
South Barrington	6,947

Source: CNT Location Efficient Mortgage Database.

Dallas–Fort Worth still spend more (approximately $2,500 annually) on transportation than do residents of dense, transit-oriented cities like Chicago, Honolulu, or New York (*45*, p. 14). Taken in the aggregate, such sums can reach large magnitudes.

Although the daily choice of which travel mode to use is made in each household, local and regional planners have the potential to reshape metropolitan regions in a way that could support sustainability and systematically reduce the demand for automobile travel and resulting auto-generated CO_2 emissions. Travel demand studies indicate that strategies most likely to reduce automobile travel and ownership include compact development along transit lines, integrated land-use zoning and development, frequent transit service, parking restrictions, well-maintained pedestrian and bicycle infrastructure, and regional strategies to encourage infill instead of green field development. Additionally, as the examples above suggest, land-use patterns that lower local CO_2 emissions would trim household transportation expenses and reduce the cost of auto-oriented infrastructure to society.

Neighborhood Travel Emissions

Figures 3–2 to 3–7 map CO_2 emissions from automobiles in three cities that are dissimilar in terms of geography and history. Values mapped were created by dividing the VMT for each quarter-section by average miles per gallon, and multiplying this figure by the pounds of CO_2 produced by each gallon of gasoline consumed. The geographic unit is a quarter-section, which is one-half-mile by one-half-mile square. In each case, remarkable parallels emerge.

Figures 3–2, 3–4, and 3–6 illustrate aggregate CO_2 emissions generated per square mile in each city. These images conform to conventional expectations regarding cities and pollution: high concentrations of people and industry generate high concentrations of pollutants. Although this is true in general terms, it masks the effect of urban form and land use on the emissions of individual households, which often are much less than that of rural or less dense equivalents. Fig-

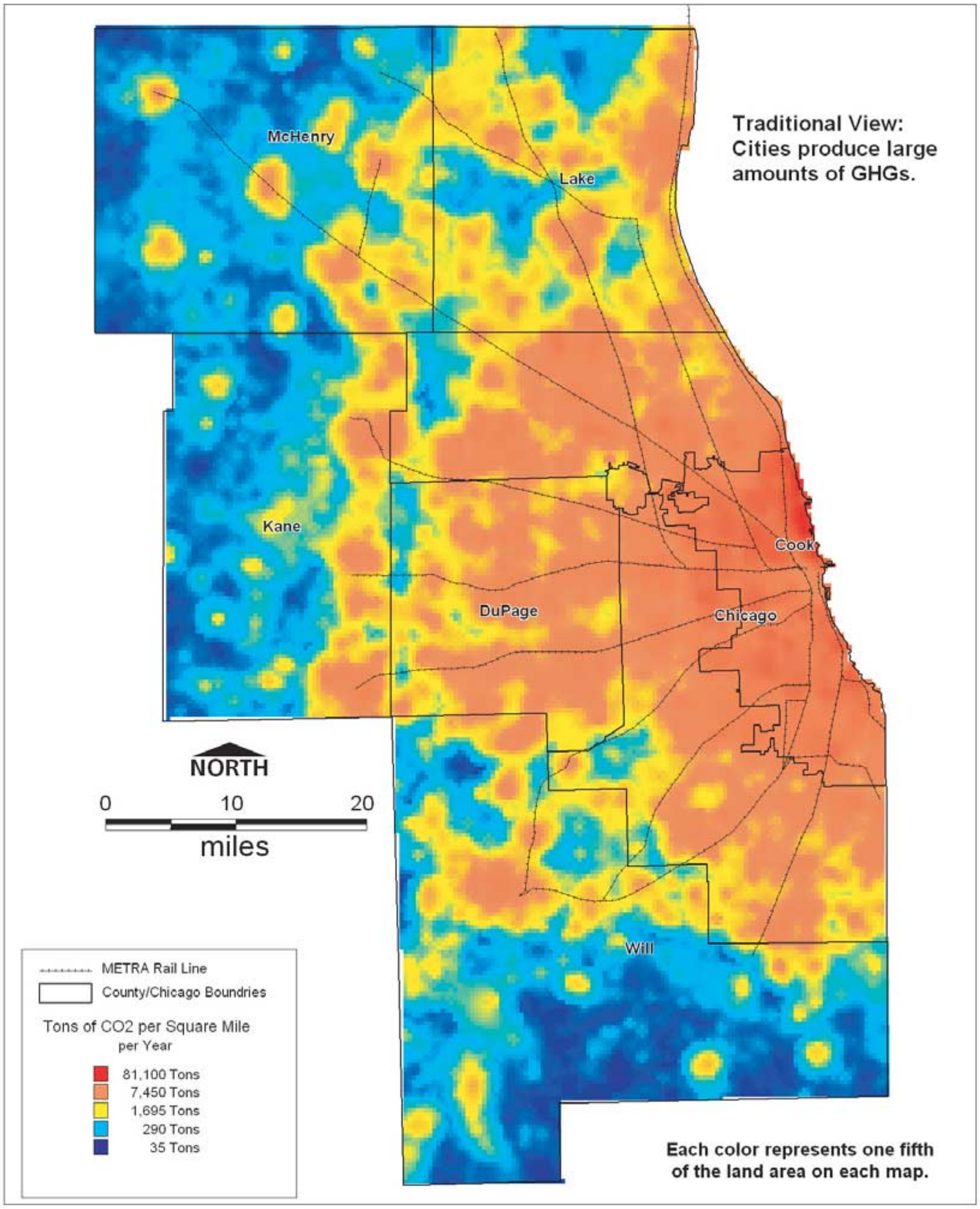


Figure 3-2. CO_2 emissions per square mile: Chicago.

ures 3–3, 3–5, and 3–7 illustrate CO_2 emissions generated per household in each of the three cities. In this case, each map for a particular city shows inverted emissions values. Although the densely populated areas of Chicago, Los Angeles, and San Francisco produce higher aggregate emissions than their less densely populated outer suburbs and hinterlands, this relationship of central city to periphery is inverted when the unit of measure is no longer gross emissions *per unit land area*, but rather gross emissions *per household*. In the latter instance, the transportation efficiencies of dense urban areas emerge clearly. On a per household basis, the lowest levels of emissions in all three regions are concentrated in the central cities, in those areas served by transit (particularly visible in the Chicago case), and along the commuter rails extending into the suburbs. Even in Los Angeles, it is the older, more densely inhabited zone extending from Santa Monica to downtown L.A., bordered on the south by Interstate 10, and on the north by the Santa Monica Mountains, that displays relatively high transportation efficiencies in comparison with the rest of the region. These maps, based on fine-grained VMT measurements in each city, offer visual confirmation of several decades' worth of literature describ-

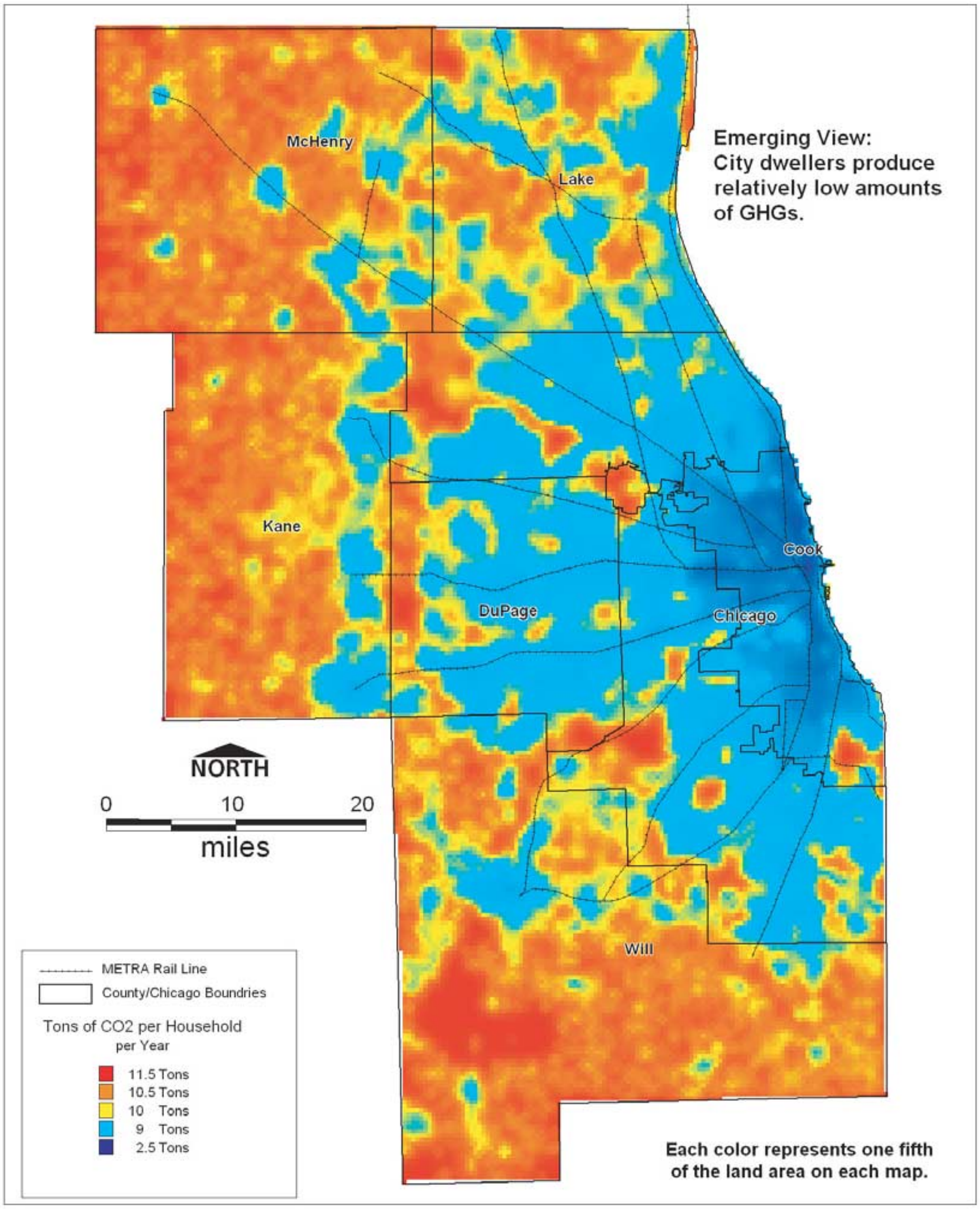


Figure 3-3. Household carbon dioxide emissions: Chicago.

ing the determining influence of urban form and density on travel demand. They also supplement this cumulative knowledge with a visual representation of the disproportionate contribution of low-density, sprawling urban areas to total GHG emissions.

Travel Emissions across the Country

Similar relationships may be observed at the national level. Measuring emissions by county (the smallest geographic unit for which household, vehicle ownership, and VMT data are available) the results may again be interpreted from two different perspectives. At the county level, measurements of VMT, and therefore CO_2 emissions, tend to be higher in the places one would expect: the two coasts, the upper Midwest, and large American cities. At the household level, however, this relationship reverses (Figures 3–8 and 3–9), and precisely those regions that emit the most GHGs per unit area, emerge as the most efficient in terms of emissions per household.

The Environmental Protection Agency (EPA) collects data on criteria pollutants generated by vehicle travel in the United States per county. Maps generated with this data do not include

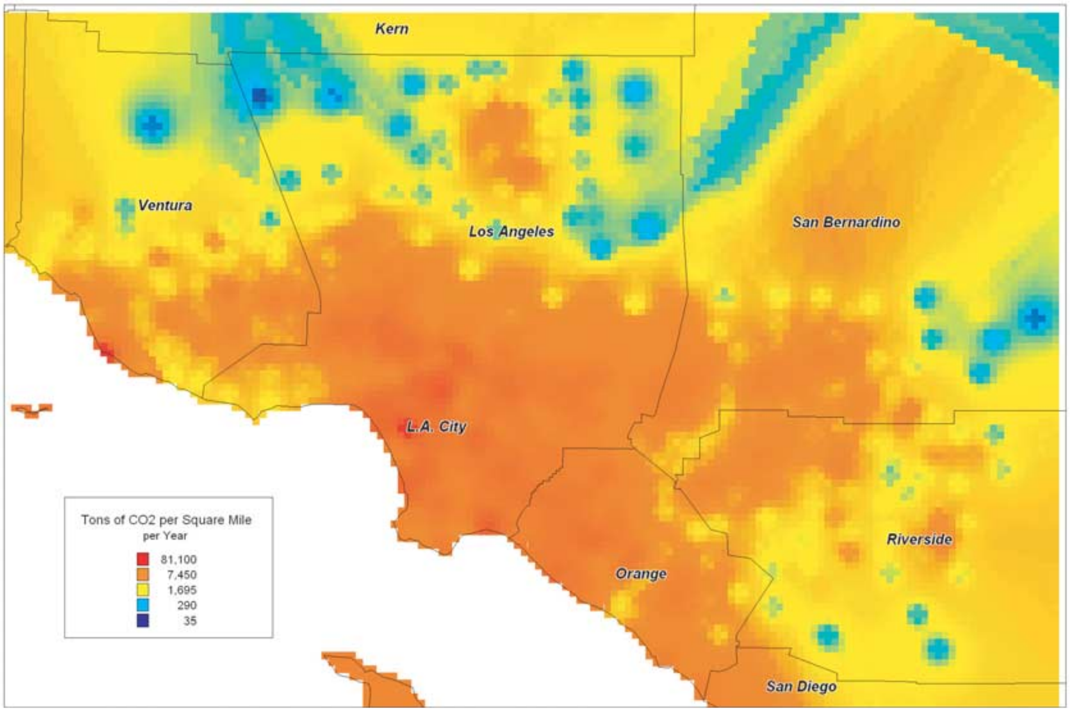


Figure 3-4. Carbon dioxide emissions per square mile: Los Angeles.

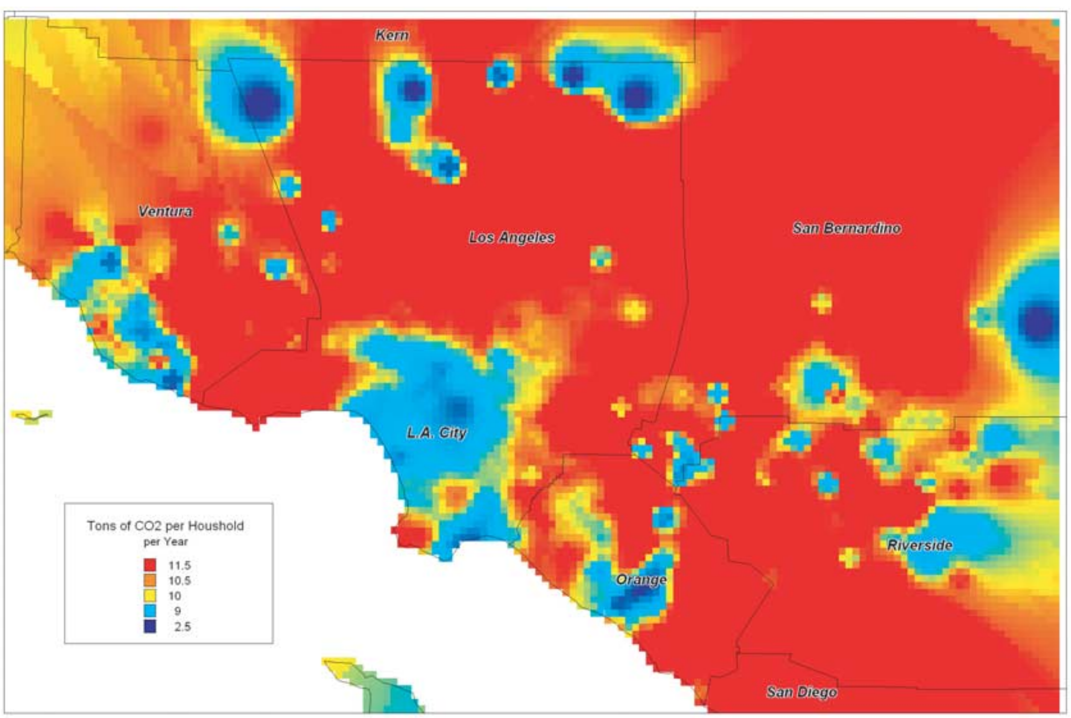
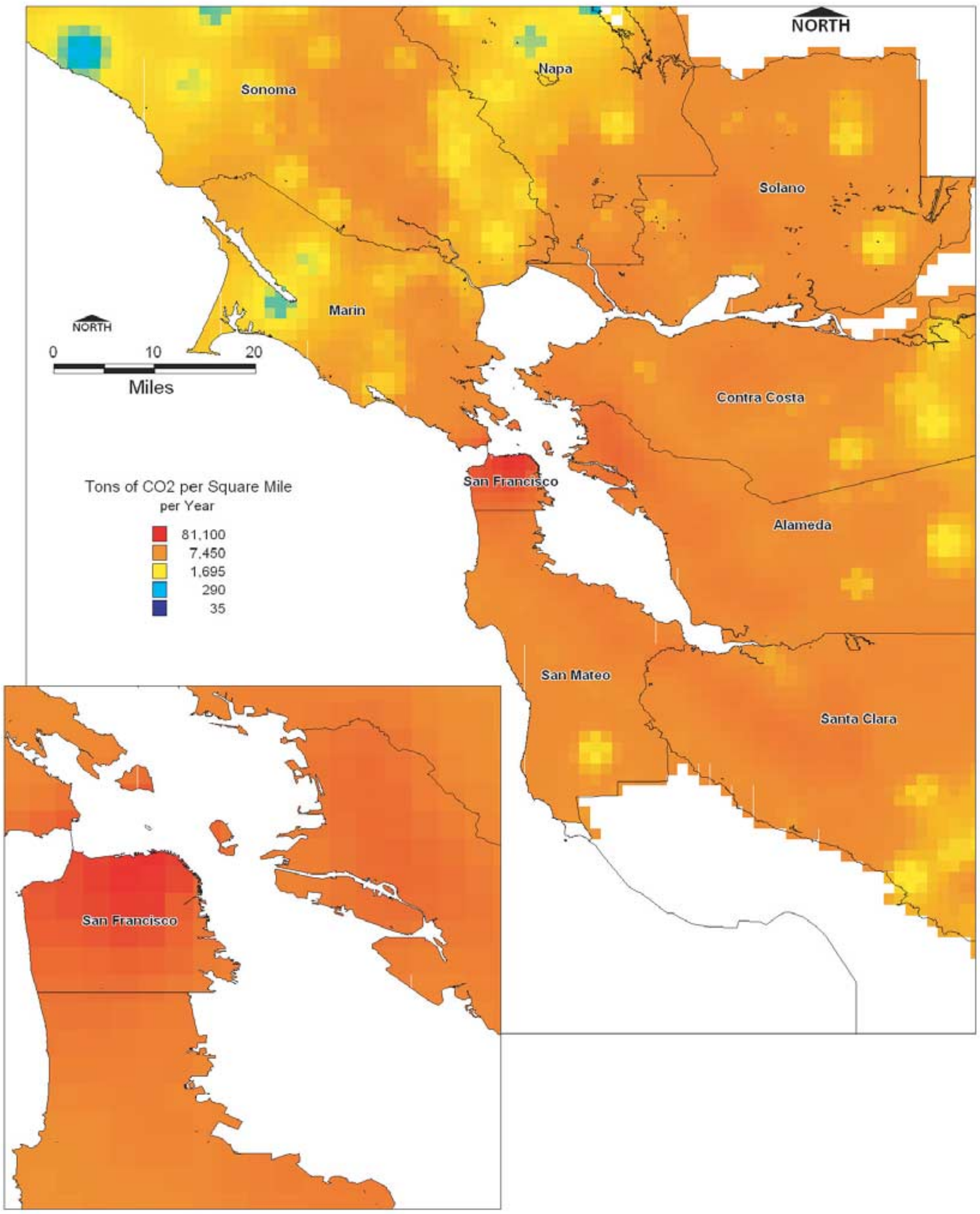
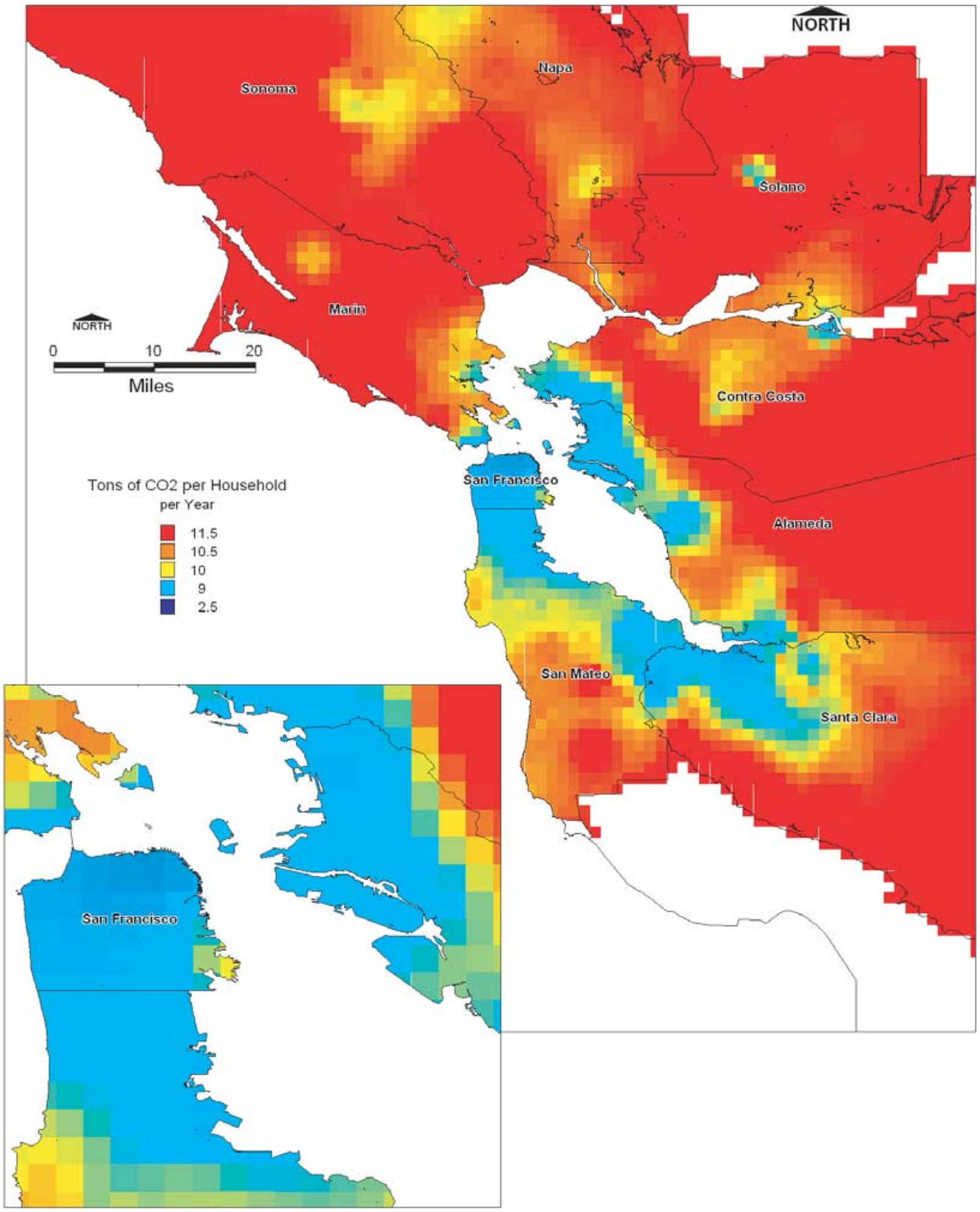


Figure 3-5. Household carbon dioxide emissions: Los Angeles.



Data Source: 1990 Census, California Dept. of Transportation, and Federal Highway Administration.

Figure 3-6. Carbon dioxide emissions per square mile: San Francisco.



Data Source: 1990 Census, California Dept. of Transportation, and Federal Highway Administration.

Figure 3-7. Household carbon dioxide emissions: San Francisco.

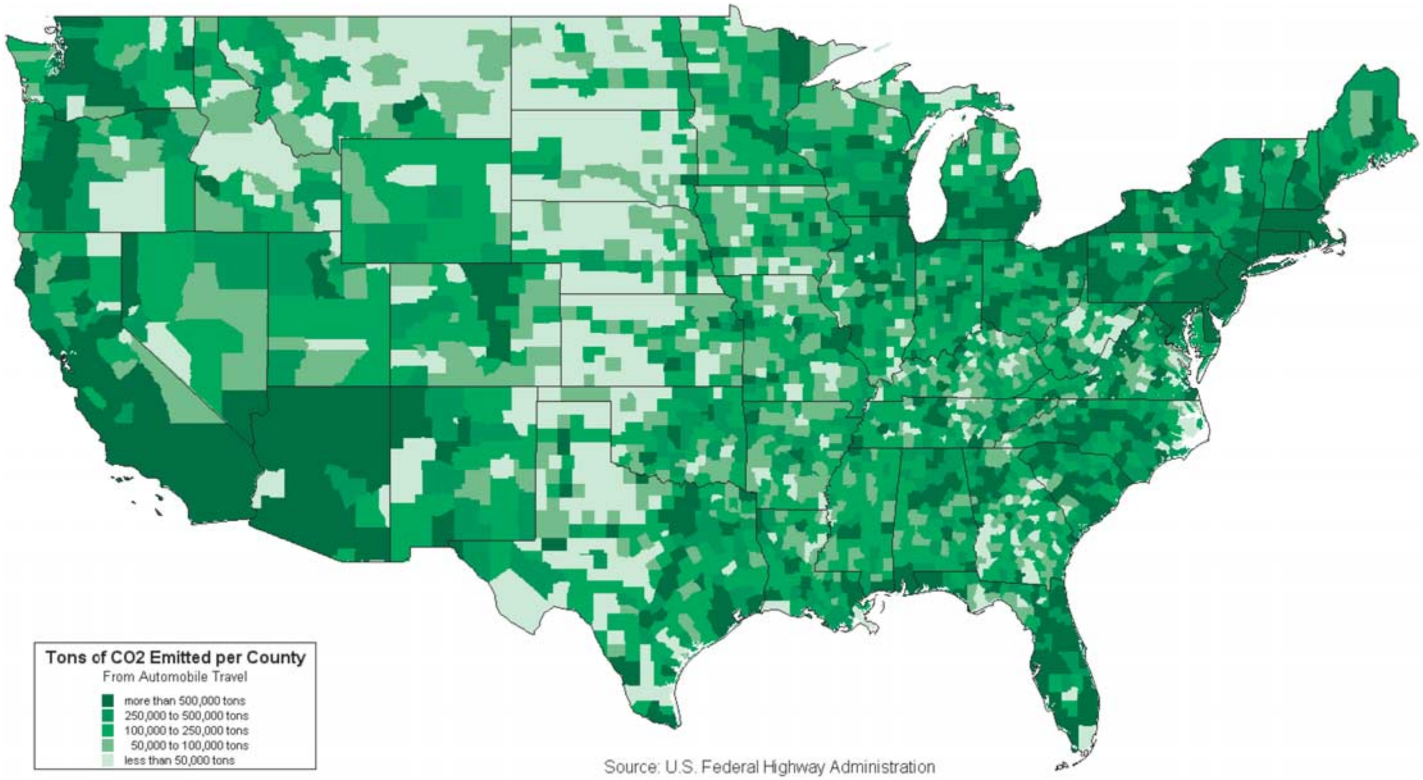
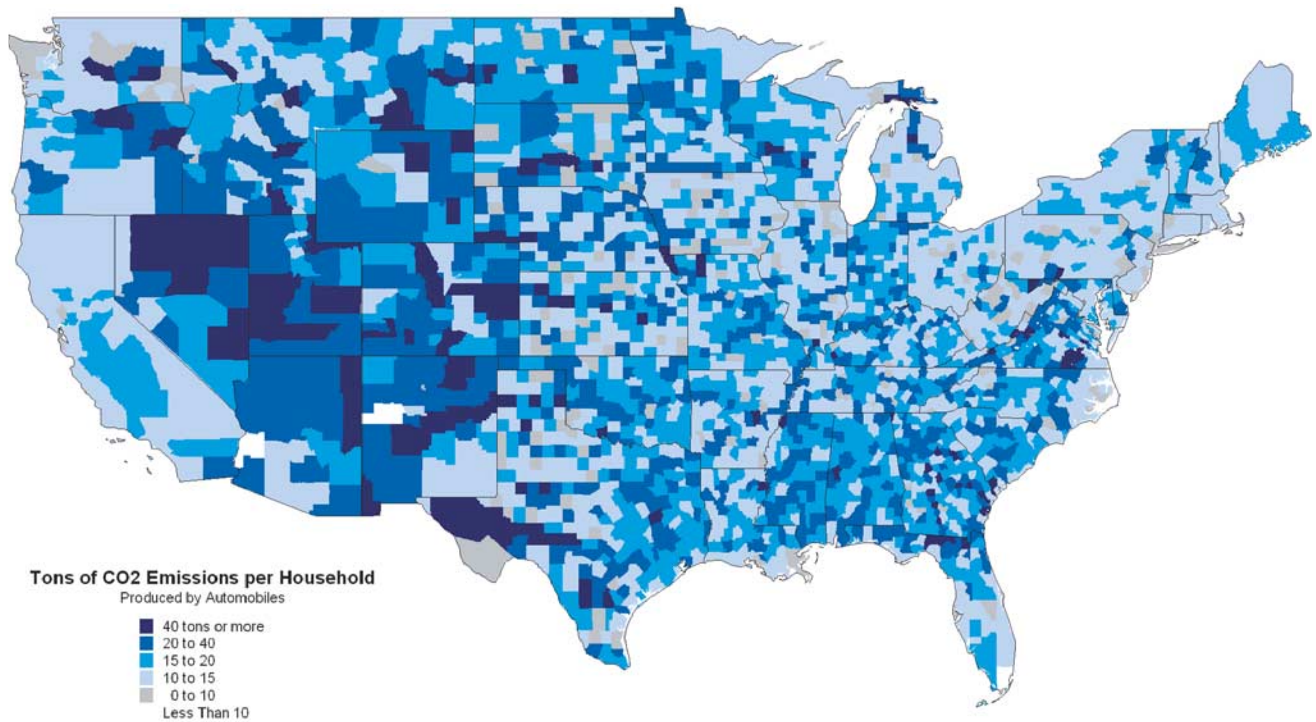


Figure 3-8. National carbon dioxide emissions per county from automobile travel.



Average volume of CO2 emitted per household in each county. Source of VMT Data: U.S. Federal Highway Authority, 1999

Figure 3-9. National carbon dioxide emissions per household from automobiles.

CO_2 or other GHGs, because they are not regulated by current pollution control measures. To produce the maps in Figures 3–8 and 3–9, CNT used the EPA's VMT data to map CO_2 emissions from automobile use for each county in the United States. The Environmental Protection Agency (EPA) obtains VMT estimates that FHWA collects from state bureaus of transportation. The states formulate their estimates by conducting traffic counts in each county and projecting those figures to arrive at an estimated amount of miles traveled per year in each county. Since motor gasoline converts to a known amount of CO_2, CO_2 emissions from VMT in each county can be estimated by using an average of fuel consumed per mile traveled.

Emissions from travel can be approached in two different ways. Places like Los Angeles, Houston, Chicago, Atlanta, and other large metropolitan areas have smog problems in the summer months because of the number of people driving each day. However, analysis of county VMT figures indicate that, although total VMT is much higher in urban than in rural counties, the estimate of miles driven per household in counties with dense development is significantly lower than in their rural equivalents. People who live close to jobs, shopping, and other amenities travel shorter distances than people who live where jobs, shopping, and amenities are spread out over a large area. So, while more CO_2 is produced in densely populated counties, each household in dense counties is producing less CO_2 than a similar rural household.

High levels of emissions can also be seen in counties that are traversed by interstate highways, most conspicuously those corridors in the Great Plains followed by Interstates 70, 80, and 90. The visibility of highway corridors in maps derived from county VMT reveals a limitation in the representations drawn from the EPA data, based as it is on traffic counts. Although it does not diminish the general interpretation of Figure 3–8, that gross emissions are concentrated in America's urban areas, it should be noted that data based on traffic counts, rather than local trip generation, will not discriminate between local traffic and traffic from out of county or out of state. This suits EPA's purpose of tracking the total quantity of auto pollution in the United States, but allows small distortions to appear in mapping at the county level. Some rural counties appear to produce more emissions (i.e., darker on maps) than they would if long-haul Interstate traffic were discounted.

The same distortion arises in the per household VMT data: emissions are exaggerated by counting all VMT through a county. For example, Cook County, Illinois (home of Chicago), appears to have higher per household emissions than Chicago's suburban counties, but it is also home to major Interstate highways and a popular tourist destination. The same holds for rural counties with Interstate highways: low populations and high through-traffic warps the estimate of per household emissions.

One powerful explanation for the sharp contrast between rural and urban driving emissions is that households in urban areas tend to have access to a wider range of transportation options for any given trip. Higher population and greater accessibility both function to achieve this effect. The higher population density of urban areas increases the economic viability of transit systems. When points of origin and destination are closely spaced and connected by infrastructure, people in urban areas typically have options other than automobiles for traveling from one point to another. Making regional planning decisions based on the role of transit in such contexts is one way of contributing toward climate stabilization and improving the physical health of communities.

TRANSIT AND SUSTAINABLE SURFACE TRANSPORTATION POLICY

The essence of sustainability is the integration of economic development and environmental improvement. As described by the 1997 Task Force for the President's Council on Sustainable Development (sustainable communities are those that "flourish because they build a mutually supportive, dynamic balance between social well-being, economic opportunity, and environmental quality" (*46*, p. vi). Of the many aspects of sustainability, transportation is central to the dynamic balance between economies and environments, since varying transportation policies have profoundly different effects on the urban landscape. In particular, the relationship between sustainability and mass transit has led to a range of policies intended to make more efficient use of urbanized land, reduce traffic congestion, cut back vehicle emissions, and improve pedestrian mobility. Each of the examples that follow illustrate how the use of transit or other nonmotorized transportation options is enhanced when travel demand factors are taken into consideration in the planning, marketing, design, and operation of transit. Aside from the potential economic benefit of reducing the consumption of resources associated with urban sprawl, these examples of transit-supported sustainability provide a solid basis for a range of geographically specific actions to reduce GHG emissions in America's large urban areas. Global issues like climate change can be addressed by very local, concrete actions taken to influence the way people build and move through their environment.

Interest in transit and urban sustainability has grown together with public transit use: the 1990s were a record decade for transit, with ridership figures growing by 21% nationwide from 1995 to 2000, approaching levels not reached since the early 1960s (*47*). With more people using transit, a strong rationale exists for capitalizing on this trend as a key strategy in the effort to reduce national GHG emissions from the transportation sector. Looking beyond the success of existing transit systems, however, many municipal planners, transportation scholars, and sustainability advocates have come to realize that new systems are not guaranteed the high level of ridership enjoyed by their forerunners early in the twentieth century. In an environment in which transit competes with automobiles, new transit systems will be effective only when assisted by policy and planning measures designed to make transit use a desirable mobility option for urban residents. Planning for transit-supportive land use, encouraging residential development in proximity to transit stations, providing workplace transit incentives for public and private sector employees, and designing transit stops and transit area neighborhoods to be as accessible by foot or bicycle as by car, are a few of the tools available to enable transit to work in concert with the modern urban environment. Taken together, these tools amount to models of urban design that differ fundamentally from the auto-oriented development predominant in America since World War II.

State and Federal Policy

The importance of transit in building sustainable communities has been acknowledged in the substance of a number of federal and state policies formulated over the last decade. Most prominent at the federal level, and symbolic of a new orientation, was the 1991 Intermodal Surface Transportation Efficiency Act (ISTEA), carried forward in 1998 as the Transportation Equity Act for the 21^{st} Century (TEA-21). Broadly understood, the purpose of TEA-21 is to change the way transportation planning gets done, shifting the emphasis from building more highways to making existing systems more efficient. Under TEA-21 legislation, community involvement in transportation planning is a priority, and greater authority is given to states and municipalities to decide how transportation spending will affect their constituencies. Two of many possible examples of state-level initiatives combining land use, air quality, and transit reform are found in Maryland and Georgia (for a list of other state programs, see www.pewclimate.org/states/all.cfm). At the state level, in 1997, Maryland passed an ambitious "Smart Growth" legislative package. As with TEA-21, the Maryland legislation sets out to accomplish many things at once, by focusing on one element that links several others together—surface transportation. Maryland hopes to save its remaining open spaces and make its urban areas more attractive by increasing the efficiency of existing surface transportation infrastructure. The state recently established an Office of Smart Growth to help coordinate efforts mandated under the new law.

Similarly, the state of Georgia recently established the Georgia Regional Transportation Authority (GRTA) to coordinate municipal transportation planning in areas that fail to meet the standards of the Clean Air Act. A large part of the federal funding included in the transportation plan approved by GRTA for 2003 to 2005 is earmarked for new transit infrastructure, promotion of reformed land use, and pedestrian-friendly urban design. In 2002, New York became one of the first states to formulate a GHG reduction policy in its Energy Plan. The plan sets the goals of a reduction of GHG emissions to 10% below 1990 levels by the year 2020, a 50% increase in the use of renewable energy in the state by 2020, and a 25% reduction of primary energy use per unit of gross state product by 2010 (*49*). While these and other initiatives intended to reform the urban environment of the United States are not intended to reduce emissions of GHGs, it should be emphasized that any measure that reduces VMT will simultaneously reduce the amount of CO_2 and other GHGs released into the atmosphere. Increasing the awareness of climate change issues can only lend weight to the many local policies, programs, and community initiatives already focused on the role of curbing regulated pollutants by changing travel habits and using transit to build sustainable communities.

Innovative Programs: Incentives for Reducing Travel Demand

Hundreds of organizations in the United States are working locally and regionally to encourage planners and policy makers to create transportation systems that will provide real mobility options for residents, and produce collateral benefits such as lower GHG emissions, improved air quality, better physical health, and neighborhoods rich in services and amenities. For planners and policy makers to consider these options, however, there must be a perceived market demand for sustainable development. Incentive products that enable individuals to take advantage of the assets and convenience of a particular location are a way of reshaping the market. Products such as the location-efficient mortgage (LEM) discussed in the following section, and business concepts such as car-sharing, are two innovative, market-based approaches for helping households realize the benefits of living in a compact, well-designed community.

The diversity of such initiatives is remarkable. They range from encouraging nonmotorized forms of transportation with enhanced bicycle and pedestrian facilities, fostering carpooling with high-occupancy vehicle (HOV) lanes, setting aside dedicated bus lanes, making it easier for commuters to travel across several jurisdictions using two or more modes with a single fare, (intermodal transit pass programs) providing downtown shuttle bus service, promoting car sharing, and making commuter stations more appealing through renovation. Travel demand measures, such as employer-sponsored transit pass programs and other such incentives, share the goal of encouraging alternatives to driving. The Washington Metropolitan Area Transit Authority's "Metrochek" program of employer-sponsored transit benefits recently experienced a dramatic upsurge in pass sales (sales of Metrochek passes to federal agencies rose from a total of $26 million for fiscal year 2000 to $85 million for fiscal year 2001), as a result of a year 2000 executive order mandating that tax-free transit benefits be made available to all federal employees (*50*). Projects like the Los Angeles Neighborhood Initiative (LANI), build on the presence of transit as an essential dimension of a neighborhood's pedestrian friendliness (*51)*. Transit use also may be encouraged through innovative financial instruments. LEM can reduce the cost of home ownership anywhere that lenders recognize the transportation savings accruing to households located near transit service.

SUSTAINABLE SURFACE TRANSPORTATION PROGRAMS

Intermodal Transit Passes encourage commuters to use transit across multiple jurisdictions if the fare structure is uniform.

Urban Design improvements at the interface of transit and pedestrian environments, such as bus bulbs and sheltered transit stops, attract riders.

In some instances, simple urban design improvements can work in favor of transit. The City of Portland, Oregon, addressed problems of pedestrian congestion at bus stops by constructing a number of bus bulbs, projections of the sidewalk into a lane of the street, permitting transit riders to stand aside of foot traffic, and relieving buses of the need to pull into and away from the curb in heavy traffic. Two years after completion of the project, ridership was up 19%. Cases drawn from the Project for Public Spaces, Inc., reveal that when San Francisco redesigned Upper Market Street to replace a bus with a MUNI streetcar line in 1995, ridership on the streetcar nearly doubled over that of the bus it replaced (*52*). By correcting for the lack of urban design elements such as pocket parks, pedestrian walkways, or pedestrian-friendly transit stops, as well as working to increase the appeal of the transit experience, such projects improve the livability of neighborhoods—a concept given wide circulation since the middle 1980s by New Urbanist architects (*53*). A crucial part of neighborhood livability is a reduced dependency on automobile transport.

Transit-Oriented Development

Much of what the New Urbanists propose is an updated version of American urbanism as practiced before the age of the automobile, when city neighborhoods were densely populated and well served by local amenities, all of which were structurally dependent on the presence of efficient mass transportation. This has influenced urban and transportation planners who argue that reducing dependency on automobiles means doing more than simply linking up existing urban and suburban areas with transit networks, but actually changing the way we build, renovate, and grow neighborhoods and cities. As a recent review of the empirical literature on urban form and travel concludes, though an immediate, more transit-supportive reconfiguration of the urban environment may be exceedingly difficult to achieve, consistent application of sustainable surface transportation policies "could result in measurable reductions in vehicle travel and air pollutant emissions" by the year 2010 (*38*, p. i). As UC Berkeley's Robert Cervero argues with reference to California, "for rail transit to compete with the automobile in California, the metropolitan structures of the Bay Area, greater Los Angeles, and other areas will need to more closely resemble . . . places . . . which have high shares of rail commuting and high concentrations of housing and offices within walking distance of stations" (*54*, p. 181). The development of successful transit systems, in this view, means the integration of transportation and urban planning in what has come to be known as transit-oriented development (TOD). Michael Bernick and Cervero refer to successful instances of such development, both past and present, as transit villages (*55*).

Scholars sympathetic to TOD are careful to point out that transit in the United States cannot be effective absent a range of supportive public policy elements. Or, similarly: "Transit investments and services are incapable by themselves of bringing about significant and lasting land use and urban form changes without public policies that leverage these investments and the pressure of such forces as a rapidly expanding regional economy" (*56*, p. 5). In a national context where transit planning is not always coordinated with the growth of urban areas, nonetheless there is some consensus on the most desirable mix of policy options available for promoting transit use in automobile-oriented environments. These measures typically focus on parking maximums, shared parking, flexible zoning for increased densities and mixed uses, innovative strategies for land acquisition and development, and a design emphasis on sense of place and pedestrian friendliness. All together, they make up the substance of TOD planning.

Parking and Residential Density

Zoning regulations, for example, specifying a certain minimum quantity of free parking per type of land use—a standard planning practice—may actually encourage single-occupant vehicle use by hiding the true market costs of free parking (*57*, *58*). The presence of free parking at a place of employment served by Bay Area Rapid Transit was found in one case study to decrease the likelihood of taking transit to and from work by 20% (*59*, p. 129). Zoning restrictions on the density of station area development can disrupt what is perhaps the most well-established correlation in transit policy research—high urban density and increased transit ridership. "On balance, research consistently shows density to be one of the most important determinants of transit modal choice" (*56*, p. 25). Where high densities are encouraged, the proportion of residents using transit for commuting or personal trips rises dramatically above that of less dense neighborhoods. A series of research studies carried out in the Washington, D.C. area between 1987 and 1992 demonstrate this fact. The studies, conducted by JHK Associates, measured the proportion of residents in Washington, D.C. station area developments that took the subway to work. Taken together, the two studies found that the percentage of station area residents commuting to work within Washington, D.C. (as opposed to those commuting to Fairfax or Montgomery counties from Washington, D.C.) was as high as 63% in one case and 74% in another. A 1992 study suggesting that density influences trip generation compared transit use in old, densely populated neighborhoods with neighborhoods in Maryland's more auto-oriented Montgomery County: "The study found that residents of the TOD's patronized transit between 10% and 45% more than residents of nearby auto-oriented neighborhoods" (*59*). The JHK studies also documented that transit use declines as distance increases between residences and transit stations. Similar studies of ridership on the BART system by both Loutzenheiser and Cervero conclude that one of the most important determinants of transit use is walking distance to transit stations (*59*, *60*).

Not all density is conducive to increased transit use, however. The most well-conceived TOD will not effectively increase ridership if it is not part of a larger system that situates the origins and destinations of transit trips (such as home and work) in proximity to transit stops. This is the principal conclusion reached by Cervero (*59*). Density that emphasizes one land use to the exclusion of others—commercial districts that empty out in the evening, or residential areas that offer no amenities or destinations, can discourage pedestrian activity and access to transit. Many of the urban design principles of New Urbanism, such as public plazas, grid street design, a variety of pedestrian design elements, and traffic-calming measures, are found to have positive effects in conjunction with already sufficient densities. An internal study by Chicago's Metra commuter rail line examined four Chicago communities served by the line and concluded with an endorsement of pedestrian-friendly urban design as a way of promoting ridership.

As reflected in their high ridership levels and percentages of walkers, several of the case-study stations exhibit the key ingredients for pedestrian-friendly stations and exemplify the extent to which a pleasant walking environment enhances ridership. Most of the case-study stations are surrounded by convenient commercial areas, pleasant surroundings, sidewalks, and distinct pedestrian access to and from the residential areas (*61*, p. 41).

Pedestrian Friendliness

The pedestrian friendliness of a given neighborhood is also known to affect the percentage of vehicle ownership and the likelihood that people will choose to make trips on foot rather than by car. On the basis of a transportation model developed in Portland, Oregon, the evaluation of transit use in different so-called pedestrian environments demonstrates that zones "with substantial employment and good pedestrian-design tend to attract a higher fraction of transit trips than zones with little employment and poor pedestrian environments" (*38*, pp. 34–35). Recently, this approach has been used by the city of Santa Monica, California, (see the Los Angeles case study below) in an extensive program of pedestrian improvements along several transit thoroughfares consisting of widened sidewalks, tree plantings, crosswalk light fixtures, and lighted bus shelters (*62*).

The examples examined below—Chattanooga, and the greater Washington, D.C. and Los Angeles metropolitan areas—were chosen on the basis of the presence in each of transit infrastructure that draws a significant number of riders who might otherwise travel in cars. In each of these cases there are indicators that the programs in question are lowering the potential number of VMT. Additionally, transit infrastructure operates in each case in the context of some form of TOD in which the bases of travel demand are taken into account in the initial development or extension of transit systems. The examples illustrated here also highlight the range of particular circumstances—geographic, economic, or political—affecting each locality and the fact that no one case can be offered up as the way to successfully develop high-volume transit use. Chattanooga has managed to reinvigorate its local industry and downtown commerce, clean up its air, and eliminate traffic congestion—all partly through its commitment to an emissions-free electric bus system. Its geography and history of chronic air pollution had much to do with the choices made. The success of Washington, D.C.'s transit authorities in building over 100 miles of rail system since the 1970s is due to the substantial land-use authority of Arlington County, Virginia, and the State of Maryland's Department of Planning; the District's willingness to shift funds from Interstate to subway construction; long-term regional planning for coordination of transit with growth; and sustained periods of economic vitality. The Los Angeles region, which has been shaped largely by America's relationship with the automobile, is haltingly engaged in one of the most massive infrastructure investments in the nation—a 30-year project to make modern L.A. the transit capital it was in the first decades of the twentieth century. At the same time, it is home to one of the most successful local bus systems in operation—the Santa Monica Blue Bus—and a range of smaller initiatives that are highlighting the potential for transit to significantly reduce VMT. Throughout the case studies that follow, the assumption is made that wherever transit is operating effectively, it is holding back a potential rise in automobile-generated GHG emissions.

Case Study: Chattanooga, Tennessee

The role of transit in Chattanooga is one part of a comprehensive, decades-old project to reverse the fortunes of an ailing industrial center (*63*, *64*). The city's implementation of innovative transit technology has taken place within the context of a host of other projects designed to reconstruct the city's economy and improve its livability. This experience suggests that transit projects are successful when they work in conjunction with initiatives to restore density to urban cores, encourage a mixture of downtown commercial activities and housing options, and provide an intrinsically pleasant experience. Transit innovation in Chattanooga also benefited from the local community's commitment to maintaining the region's

GREENHOUSE GAS REDUCTION BENEFITS OF CHATTANOOGA TRANSIT PROGRAM

Alternative Technology such as electric shuttle buses reduces emissions of regulated pollutants and GHGs, draws riders, and cuts auto trips downtown.

Reduced Parking in city center encourages transit use, reducing VMT.

Mix of Land Uses in city center encourage walking, a low-GHG mobility option.

hard-won air quality. (Unlike other cases studies in this chapter, carbon savings derived from public transportation ridership in Chattanooga is negative. Because ridership on CARTA is low overall relative to the number of vehicles in service, less CO_2 would be emitted if CARTA riders switched to auto trips. This does not diminish, however, the value of the small scale of Chattanooga's experiment—only part of its larger transit service—with electric shuttles in the downtown area.)

Several circumstances account for Chattanooga's enthusiastic embrace of sustainable community policies. One is Chattanooga's early experience with severe air pollution. Chattanooga took rapid steps to improve its air quality after it was ranked worst in the nation in 1969. In fact, Chattanooga's municipal regulations concerning air pollution became the model for the Clean Air Act of 1970. Due to the concentration of heavy industry in a bowl shaped valley of the Tennessee River, Chattanooga's smog problem reached legendary proportions in the middle decades of the century, a problem that began to affect the livability of the region. This was manifested in disinvestment in Chattanooga's historic core, as residents and the business that served them left the city. More so than other areas, the quality of life implications of industrial pollution were dramatic—Chattanooga simply could not afford to ignore the problem of air quality. Its implementation of an emissions-free, electric bus system in 1992 was the latest in a line of air quality measures stretching back over two decades.

Although Chattanooga was successful in bringing its industrial air pollution under control in the early 1970s, like many industrial cities it suffered a major setback later in that decade as heavy industry left the region. Economic conditions reached a low point in the early 1980s, when the largest mall in Tennessee was built a short distance from the historic city center, gutting downtown of small business. At this point, Chattanooga's community leaders decided that the city must reinvent itself to survive economically. This led to a change in government structure, in which a city commissioner system was replaced by a more inclusive mayor–council system, and the creation of a 20-year regional plan based on extensive community involvement in shaping the new face of Chattanooga. Some of the many objectives agreed to in the over 100 public consultations that went into the 1984 *Vision 2000 Plan*, was the community's desire to reduce congestion in the downtown area, provide for some form of public transportation, make downtown commutes more efficient, and draw visitors to several of the area's anticipated attractions.

Chattanooga's reinvention was well underway by the time the first electric buses were dispatched in 1992. By then, a $45 million, privately financed freshwater aquarium had been built, serving as the anchor for downtown Chattanooga's redevelopment. The zero-emissions buses were conceived as a component of the overall high-quality of life envisioned in the 1984 plan, with an extensive greenbelt replacing the former industrial area along the banks of the Tennessee River and the conversion of roadways like Walnut Street Bridge into pedestrian causeways.

Making downtown Chattanooga a more desirable place to work, live, and recreate meant making it more pedestrian friendly. Eliminating the city's auto dependency and traffic congestion was a crucial part of the process. Chattanooga's particular geography amplified the drawbacks of its dependency on automobiles: constrained at its narrowest point to a width of only four blocks, and too long to walk on foot from end to end, moving from one end of the city to another meant driving on one of only three roads that crossed the city. To accommodate this traffic, Chattanooga provided three parking spaces for each downtown visitor—so that parking composed 65% of the area's land use. None of this was conducive to the kind of concentrated economic redevelopment that was necessary to pull the city core out of decline.

The Chattanooga Area Regional Transportation Authority (CARTA) approached its transportation solution—a free, low- or no-emissions shuttle—with the same forward-looking outlook that characterized Chattanooga redevelopment in general. According to CARTA Planning Director Frank Aron, "The concept was to have people who live, work, play, and visit the downtown park once at the north and south ends of downtown and take the shuttle to their various destinations rather than drive to each place they visit" (*65*). With a mandate from the *Vision 2000 Plan* to consider alternative technologies, CARTA officials decided to follow the example of Santa Barbara, California, and put a fleet of electric powered buses into operation. The city of Chattanooga hired a consultant to investigate the feasibility of the plan, who concluded that the technology appropriate to an electric system particular to Chattanooga did exist, but not in one place or in the type of vehicle that was needed. Ferguson seized the opportunity to start up the privately financed Advanced Vehicle Systems (AVS) in Chattanooga, with an initial order of buses from CARTA (*66*). AVS custom manufactured the type of buses needed in Chattanooga, and in so doing, made a long-term investment in the vitality of the local economy.

With assistance from the FTA and the Tennessee Department of Transportation, funds were made available for an initial purchase of 11 electric buses from AVS. Part of this

1992 package included the creation of an independent research institute devoted to fuel-cell technology and the construction of a system of park-and-ride garages on the outskirts of Chattanooga to accommodate commuters bound for the downtown area. The income from the garages and the sale of AVS buses to other cities nationally has made AVS a thriving for-profit enterprise. Since the early 1990s, AVS has built and sold over 130 buses to cities such as Los Angeles, California; Tempe, Arizona; Eugene, Oregon; and Tampa, Florida. While downtown Chattanooga's revived commercial health has led to an increase in VMT, the increase "has likely grown by much less than it would have without the shuttle" (*66*). Once stigmatized as the dirtiest city in America, with a downtown hollowed out by a regional shopping mall, Chattanooga has not only turned itself around economically, but "is one of the few American cities of its size—roughly one-half-million residents—that meets federal air quality standards for criteria pollutants" (*67*, p. 5).

Case Study: Washington, D.C.

Washington, D.C. and Chattanooga present very different case studies. The presence of the federal government as a major employer guarantees that the city will not experience the same sort of profound economic crisis that Chattanooga faced. Nor does D.C. have the same air pollution problem. The problems faced by Washington are instead rapid, often uncontrolled growth, and the resulting chronic traffic congestion. Indeed, the now-familiar idea of the sprawling, auto-oriented "edge city" was developed with reference to suburban development in the D.C. area in the 1980s (*68*). Washington's present traffic congestion, not to mention the region's carbon emissions (Table 3–3 and Table A–1), would undoubtedly be much worse if Metrorail's approximately 300,000 riders and the 250,000 weekday commuters using Metrobus, had no choice but to drive to their destinations (*69*).

With 103 miles of track, Washington D.C. is home to the largest rail transit network built in the United States since the World War II. From its inception in the 1960s, Metrorail was designed to extend outward from the city core along projected corridors of development and to concentrate growth in proximity to transit. Since then, stations have opened every two to three years. As Bernick and Cervero point out, "More high-value commercial property has already been developed at more stations, with greater impact on the surrounding area, in metropolitan Washington than anywhere else in the nation during the postwar era" (*55*, p. 216). The Washington D.C. area is indeed more hospitable than many to TOD. A commitment to long-range transit planning on the part of most local governments (notably in Arlington and Montgomery Counties), successive periods of sustained economic growth, and generous financing from the District of Columbia, have contributed to a transit-friendly environment. Of course, the growth of the last three decades has also resulted in significant unplanned sprawl with no Metro service, the epitome of which is the Tyson's Corner area of Fairfax County, Virginia. Despite this type of unbridled growth, the realization of Washington's original transit goals has been substantial, with higher urban densities than would have otherwise been achieved. Surprisingly, Arlington County, Virginia, is one of the most densely populated jurisdictions in the United States, and at 7,326 persons per square mile is more densely populated than Seattle or Pittsburgh. The Arlington County Department of Public Works estimates that the presence of Metro stations attracted nearly $3 billion of real estate development between 1973 and 1990, and that the annual systemwide commercial activity attributable to Metro area development comes to one-half-billion dollars annually.

Arlington County's high density helps make the Rosslyn-to-Ballston corridor of Metro's Orange Line one of the most heavily used lines in the Metrorail system, accounting for 30% of Metrorail's ridership. Of Arlington's 11 stations, 5 have total daily entries and exits greater than 20,000. From a total of 9,892 in 1995, the Ballston station's daily ridership more than doubled by 1999, to an average weekday passenger volume of 20,634. During the 1990s, the Ballston station area underwent intense development, with a combined total of 2,297,147 square ft of office and retail space and 2,475 housing units, created on 1,314,847 square ft of site area (*70*). Urban densities such as these are most likely the reason why over one-half (64.5%) of Ballston's riders access the

GREENHOUSE GAS REDUCTION BENEFITS OF WASHINGTON, D.C. TRANSIT PROGRAMS

Effective regional planning in the D.C. area promotes density of development along rail lines, making non-auto mobility an option.

High residential density in proximity of Metro stations increases transit ridership.

Workplace incentives, such as pre-tax paycheck deductions for transit cards, increase Metro ridership.

Table 3-3 Carbon dioxide savings from transit use: Washington, D.C., 2000

Passenger Miles	1,645,802,645
CO_2 Emissions from Transit (Tons)	281,238
CO_2 Emissions from Personal Vehicles (Tons)	678,219
CO_2 Savings from Transit (Tons)	396,981

Source: Methodology outlined in Robert J. Shapiro, Kevin A. Hassett, and Frank S. Arnold, "Conserving Energy and Preserving the Environment: The Role of Public Transportation," (APTA: July 2002), 31–32. [http://www.apta.com/info/online/shapiro.pdf] station by foot. Like Ballston, the success of Montgomery County's Bethesda Station area development "was made possible by anticipatory, long-range master plans that promoted high-density, mixed-use, and pedestrian-friendly development" (*71*, p. 6). Station area density, however, does not always correspond with pedestrian-friendly design, a shortcoming appreciated by visitors to several Arlington stations, Rosslyn and Ballston among them. In acknowledgement of station area gaps in pedestrian networks, the Arlington County Department of Public Works, the Arlington County Board, and other departments recently commissioned a study on the possibility of a network of pathways and pedestrian-friendly improvements throughout the Orange Line corridor (*72*).

In Montgomery County, Maryland, substantial measures have already been taken to improve pedestrian, bicycle, and transit accessibility of station areas. The Silver Spring Station, on Metro's Red Line, benefited from a strong real estate market in the 1980s and zoning that was favorable to high-density development. Ridership in the county overall is up 16% from 1995 to 2000, but it is not clear that the design of 1980s era development is optimal for encouraging transit use at the station (*73*). As one assessment stated, Silver Spring "suffers from . . . [a] lack of street life and poor urban design" (*71*). A 1998 plan brings the prospects of Silver Spring more closely in line with TOD principles, de-emphasizing the large, regional retail complexes of the 1980s, with a focus instead on making the station a "community-oriented downtown with housing, local serving shops, and community facilities arranged along pedestrian-friendly streets" (*71*). This turnaround results, in part, from closer involvement with the Silver Spring community in the planning process. "According to a local planner, The developers spent a lot of time talking to the community, figuring out after the [1980s'] failed attempts, what the community really wanted" (*74*). This includes plans for a plaza area to host concerts in the summer and an ice rink in the winter.

Metro's presence has contributed substantially to the development of regional centers at Bethesda, Ballston, and Rosslyn, a trio of transit stops considered by many in the planning profession to be among the most successful in the nation. Although the high level of density at these stations has not gone without criticism, there is no question that dense development has greatly facilitated high transit use and that real estate close to transit stops has been at a premium. Washington, D.C.'s experience shows that TOD is a feasible land-use option, one from which transit authorities, developers, and residential and commercial tenants can all take mutual advantage. The quality of life associated with many of Arlington County's Metro stops has much to do with the benefits to pedestrian street life of higher densities, which are a function of land use based more on accessibility of transit than of automobiles. Since major urban areas are the largest sources of vehicle-related GHG emissions (see Figures 3-2 through 3-7), the success of TOD in Washington, D.C. stands as a prototype for future strategies of VMT reduction across the country.

Case Study: Los Angeles and Santa Monica, California

No other city in the United States demonstrates the centrality of the automobile to daily life as does Los Angeles. The undeniable vitality of the city (its economy is larger than that of many developing countries, and equal to that of Sweden) is heavily dependent on the ease with which things and people can move into, out of, and within the region. Today, the premise of such mobility is the automobile. Until the 1920s and 1930s, however, it was the electric trolley car. Indeed, it was L.A.'s trolley car network, the "Red Cars" run by transportation and real estate magnate Henry Huntington, that cast the mold within which modern Los Angeles would take shape. It was not the arrival of the automobile that made Los Angeles one of the most decentralized urban areas in the United States. In fact, it was Huntington's vision of L.A. as a new type of city, one interlacing urban and rural spaces together to avoid the real and perceived ill effects of nineteenth century urban density, that laid the groundwork for a city that so easily accommodated the arrival of the automobile. L.A. and transit are not as antithetical as they might seem at first (*55*, pp. 19–23).

By the mid 1920s, L.A. had the most extensive interurban railway system in the world, comprising 1,164 directional miles of track which, at its height, moved over 100 million passengers per year (*55*, pp. 19–23). L.A.'s conversion to automobile transportation, beginning in the 1920s and peaking with the construction of the Interstate freeway system in the 1950s and 1960s, channeled automobiles along the old trolley thoroughfares, linking up old regional subcenters such as Pasadena, Hollywood, Long Beach, and Santa Monica. Despite this, L.A. currently has the nation's second highest level of transit bus ridership in the nation (following New York City) (*75*). Following the methodology for converting transit passenger miles to equivalent personal vehicle emis-

GREENHOUSE GAS REDUCTION BENEFITS OF SOUTHERN CALIFORNIA TRANSIT PROGRAMS

High residential density in Santa Monica supports well-used bus system, reducing need to drive to many destinations.

Anchoring institutions at ends of Santa Monica bus lines make transit a real mobility option for commuters.

Investment in transit infrastructure in Los Angeles lays the foundation for future infill and low-emissions mobility options in this fast-growing region.

sions, L.A.'s high ridership results in considerable CO_2 savings (see Tables 3–4 and A–1).

Beginning in 1990, Los Angeles began a massive, controversial program of infrastructure investment, a thirty-year project to rebuild L.A. as the transit capital of North America. Originally conceived of as a 400-mile rail network, centered on an ambitious new subway system, the project has not been without its critics and has encountered repeated material and financial obstacles. Even so, ridership increases in the heavy and commuter rail sectors put Los Angeles among the transit systems with the largest growth in ridership for the year 2000. Currently, subcenters such as Long Beach and North Hollywood are linked by trains to downtown L.A., with a link between Pasadena and downtown projected for 2003. Linkages to West and East L.A., however, have been abandoned as too expensive, leaving the existing subway system with a total of 17.4 miles of track. Despite the recurrent engineering and financial difficulties facing the project, several developers have built, or plan to build, TODs close to Metro stations. The Pacific Court development in downtown Long Beach, at the terminus of the Blue Line, was completed in 1992, and quickly leased out. Ten percent of the residents of Long Beach, which is "nearly a third more than the countywide average for employed residents" (*77*) use public transportation to get to work. The developer of Pacific Court also has created a TOD in Pasadena, anticipating the arrival of the Blue Line in 2003; a transit village also is planned for the MetroLink commuter rail station at Sylmar, in the San Fernando Valley.

Although further extension of the L.A. Metro Rail system is unlikely in the short term, the L.A. area is already home to one of the most successful transit systems in the United States—the Santa Monica Blue Bus. In operation since 1928, the Blue Bus provides ready accessibility for Santa Monica residents to the extent that "almost everyone in the city of Santa Monica lives within two blocks of a bus stop" (*78*, p. 86). In fiscal year 1998–1999, the Blue Bus moved over 20 million passengers—a considerable number, given that the population of the area served by the Santa Monica Bus is just under 500,000 (*79*). (See Table 3–5 and Table A–1.) A recent study puts Santa Monica at the top of a list of 137 U.S. urban transit systems ranked on the basis of ridership, operating costs, and customer service (*79*). Trade publications and Santa Monica municipal bus management offer the same explanation for the success of the Blue Bus: low fares and friendly service. The Blue Bus undercuts its competition at the fare box, from which it still manages to extract 35% of its revenue (standard fares for the Blue Bus are $0.50; for the Culver City bus, $0.75; for the Los Angeles County Metropolitan Transportation Authority, $1.35). The Blue Bus also emphasizes service quality, training their drivers to be courteous to patrons, and keeping the buses as clean as possible. At any of the many West Los Angeles bus stops serviced by both the L.A. MTA and the Blue Bus, patrons report that the latter's cheaper fare and cleaner bus interiors give the system a competitive edge. To improve efficiency in the UCLA community, one of the key Blue Bus customer segments, the Blue Bus recently set up a pass-fare system that lets UCLA students, faculty, and staff use their identification cards as debit cards at the fare box, thus reducing total boarding time (*80*).

The Blue Bus benefits from an administrative emphasis on efficiency to keep costs low, and the centralized nature of the system reduces overhead expenses. Because all of the buses come from one yard, Santa Monica Municipal Bus System incurs comparatively lower administrative expenses than the L.A. MTA, which operates throughout a much larger area and from multiple bus yards. Santa Monica also has paid close attention to rider preferences. After a steady decline in ridership into the early 1990s, the Blue Bus set about a Service Improvement Program in 1997 that, in consultation with community members, helped define the most attractive potential routes and services. Since then, Santa Monica's ridership has increased steadily (*62*). The most heavily used lines each operate between major points of origin and destination (such as UCLA), guaranteeing consistent ridership along fairly direct routes. With the beach and a popular downtown pedestrian mall as year-round destination points, many of the lines benefit from tourist and weekend visitor fares in addition to regular weekday riders.

TABLE 3-4 Carbon dioxide savings from transit use: Los Angeles 2000

Passenger Miles	1,554,723,063
CO_2 Emissions From Transit (Tons)	266,587
CO_2 Emissions from Personal Vehicles (Tons)	640,686
CO_2 Savings from Transit (Tons)	374,099

Source: Methodology outlined in Robert J. Shapiro, Kevin A. Hassett, and Frank S. Arnold, "Conserving Energy and Preserving the Environment: The Role of Public Transportation," (APTA: July 2002), 31–32. [http://www.apta.com/info/online/shapiro.pdf]

TABLE 3-5 Carbon dioxide savings from transit use: Santa Monica 2000

Passenger Miles	72,791,532
CO_2 Emissions from Transit (Tons)	12,085
CO_2 Emissions from Personal Vehicles (Tons)	29,996
CO_2 Savings from Transit (Tons)	17,911

Source: Methodology outlined in Robert J. Shapiro, Kevin A. Hassett, and Frank S. Arnold, "Conserving Energy and Preserving the Environment: The Role of Public Transportation," (APTA: July 2002), 31–32. [http://www.apta.com/info/online/shapiro.pdf]

At the present time, the greatest challenge for the Blue Bus is to maintain cost efficiency in increasingly heavy local traffic. To maintain vehicle headway (the interval between arrival of buses at scheduled stops) with more cars on the road, more buses have been added to each line, effectively increasing overall costs without increasing ridership. The resulting fiscal pressure has been noticeable since 1998, and how the Blue Bus will perform as overall surface congestion continues to increase in West Los Angeles is unknown.

With the initial elements of an ambitious subway system, one of the most efficient municipal bus systems in the nation, and a handful of successful TOD developments, it is conceivable that the Los Angeles area could moderate its VMT over the long term by building on any of these assets. Recent research by the Brookings Institute, which considered population over urbanized land as defined by the National Resource Inventory of land uses and not population density in an urban area determined by a threshold number of inhabitants established by the census, suggests that "although it is still auto-oriented, Los Angeles is 'densifying' dramatically" by consuming land more efficiently than its northeastern peers, thereby raising its density as a function of population over aggregate urbanized land) (*81*, p. 14). This is not to say that L.A. is becoming Manhattan. But the study does suggest that conditions within some parts of Los Angeles and surrounding areas, physical limitations to land consumption, together with an influx of immigrants into already urbanized areas, are making for urban densities more favorable to effective transit operation. In the short term, the Santa Monica Municipal Bus System has already taken advantage of this trend; in the long term, the Los Angeles bus and rail systems have the potential to do likewise.

Greenhouse gas emissions from the U.S. transportation sector can be significantly lowered by reducing passenger VMT. One of the most immediate and practical ways of reducing this figure is by filling buses and trains with people who would otherwise make their trips by automobile. Effectuating the shift from car to transit, however, is not as straightforward as adapting a comprehensive bus system to urban geographies designed around the automobile. To optimize mass transit's competitive position in terms of speed, convenience, and desirability, urban planning and design are required to support the development that leads to frequent use of transit for work trips, and the greater choice of mobility options for personal trips. As travel demand research has demonstrated, the key to an expanded range of mobility options is a high-density use of land use that is coupled with a transit- and pedestrian-friendly environment. In locations that provide highly efficient transportation, auto trips are low because high density makes it more economical to make trips on foot, by bicycle, or by using public transportation. The presence of transit can lower emissions not only from work-related auto trips, but also from local trips made to meet the everyday needs of city residents. By making transit one of a number of equally desirable options for individual trip planning, automobile use—and emissions—could be greatly reduced.

The cases here presented demonstrate that, where transit routes connect major points of origin and destination, as does the Santa Monica Blue Bus or Washington's Metro system, people are willing to use transit. Chattanooga's downtown revitalization project highlights the growing popularity of the mixed-use, high-density urban environment that is better served by transit than by automobiles. The Chattanooga experience lends much weight to the argument that transit may be used effectively to help reverse long-standing patterns of land use. While CARTA's electric buses are helping bring crowds back to pedestrian-friendly downtown Chattanooga, the obsolescence of one of Chattanooga's earliest suburban shopping malls is a sign to many that the key to sustainability is not the continuation of auto-oriented, green field development, but rather reinvestment in old, already dense areas and densification of new, more suburban areas. In both cases, a key ingredient is the provision of mass transit in environments built to be pedestrian- and bicycle-friendly. A desirable effect is the reduction of personal automobile GHGs and smog-forming emissions.

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CHAPTER **4**

TRANSIT TECHNOLOGIES FOR REDUCING GREENHOUSE GASES

As shown in the preceding chapter's TOD case studies, increasing ridership means taking account of a wide variety of factors in the transportation planning process. Similar logic applies to GHG reduction: the most effective strategy is comprehensive, approaching the problem from multiple avenues. Improved transit service and transit-friendly urban planning, examined in the previous chapter, were two of three strategies proposed in Chapter 1; the third recommended strategy is adopting energy-efficient technologies and fuels for transit fleets. As with TOD, no single factor will significantly reduce automobile usage at a regional or local level. Emissions-reducing technology, it should be stressed at the outset, will have a significant impact only if supported by policies that make transit competitive with the automobile.

This chapter examines a range of fuels and technologies that offer alternatives to the use of carbon-rich petroleum by transit vehicles and assesses them on the basis of their potential for assisting GHG reduction. Because many alternative fuels and technologies have been developed for other purposes, it should not be surprising that some of them do not offer dramatic reductions in CO_2 emissions. A number of the fuels that are considered "alternatives" today have, in fact, been available for quite some time. Henry Ford's first automobile ran on ethanol; electricity was a more common fuel than gasoline at the turn of the century; and biodiesel was developed in the 1930s (*82*). Nor is natural gas a new technology, but one that has, like others, only recently come into wider use as a pollution-abatement measure. None of these fuels was developed specifically to address air quality issues, let alone global climate change.

The case of compressed natural gas (CNG) illustrates how a growing understanding of climate change can unsettle our notion of pollution and what technologies should be used to reduce it. Currently, the use of CNG is favored, at considerable expense, as a way to reduce emissions of particulate matter (PM), oxides of nitrogen (NO_x), and sulfur dioxide (SO_2) from transit buses across the country. At the same time, CNGs potential as a low-GHG emissions fuel is unclear. According to simulated road tests conducted by Northeast Advanced Vehicle Consortium, CNG offers no emission benefit when compared to diesel (further discussed in the subsection, Compressed Natural Gas). According to Argonne National Laboratory's Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Model, however, CNG promises modest reductions in the *long term*, on the order of 1.6 pounds of CO_2 per mile lower than petroleum diesel (See Table 4–1). When the GREET model is run for *near-term* conditions, however, it produces results more in line with those of the Northeast Advanced Vehicle Consortium. "Near-term technologies are those already or almost available in the marketplace. Long-term technologies are those that require further research and development" (*83*, p. 93). Since virtually no North American transit agencies base procurement decisions solely on the basis of GHG emissions, the challenge is to identify technologies that reduce emissions of regulated pollutants and, at the same time, generate significantly fewer GHGs. Even assuming that the GREET long-term projection is accurate, CNG may not be the best available option for meeting these twin requirements.

The Clean Air Act's stipulations are the main driver in the current trend to convert from petroleum-based to alternative fuel vehicles (AFVs) in the United States (*82*). As clean air mandates have toughened over the 1990s, many transit agencies have run demonstration projects involving commercially available alternative fuels and developing technologies. As a result, there is now a useful body of literature and working familiarity with the emissions profiles of alternative fuels and technologies in transit applications. Practical experience with AFVs also is growing among a select group of transit agencies. At the time of this writing, New York City's "2000–2004 Capital Plan" calls for the Metropolitan Transportation Authority to almost double its AFV fleet, adding at least 300 CNG buses to its existing fleet of 350. Over the next several years, New York also will be substantially expanding its fleet of 10 hybrid–electric buses, with standing orders for an additional 325, and funding for 50 more (*84*, *85*). New York's investment in AFV bus technology is part of a comprehensive pollution reduction strategy involving the use of new, low-sulfur fuels in all diesel buses, the retirement of old diesel buses, and the purchase of new models with particulate traps and much cleaner, state-of-the-art diesel engines. Los Angeles, the second largest transit agency in the nation, is abandoning diesel entirely. Since 1996, the Los Angeles MTA has replaced half of its 2,000-vehicle fleet with new CNG buses, making it the largest AFV transit fleet in the nation (*86*).

TABLE 4-1 Comparative carbon dioxide emissions from bus fuels

Fuel	Bus Emissions (lbs CO_2/mile)
Gasoline	16.1
Petroleum Diesel	13.3
CNG	11.7
B20 (20% Biodiesel/80% Diesel)	11.5
Ethanol from Corn	11.0
Hydrogen from Natural Gas[CNG?]	7.3
B100 (100% Biodiesel from Soybeans)	3.7
Hydrogen from Electrolysis	1.3

Source: Argonne National Laboratory's GREET Model. All life cycle GHG emissions have been converted to CO_2 equivalents.

The transit industry, as these examples are meant to suggest, is in the midst of a period of relative transformation, led by the largest agencies and a handful of small ones. Although the CO_2 contribution of transit buses is slightly more than 1% (6.3 million metric tonnes) of total CO_2 produced by the transportation sector, according to statistical information taken from APTA and the Energy Information Administration, this share could increase if transit were able to significantly reduce automobile VMT by capturing single-occupant drivers. (See Emissions Projection Model, Appendix B.) Transit and other fleets also are targeted to receive federal incentives to adopt alternative fuels or technologies because of their visibility to the public, where the successful operation of low-emissions technology may speed its acceptance by the general public.

Public awareness of the positive link between global climate change and emissions of CO_2, CH_4 and N_2O has not yet played a role in transit's move away from diesel as the fuel of choice. After a decade of trial and experimentation, however, we have a better sense of how certain technological alternatives affect GHG emissions and which ones better accomplish the simultaneous goals of eliminating smog-causing atmospheric pollutants and reducing the amount of GHGs introduced into the atmosphere. In the remainder of this chapter, the GHG profile of existing fuels and technologies will be highlighted, so that the advantages and disadvantages of each option may be weighed in light of the many other policy considerations that transit agencies must take into account in procurement decisions.

OPTIMAL TRANSIT TECHNOLOGIES FOR GREENHOUSE GAS REDUCTION

Obtaining large reductions in GHG emissions will require combinations of advanced vehicle technologies and fuels that can be manufactured and consumed with the greatest energy efficiency (*87*, p. 75). This means taking into account the GHGs generated at every stage of a fuel's production, transportation, and end use, or *life cycle* or *fuel cycle*. Life-cycle studies of all alternative fuels are required by the 1992 Energy Policy Act, which charges the Energy Information Administration to "collect and report information on greenhouse gases emitted by use of replacement fuels" (*88*). Life-cycle emissions estimates of alternative vehicle fuels taken from the most advanced emissions calculating tool, Argonne National Laboratory's GREET Model, are listed below (Table 4–1). Appendix C describes the challenges of using existing sources to determine the quantities of GHG emissions from alternative fuels.

Although Table 4–1 suggests that buses powered by ethanol and CNG promise modest reductions when substituted for petroleum diesel, in addition to low levels of emitted regulated pollutants, empirical trials of a variety of gas, alcohol, and diesel buses on urban duty cycles have produced varying results with the conclusion that much depends on the engine technology used (*89*). On the basis of year 2000 vehicle emissions testing by the Northeast Advanced Vehicle Consortium, CNG buses produced the highest emissions on a simulated New York City duty cycle, as well as on a simulated central business district duty cycle (*90*). Thus, while transit bus fleets, under regulatory or public pressure, are converting diesel-powered vehicles to a combination of cleaner burning (low-sulfur) diesel or CNG, neither low-sulfur diesel nor CNG can be said to offer guaranteed improvements in combined CO_2 or CH_4 emissions at the present time. "In general, fuel switching by itself has limited GHG emission reduction potential. Combinations of fuel switching and use of advanced vehicle technologies . . . achieve larger GHG emission reductions" (*87*, p. 75). Although it is considerably more expensive and lacks an established distribution infrastructure, biodiesel (discussed below) may be used in existing diesel engines with little modification and with great emissions reductions. Within the transit industry, however, use of biodiesel has yet to move beyond the demonstration phase.

Substituting alternatives for petroleum diesel fuel, however, is not the only alternative. Any of the conventional or alternative fuels become much more efficient (and significantly reduce GHG emissions) when used in a hybrid–electric engine, although not all fuel–engine configurations are equally practical given current technological preferences. The problem of reducing GHG emissions is therefore linked to the capacity of technologies to deliver improved fuel efficiency. The ideal transit bus, in terms of working technology currently available on the market, would be a hybrid–electric, low-sulfur diesel or biodiesel propulsion system installed in a lightweight, composite fiber body. For electric or hybrid–electric buses, (and potentially for electrified rail systems*)* regenerative braking technology offers energy savings by recapturing up to 25% of the kinetic energy lost by a decelerating vehicle and applying it to the vehicle's energy stores. Bus fuel efficiency can be further increased with the adoption of lightweight body and chassis structures. The use of lightweight materials, such as carbon or composite fiber can, by one estimate, reduce fuel consumption by one-tenth of a gallon per mile, a considerable savings in fuel and costs when considered over the lifetime of a vehicle. John Franks, Senior Director of Bus Maintenance, Houston Metro, personal communication, January 2, 2002. As an ancillary strategy for certain niche applications, such as bus service in downtown business areas and airport shuttles, battery powered electric buses are more fuel-efficient and less polluting than diesel buses. Electric buses have been very well received by the public in such places as Chattanooga and Santa Barbara. These technology options all have the multiple advantages of helping transit vehicles meet existing air quality standards, lowering GHG emissions, and enhancing ridership.

Large efficiency gains in rail technology are less immediate. Progress in railcar weight reduction has been incremental rather than revolutionary, and limited by certain safety factors such as flammability regulations. Urban rail systems will be made more efficient when an energy storage device is perfected that allows the application to an electrified transit system of the same principles at work in the hybrid–electric drive system; that is, the recuperation of energy lost in the vehicle's braking. The benefit of this would be a lowering of the system's energy use drawing from the local utility grid. Research is underway on the use of flywheels and ultracapacitors to capture and reuse the energy lost by braking railcars.

In both bus and rail transit, increasing the mileage of transit vehicles is a strategy that will make economic sense to a transit agency and address the problem of climate change in the absence of federal regulation of GHG emissions. The optimal strategies for doing so involve converting transit vehicles to alternative propulsion technologies, rather than simply substituting alternative fuels for petroleum diesel. In the near term, hybrid–electric technology offers the greatest potential for GHG reduction; in the longer term, depending on the course of research and a drop in production costs, fuel-cell technology promises even greater efficiencies. In the following section, the relevant technology and fuel alternatives will be assessed on the basis of their ability to meet the twin objectives of increased efficiency and reduced GHG emissions.

ALTERNATIVE TRANSIT FUELS AND TECHNOLOGIES AVAILABLE ON THE MARKET

Compressed Natural Gas

Based on the recent procurement activity and successful demonstration programs of the nation's two largest transit agencies (i.e., New York and Los Angeles), CNG is emerging as the most likely successor to diesel. In the early 1990s, liquefied petroleum gas (LPG, or propane) was the fuel of choice for AFVs; since then, the market preference has decisively switched to CNG (*82*, p. 1). Nationwide, in 1999, the number of CNG buses manufactured far outweighed any of the other AFV types. This has less to do with the cost efficiency of natural gas (conversion to CNG represents a commitment to higher capital and operational expenses) than with federal and state prioritization of programs promoting CNG. CNG has proven clean air advantages: it has been demonstrated to generate significantly less particulate matter and NO_x, which makes it attractive to urban transit agencies working to reduce smog levels. When CNG is sold as a fuel, favorable tax treatment makes it economical compared with other fuels. The capital costs of converting a transit facility to CNG, on the other hand, are high. This is largely accounted for by the pressurized tanks required to store the fuel at the facility. Capital costs for converting a bus from diesel to CNG total $50,000 (compared with $20,000 for an ethanol bus). Capital costs for converting a diesel transit facility (including buses) to CNG total $3.75 million in 1994 dollars for a 50-bus facility (compared with $0.10 million for ethanol) (*91*).

The emissions profile of natural gas, however, is mixed. While CNG performs well in GREET's long-term emissions simulation, engine duty-cycle performance tested by the Transportable Emission Testing Laboratory of the University of West Virginia shows lower efficiency in CNG buses during heavy-duty application, resulting in high GHG emissions (see Appendix C). As the Northeast Advanced Vehicle Consortium (NAVC) reports in their emissions testing of AFVs, "CNG buses consume more fuel for the same output [as diesel] . . . canceling out nearly half of the CO_2 benefit" (*90*, p. 38). CNG buses also suffer a "weight penalty" due to the larger and heavier fuel tanks required to keep natural gas pressurized and to carry enough to complete a typical round of service. Heavier vehicles consume more fuel. Perhaps more importantly, CNG buses emit much higher amounts of methane (CH_4) than do diesel buses, which emit virtually none. Since methane has 21 times the global warming potential of CO_2, a small volume of methane emissions can cancel out a much larger decrease in CO_2 emissions (*88*). As NAVC reports, "even though the CNG buses emit less CO_2, the impact from the released methane creates a larger GHG impact." NAVC found that, on a certain duty cycle, a CNG bus "actually had higher total GHG emissions" than a comparable diesel bus (*90*).

A comprehensive conversion of the national stock of transit buses to CNG would have numerous beneficial effects on the air quality of urban areas, but would do little to reduce GHG emissions. Although trends indicate a clear shift to CNG by major transit agencies, those involved in alternative fuel programs at the nation's two largest transit agencies view CNG as a transitional technology. "Natural gas will have outlasted its usefulness in the near future," says New York City Transit's Assistant Chief Maintenance Officer Dana Lowell. "CNG is ultimately a transitional strategy," echoes L.A.'s John Drayton, Alternative Fuels Program manager for the city's MTA (*92, 93*). Expected improvements in the petroleum refining process and complementary advances in engine technologies may soon make diesel just as clean to burn, and more attractive in terms of capital and other costs, than CNG. Both agencies anticipate that the other likely competitor of the CNG bus is the hybrid–electric transit bus.

Battery-Powered and Hybrid–Electric Buses

The number of battery-powered electric buses being manufactured is on the rise, although inherent limitations on battery technology make the electric bus an unlikely successor to the diesel engine for most heavy-duty, urban applications. Where conditions are appropriate, however, battery-powered electric buses have proven to be economical, reliable, and very popular with the public. Electric buses emit no GHGs directly, but only indirectly at the utilities from which they draw their power. The Santa Barbara Electric Transportation Institute estimates that, given the mix of fuel sources used to generate electric power in the Southern California region, Santa Barbara's electric buses cause approximately one-third less CO_2 to be emitted than would an equivalent diesel fleet (*94*). Since power plants generate large amounts of electricity at a time, they produce the energy needed to drive a bus much more efficiently than would a single bus engine, and therefore generate proportionately fewer GHG emissions. Most electric fleets also recharge at night, when the more efficient 24-hour plants are on line, thereby avoiding the higher emissions of peak-hour power plants (*94*).

For geographic conditions of low relief and a temperate climate that have short distance routes and frequent-stop duty cycles, electric buses are an optimal technology (*95*). The nation's two largest operators of electric buses, Chattanooga and Santa Barbara, both made the decision to implement electric transit vehicles as part of larger projects to improve the livability of their central business districts. In both cities, "electric propulsion enabled quiet, exhaust-free, odorless operation, and proved to be an immediate success with riders . . . Drivers reported that prospective riders would forego a ride on a diesel bus in order to wait for the next available electric bus" (*95*, p. 1). The first to adopt battery electric technology, Santa Barbara, put its two initial electric buses into operation in January and May 1991. The two prototypes, which went into operation on routes formerly served by diesel buses, then captured 75% of Santa Barbara's 300% ridership increase for 1991 (*96*).

In comparison, hybrid–electric motors, since they are not dependent exclusively on battery power, have shown a much greater range of performance capabilities in a variety of demonstration projects across the United States. The advantage of hybrid technology is twofold: first, because the engine only runs when the battery or drive system signals the need for more energy, it does not idle when the vehicle is coasting or at rest. This feature, currently available in personal automobiles, is not yet available in transit vehicles. Hybrids still consume less fuel while idling, however, and the stop-idle feature is expected soon to become standard in buses, as is the case for cars. The greater efficiency of hybrids comes from regenerative braking. In real-world operation, regenerative braking is estimated to recuperate 25% of a vehicle's kinetic energy at the moment of deceleration, converting the braking energy into electricity, which is then used to recharge the vehicle's battery. The result is increased fuel efficiency and, by extension, reduced GHG emissions.

"Hybrids," observes New York City Transit's Dana Lowell, "are the only technology that reduces regulated and non-regulated emissions at the same time." Judging New York's 10-vehicle hybrid fleet to be "very successful," the city has now placed orders for 325 diesel hybrid–electric vehicles, and expects the technology to be fully viable for commercial applications (*92*). Hybrid–electric buses have demonstrated equal or superior performance to diesel-powered buses in almost all service situations. They have been operated in heavy-duty cycles in New York, the Los Angeles area, and Cedar Rapids, Iowa, where, according to a recent TCRP report, they have shown "numerous . . . advantages [over diesel powered buses] such as smoother and quicker acceleration, more efficient braking, improved fuel economy, and reduced emissions" (*97*, p. iii). "The number of [hybrid–electric] vehicles," the report concludes, "is expected to quadruple in the United States alone during the next couple of years. In another several years, the worldwide hybrid bus fleet may well reach into the thousands or even tens of thousands" (*97*, p. 48).

Currently, getting the most out of the batteries that serve both electric and hybrid–electric buses is the greatest technical challenge, and one of the biggest research areas for groups like the Southern Coalition for Advanced Transportation (SCAT), NAVC, and Chattanooga's own Electric Transit Vehicle Institute. "The biggest push in R&D," according to SCAT's Kevin Shannon, "is batteries, moving towards hybrids, complemented by natural gas or propane turbines" (*98*). Other agencies are watching New York's commitment to hybrids closely, and are ready to move ahead with the technology once they are confident that hybrids can survive heavy-duty service applications. According to the Santa Barbara Electric Transportation Institute's Zail Coffman, "Hybrid is really the coming thing. Fuel consumption on hybrids is 15 to 30% more efficient than a conventional diesel vehicle . . . Hybrids are going to make a big impact over the next decade" (*94*).

Biodiesel

A transit bus, running on 100% biodiesel (B100) instead of traditional diesel fuel would reduce CO_2 emissions per mile by nearly 72% across the life cycle of the fuel. A transit bus running on the more commonly used mixture of 20% biodiesel and 80% diesel (B20) instead of traditional diesel would reduce CO_2 emissions per mile by about 14% (*99*). (See Table 4–1.) For both the pure form of biodiesel, and B20, the greatest percentage of biodiesel's reduction of GHG emissions are a consequence of its renewability as a biomass fuel. Unlike the carbon stored in fossil fuels, the carbon in biodiesel is renewable, and can be made from any kind of fatty oil (derived from peanuts, mustard seeds, canola, soybeans, or even used cooking oil). Rather than being released into the atmosphere after millions of years of sequestration beneath the Earth's surface, the life cycle of biodiesel requires no more carbon than is already circulating in the biosphere from season to season. The same is true for ethanol; the difference lies in the greater amount of energy needed to turn corn—ethanol's most common feedstock—into fuel. The *manufacture* of ethanol is, in fact, more energy-intensive than that of any of other fuel. (See Table C–1.)

Biodiesel is an organically produced fuel, made either from the oil of vegetables (such as soybeans) or recycled cooking greases (*100*). As stated in the National Renewable Energy Laboratory's life-cycle study, "biodiesel's life-cycle emissions of CO_2 are substantially lower than those of petroleum diesel . . . [U]se of biodiesel to displace petroleum diesel in urban buses is an extremely effective strategy for reducing CO_2 emissions" (*100*, p. v). Biodiesel has the added advantage of reducing methane emissions, together with all regulated pollutants except NO_x. In contrast to both natural gas and the alcohol fuels, biodiesel offers an energy content equivalent to diesel, resulting in comparable mileage in transit buses (*101*). Using B20 requires no modification of conventional diesel burning engines; higher blends of biodiesel require replacement of rubber engine seals with synthetic engine seals. Seals notwithstanding, biodiesel actually increases engine lubricity, and helps to clean out the fuel system.

Biodiesel, like the alcohol fuels, currently is at a competitive disadvantage with diesel due to its relatively high cost of production. B100 can cost nearly $2 per gallon with taxes. Biodiesel is no longer a demonstration project, however; a competitive market in B20 has emerged over the last 2 to 3 years, with municipal school districts and the U.S. military two of its biggest consumers (*101*). A 1998 amendment to the Energy Policy Act authorized use of biodiesel "as a way for federal, state, and public utility fleets to meet requirements for using alternatives fuels" (*102*, *103*). The biodiesel industry hopes that continued use of the fuel by various private and public fleets will expand the market and lower production costs. Impending air quality regulations may soon be working in favor of biodiesel as well. At the time of this writing, federal subsidies for biodiesel do exist, although their continuance is uncertain. Production of biodiesel is subsidized by the USDA as part of its Bioenergy Program. Transit agencies must meet an EPA deadline of 2006 to reduce the sulfur content of their diesel fuel to 15 parts per million. As more expensive, low-sulfur diesel comes to market in response to this demand, biodiesel will become more competitive. Manufacturers of ethanol or biodiesel can apply for direct government subsidies to buy the feedstocks (corn, soybeans, animal fats) under a program set up in October 2000. The 2-year program is funded at a rate of $150 million annually. Payments are based on output increases (using eligible commodities) over the previous year. In January 2002, biodiesel producers who used animal fats and oils produced in the United States to make biodiesel also were eligible to participate in the program. Some analysts point out that another cost advantage lies in the easy convertibility of the existing petroleum distribution system, which could support biodiesel with "little or no modification" (*104*). Several municipalities are running, or have run, a portion of their fleets on biodiesel, often with financial assistance from agencies such as Department of Transportation's Congestion Mitigation/Air Quality program. Cincinnati's Metro experimented with soy-based biodiesel in the early 1990s, and biodiesel based on both cooking oil and animal fat in 2000. It is currently nearing the end of a 2001 trial running 150 buses on B20 (*105*). In the case of Cincinnati, cost rather than performance is the obstacle to long-term adoption of biodiesel.

Alcohol-Based Fuels

The GREET estimated life cycle of GHG emissions per mile from ethanol is 17% lower than that of petroleum diesel. For methanol, life-cycle emissions are higher than those of petroleum diesel (*88*) (See Table 4–1). As with biodiesel, the emissions savings for ethanol results from the assumed re-absorption of CO_2 by the growth of the following year's feedstock crop. The lower energy efficiency of ethanol, however, coupled with its high cost, have inhibited widespread adoption of ethanol technology. The Los Angeles MTA, while citing numerous mechanical difficulties stemming from the corrosive nature of ethanol and frequent engine failures, found ethanol's lower on-the-road efficiency the most serious strike against it. "Ethanol was strangling the agency," according to L.A.'s John Drayton. "We were paying more for the fuel and getting less mileage" (*93*). After a period of demonstration programs ending in the late 1990s, no transit buses using alcohol fuels such as ethanol or methanol were manufactured in 1999, and there are few indications that alcohol fuels will become the market preference for AFV buses at any time in the near future. Although capital costs are greater for CNG buses, two factors weigh heavily in favor of natural gas and against the alcohol fuels: the lack of a well-developed distribution infrastructure for the alcohols, and their higher market cost (*91*).

A number of cities ran demonstration programs with ethanol or methanol buses in the 1990s: Minneapolis, Peoria, and Los Angeles ran ethanol buses, while New York City and Miami tested methanol buses. Dana Lowell of New York's MTA calls the agency's experiment with methanol "a total disaster," and compares it with the outcome of a similar program in Los Angeles. In the early 1990s, when New York ran the program, according to Lowell, methanol engines were prohibitively expensive, hard to procure, and too difficult to maintain (*92*). While evaluations of performance vary somewhat from one transit agency to another (Peoria, for example cited no notable maintenance problems), those interviewed for this report agree that the cost of running buses on either alcohol fuel was a significant disincentive to continuing the program (*92*). At the time of Peoria's program (1992 to 1998), ethanol cost 18¢ more than diesel per mile. At the time of Los Angeles' program (1989 to 1997), ethanol cost 35¢ more than diesel per mile. Higher costs, in these cases, are incurred in the production process, and in the lower energy content of alcohol-based fuels, which results in higher total fuel consumption (*93*, *106*). Despite ethanol's GHG emissions reduction advantage over conventional fuels, mechanical difficulties and high costs make it an unlikely resource.

Lightweight Materials

Anything that lowers the weight of a transit vehicle will improve its fuel efficiency. The lighter the weight of a vehicle, the less fuel is required to propel it. Currently, several manufacturers have brought to market an alternative to the conventional, steel/aluminum-frame bus: the composite fiber bus body. Made either of expensive but very strong carbon fiber or more affordable but still sufficiently strong fiberglass, composite fiber bodies can offer decreased weight together with other features that would reduce operating and maintenance costs for a transit agency. Based on a program run in the early 1990s, Houston's Metro determined that, as Metro Senior Director of Bus Maintenance John Franks put it, "Lightweight buses pay for themselves." Houston's German-made, carbon fiber bus required a smaller diesel engine than a bus with a traditional frame, which led to immediate savings. Houston also expected future savings from reduced brake and tire wear and better mileage (*107*).

Between 1992 and 1999, Los Angeles MTA operated six inexpensive fiberglass, single-frame buses with favorable results. Composite fiber buses impressed the MTA with their resistance to corrosion, and their strength in collisions. Composites are "incredibly strong for their weight," remarks MTA's John Drayton. MTA also took note of the precision engineering behind the composite manufacturing process. While a typical steel bus has 10,000 parts holding it together, current lightweight models have less than 50. The effect of fewer parts on the performance of the vehicle is, as Drayton says, that "everything works better" and Los Angeles MTA is very confident about the potential for composite materials in transit buses." The production techniques involved in casting a single shell, or *monocoque* frame, Drayton emphasizes, "aren't rocket science, but techniques used in the boating industry for years," where they are used to create materials that withstand stresses of similar magnitudes. While composite materials currently in demonstration have yet to prove themselves over the 12-year life span of a typical transit bus, so far there are few indications that testing will diminish the high expectations for composites (*93*).

ALTERNATIVE TRANSIT FUELS AND TECHNOLOGIES IN DEVELOPMENT

Energy Storage Systems

Most of the R&D involving rail transit is concentrated in energy storage systems. Although a variety of high-speed rail technologies are being studied (such as magnetic levitation), as are alternatives to diesel fuel for rail freight (i.e., gas turbines), these efforts deal primarily with long-haul rail transport, rather than the predominantly electrified light- or heavy-rail systems typical of North American urban areas (*108*). Research also is being done at the Center for Electromechanics at the University of Texas, Austin, on an "Advanced Locomotive Propulsion System" that would use a gas turbine to achieve the same performance as diesel on long-haul runs and supplementing the turbine with flywheel technology to increase energy efficiency. As for weight reduction, it is unlikely that the dramatic reductions achieved with composite materials in bus design will be replicated in rail cars, given the more stringent fire safety regulations to which they are subject. Work on rail technology is "improving, but without revolutionary breakthroughs," according the David Phelps, a Senior Project Manager at APTA (*109*).

Since the majority of light-rail transit systems in the United States are electrified, their GHG emissions profiles will match those of the utilities that power them. Reducing emissions from a typical metro system is therefore an issue of increasing the efficiency of an entire system of trains, rather than the individual vehicles that compose it. The principle behind the technology for doing so, however, is not so different from the principle behind regenerative braking in a single hybrid–electric bus: to capture the kinetic energy lost when a vehicle decelerates, to store it, and to use it to accelerate the same or different cars at a later point in time. In a hybrid–electric or electric bus, the rate at which energy is drawn from and put into the battery is not beyond the performance range of conventional technology. For a system of rail cars, however, the challenge lies in finding a way to quickly absorb a relatively large electric charge, and store it long enough to distribute it to a vehicle elsewhere in the system, something which current battery technology is unable to do. Flywheels and ultracapacitors, which are also being tested for use in transit buses, are two promising energy storage technologies for overcoming this hurdle. Flywheels are devices that store energy in the momentum of large masses revolving with very little friction; ultracapacitors are, as the name suggests, very large capacitors, devices able to receive and distribute a large electric charge in a short time. As is often the case, gains in efficiency in one part of a system can lead to further gains elsewhere in the system; one maker of flywheels notes that regeneration of braking power reduces heat in subway tunnels, thereby reducing the need to use electric fans to remove it (*110*).

Regenerative braking, according to APTA's David Phelps, is "the most exciting area in rail technology advance currently" (*109*). The Center for Electromechanics at the University of Texas, Austin, is working on a demonstration gas–turbine flywheel locomotive that it hopes to test in 2004 in Pueblo, Colorado. Looking further ahead, researchers at this institution expect the "commercialization phase of flywheel technology to be about 8 to 10 years away" for high-speed applications (*108*). More relevant for urban transit is "wayside energy storage" in which a flywheel or ultracapacitor is located, not on the locomotive, but beside the track, as part of a power distribution system. A train decelerating into a station would send the energy recuperated from braking to a nearby storage device, which would then discharge it at the appropriate moment. One such wayside storage device employing a flywheel, is in demonstration in the United Kingdom (*110*). With current technology, recuperated energy in an electrified system is useless unless there is a second train accelerating at just the moment that the first train is slowing down, allowing the power to be sent through the rails for a short distance from one train to the other.

Hydrogen Fuel Cells

Hydrogen fuel cells have been widely touted as the ideal, emissions-free replacement for the internal combustion engine, and its most likely successor in mass production. It is on the grounds of such expectations that R&D in hydrogen increased substantially over the 1990s, most notably through the Partnership for a New Generation of Vehicles, which involved the "Big Three" American automakers in coordinated fuel-cell research. Initiated by Ballard Power Systems on the part of this auto consortium, together with the California Air Resources Board, and the California Fuel Cell Partnership, in the 1990s, hydrogen transit buses were put into trial operation in three different locations: Chicago, Vancouver, and Washington, D.C. (at Georgetown University only). More recently, SunLine Transit Agency in Thousand Palms, California, completed a 13-month hydrogen bus study. Committed to developing hydrogen fuel-cell technology, SunLine plans to begin testing another fuel-cell bus in mid-2002. "Our desire," says SunLine's Richard Cromwell, "is to end up with a fuel-cell fleet" (*111*, *112*). The first U.S. transit agency to fully convert its fueling and infrastructure to CNG, SunLine sees its commitment to natural gas as "the bridge" to hydrogen. "With CNG," says Cromwell, "you have a compressor on the bus, you just adjust the lines to use hydrogen as well as natural gas . . . it's one change" (*111*).

If the process of splitting hydrogen from the other elements to which it is attached is done utilizing power drawn from hydro, wind, solar, or biomass sources, hydrogen has the potential to be both renewable and entirely free of emissions at the production and consumption ends of the life-cycle. SunLine Transit currently powers some of its hydrogen generation from solar panels, a truly zero-GHG method of making hydrogen. SunLine expects that, in less sunny parts of the United States, hydrogen will most likely be made from methane, in a process called natural gas reforming. Although hydrogen may be manufactured from many feedstocks, the existence of extensive natural gas pipelines and cheap natural gas would allow the manufacture of hydrogen to take place in a decentralized fashion at the site of refueling. Steam reforming at the station releases virtually all of the carbon in CH_4 as CO_2; however, the extremely high efficiency of the hydrogen fuel thus produced is such that lower GHG emissions per mile of travel can be attained.

COSTS OF EMISSIONS REDUCTION FROM BUSES

Any decision to incorporate alternate technologies or fuels into transit fleets will be heavily influenced by the projected costs of implementation. However, projecting costs is challenging since most of the technologies in question have not been thoroughly tested under operating conditions and a clear market preference for any one technology has yet to emerge. Costs are changing constantly as companies compete in a limited market and products undergo rapid evolution. See Appendix C for a methodology to compare estimated costs based upon the current costs of alternative fuels. As technology evolves, future costs for developing technologies can be substituted for those in Table C–2 to yield more accurate estimates over time.

The emissions per vehicle mile for buses running on alternative fuels can be calculated using data in Table C–1.

All of the technologies are compared to petroleum diesel—the current standard. Fuel costs are based on current costs as reported by government research institutions (see the sources listed for Tables C–1 and C–2). Vehicle costs have been chosen to reflect a hypothetical mature system in which fuels and technology are available at market costs. The costs to reduce emissions are calculated as dollars per ton of equivalent CO_2. Three scenarios are used to illustrate how costs can be used to assist in making decisions about which technologies transit agencies can consider given the current market restraints.

Overall, the results of Scenario 1 (Table C–2) indicate that for some of the alternative technologies– (hydrogen fuel cells and CNG) fuel cost savings can compensate for additional costs that would be incurred from purchasing buses that use alternative fuels. As the costs of these buses become lower over time, low fuel prices could make them more attractive to transit agencies.

Scenario 2 assumes the same cost of fuels as Scenario 1, but assumes savings from lower fuel costs can be invested in the bus. It also assumes that no financial benefit is gained from emission reductions. The operating costs saved from lower fuel costs over the million-mile life of a bus could, however, be substantial. Million-mile savings with CNG only amount to $10,000, a fraction of the estimated $50,000 needed for the bus. With a fuel cell and low-cost hydrogen from natural gas, the savings of $320,000 could be achieved in the near future.

Scenario 3 also assumes the same cost of fuels as Scenario 1, and that the investments of Scenario 2 are feasible. Additionally, it assumes that the benefits of lower emissions will be quantified through the trading of GHG emissions at a price of $10.00 per ton. These revenues to the transit agency of up to $60,000 over the million-mile life of a bus could increase the funds available for more expensive buses over those available in Scenario 2. By itself, CNG fuel substitution appears to offer relatively modest emissions reductions. In combination with a fuel cell, however, both considerable emissions reductions and cost savings can be achieved.

The transit industry has been the focus of much technological innovation over the last decade as clean air standards have tightened and public tolerance for air pollution in large urban areas has diminished. Those transit agencies that have demonstrated or committed to alternative propulsion technologies have enjoyed the rewards of high public visibility, which has often been accompanied by increased ridership. Experience has shown that hybrid–electric and battery-powered buses are especially popular with the public, and this may go far toward gaining their acceptance in the much larger market for passenger automobiles. It is important to stress, however, that technology alone is not the solution to the problem of GHG emissions in the transit industry or elsewhere. The contribution of transit to total U.S. carbon emissions is very small, on the order of just over 1%. Introduction of low-emissions technology into this sector alone will not significantly contribute to a reduction of GHG emissions. If, however, such technology can help transit agencies reduce costs and improve customer satisfaction, it may assist in a general expansion and public acceptance of transit service, and thereby encourage more people to become riders rather than drivers.

EMISSIONS-REDUCING POTENTIAL OF ALTERNATIVE FUELS AND TECHNOLOGIES

Most of this chapter has described the potential for transit vehicles to reduce GHG emissions by substituting new fuels and technologies for conventional ones. However, it is unlikely that any of the fuels or technologies described above will have a large impact on U.S. emissions unless they are adopted on a broad scale. The research team created an emissions projection model to determine the emissions impact of a large-scale shift to alternative fuels and technologies within the transit industry. For the sake of comparison, this is modeled against three other technology adoption scenarios. GHG emissions have been calculated from transit, and projected 20 and 40 years into the future.

The model is consistent with emissions and procurement data collected from the Federal Transit Administration, U.S. Department of Transportation, the American Public Transportation Association's *2001 Fact Book*, and the GREET Model. The large-scale implementation scenario assumes a more rapid adoption of technologies than is presently the case, so that the emissions benefits may stand out clearly.

The remaining model scenarios project forward current rates of emissions and adjust the initial rapid adoption scenario for higher or lower growth in transit VMT. The growth trends for transit and automobiles over the last five decades suggests that rapid changes in VMT and transit passenger miles are not unprecedented; the model therefore projects future growth based on the relative increases in transit ridership experienced over the past five years.

Potential reductions in GHG emissions are projected from for the periods from 2000 to 2020 and 2000 to 2040. The model estimates the reductions of GHG emissions in metric tons of CO_2 equivalent per year that would be achieved over these corresponding 20- and 40-year periods by converting the technologies used by transit and rail fleets to emit cleaner byproducts and produce lower GHG emissions than currently attained. Figure 4–1 shows four possible scenarios for future GHG emissions from U.S. transit. In total, transit could prevent 40 Tg CE between now and 2020 and 320 Tg CE between now and 2040 by adopting alternative technologies under a high-growth scenario.

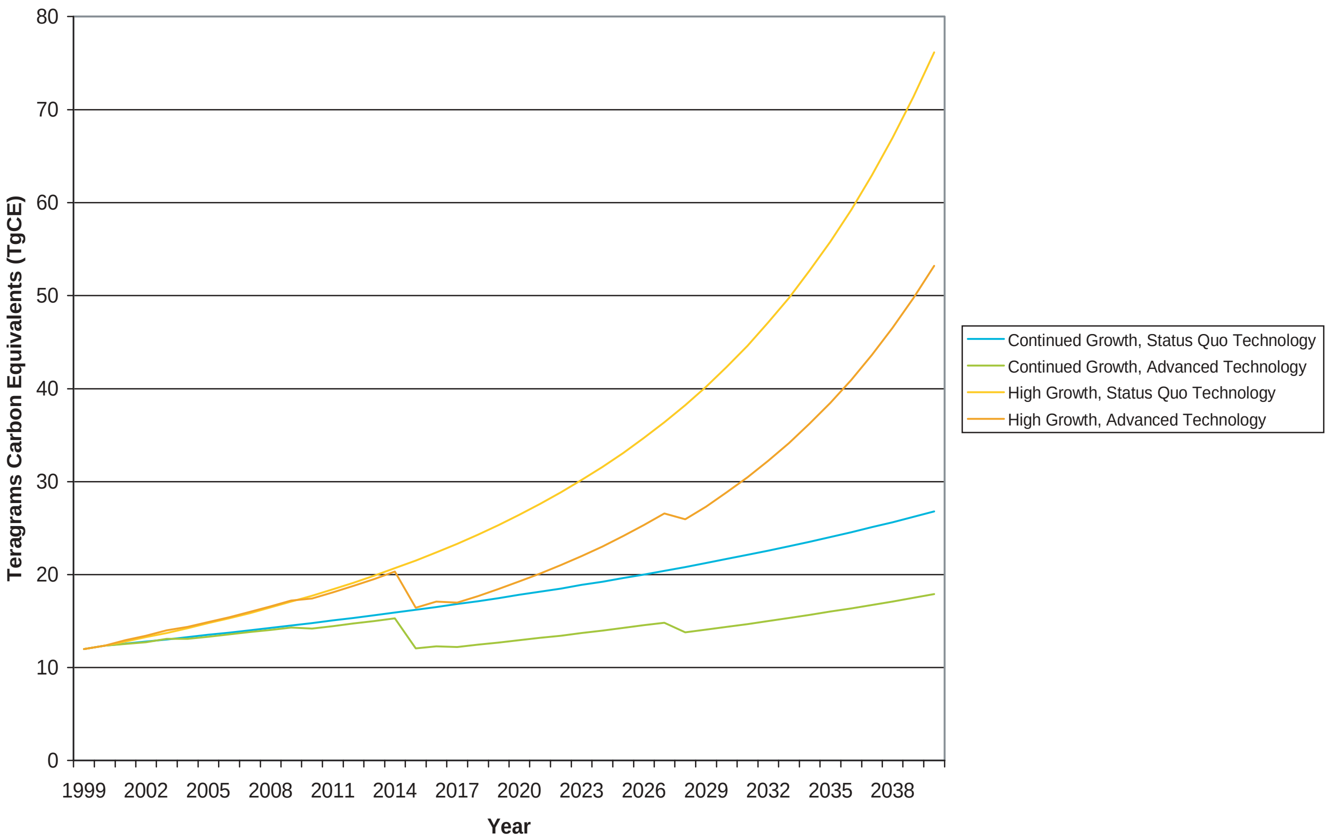

Figure 4-1. U.S. transit emissions projections, 1999 to 2040 (carbon equivalents).

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CHAPTER 5

WEB-BASED TOOLS FOR REDUCING GREENHOUSE GAS EMISSIONS

INTRODUCTION

Tools developed in conjunction with this report have been posted on a companion website www.TravelMatters.org. The site is intended for individuals seeking information on global warming as well as transit and planning professionals poised to make significant decisions about the climate change impact of local and regional transportation systems. All individuals may take advantage of a trio of resources provided by the website—two interactive emissions calculators, eight online emissions maps, and accessible educational content. The website also is supplemented with a glossary as well as links to related websites.

A personal calculator computes individual transportation emissions based on the mixture of modes used in a given month. A transit calculator computes emissions generated by public transportation fleets, and is intended for use by transit planners, researchers, and civic groups. Both calculators allow users to devise "what if" emissions scenarios, in which they switch transportation modes, fuels, or technologies, in order to lower emissions totals. Together, the calculators serve to inform individuals, transit professionals, urban planners, and public interest groups about GHG emissions resulting from transportation, and identify ways to reduce emissions. As the issue of climate change gains prominence on the policy horizon, TravelMatters will be available as a resource for the enrichment of public discourse on the moderation of GHG emissions from the transportation sector.

In addition to the emissions calculators, which offer a quantitative description of GHG emissions, the TravelMatters website also hosts colored maps delineating the geographic distribution of emissions in urban and rural areas. These maps offer striking visual support for the ways in which land use and transportation infrastructure directly affect GHG emissions. Text from this report also is presented as educational content for users interested in the science of climate change, the definition and role of GHGs, the factors that influence the demand for automobile and transit trips, and alternative transit technologies and fuels.

CHANGING BEHAVIOR

One project goal was to develop tools that translate abstract ideas about a global environmental issue into concepts that are on a human scale and easily accessible to the educated lay person. Such tools should attract the user's attention, hold it long enough to convey basic information about the issue, and persuade the user to take action. From the project's inception, the TCRP H-21 panel has provided many useful suggestions concerning the user interface for the TravelMatters website. The panel has also offered useful ideas on the articulation between the website and published TCRP report. To design an optimal tool for the needs of the intended audience of transit professionals and concerned individuals, the research team worked in regular communication with a variety of specialists and conducted a series of testing groups. We began by meeting with representatives of metropolitan planning organizations (MPOs) at the annual conference of American Metropolitan Planning Organizations in March 2002. Here the team presented the basic idea of the project: that surface transportation systems can be designed to cost-effectively reduce GHG emissions. The research team also presented detailed descriptions of alternative transit technologies, the metropolitan CO_2 emissions maps mentioned above, and the emissions calculators. Audience response to the project goals was favorable, and participants agreed that the calculators could be useful for an agency monitoring emissions with future CO_2 regulation in mind. At the same time, the team was advised to link GHGs with emissions that currently are regulated by the Environmental Protection Agency, and therefore of more immediate concern to transit agencies and MPOs. In response to this suggestion, the next generation of www.TravelMatters.org (scheduled for availability in 2004) will enable users to calculate transit emissions from criteria pollutants.

The testing group included users representing the concerns of advocacy groups dealing with air quality and transportation issues, transit planners and operators from a range of small and large agencies (including the nation's two largest transit systems—New York and Los Angeles), as well as a variety of professionals with experience in alternative fuels and technologies. Additionally, staff were consulted at several professional transit-related organizations, such as APTA, the Federal Transit Administration (FTA), and the Energy Information Administration (EIA). Functionality of the site was tested internally by CNT. In each instance, feedback from these tests has been crucial to the development of the final TravelMatters website.

Users of the TravelMatters transit calculator may create hypothetical procurement scenarios. These "what if" scenarios allow transit planners to substitute fuels currently in use with alternatives, in order to gauge possible emissions reductions. Once new scenarios are created, the corresponding CO_2 emissions are calculated. Data for fleet emissions profiles are extracted from the FTA's National Transit Database for 2000. In the next version of www.TravelMatters.org, the research team anticipates that the transit vehicle database will be able to automatically update fleet profiles as soon as it is notified of updates in the FTA source data.

TRANSPORTATION EMISSIONS CALCULATORS

Most people are unaware of the amount of CO_2 they cause to be emitted into the atmosphere as a result of their transportation choices. The TravelMatters calculators are intended to correct this low awareness level by educating people to the GHGs generated in the course of their daily travel, and encouraging them to shift to travel modes that generate comparatively fewer emissions. The individual calculator profiles most make and model of automobile available on the market, and also accounts for personal travel by air, ferry, carpool, or on foot. The individual calculator thus allows users to compile highly accurate registers of their monthly travel activity, and related emissions profiles. The transit planning calculator is similarly comprehensive. The TravelMatters database contains information on the vehicle type, fuel consumption, annual ridership, and VMT of nearly every transit agency in the United States.

Transit Planning Calculator

The transit planning calculator is designed for use by professionals wishing to estimate GHG emissions for transit systems based on the technology type and quantity of fuel consumed by a fleet. The interface is accessible to any user: professionals in the transit field (such as fleet managers or environmental analysts) or independent researchers, regional planners, and local government officials. Planning agencies can use this calculator to establish a baseline of emissions from which to set emissions reduction targets or simulate emissions for various procurement scenarios. Establishing a baseline emissions level also will position transit systems to take advantage of emerging CO_2 trading markets, as well as any future regulatory trading and reduction programs. Similar in spirit to the individual calculator, the transit or planning professional will be encouraged to set up an account and track emissions over time to record the effect of changes in fleet technology and ridership.

The calculator tracks fleet emissions according to a methodology derived from APTA's "Conserving Energy and Preserving the Environment: The Role of Public Transportation (*44*) (see Appendix A, Table A–1). Greenhouse gas emissions, unlike regulated pollutants such as particulate matter and NOx, are strictly a function of the amount of fuel combusted. In fact, CO_2 emissions are much easier to estimate than emissions of criteria pollutants because CO_2 is not reduced in the fuel cycle by catalytic converters, filters, or other emissions-control technologies. The carbon in each type of fuel is converted to CO_2 at a particular rate, so the fuel efficiency of a vehicle—(i.e., the amount of fuel consumed per distance traveled) determines the GHG efficiency of transit vehicles. Although transit agencies are not yet required to track their GHG emissions, it is a simple process to do so and is comparable to, but easier than, monitoring regulated pollutants. The TravelMatters calculator can facilitate this tracking.

The calculator can determine the annual GHG emissions of almost any U.S. transit agency, by vehicle and fuel type. This quantity can then be used as a baseline for comparison against a variety of "what if" scenarios, in which different variables are adjusted in order to reduce emissions. For example, TravelMatters allows users to vary the mix of electricity sources providing power to rail transit systems, variables such as ridership may be increased, and vehicle types may be switched.

PROJECTION MODEL

The emissions projection model estimates different rates of emissions growth over a 20- and 40-year period, in metric tons of CO_2 equivalent per year, for each of four different scenarios. The model highlights the emissions reduction potential of both alternative technologies and greater use of transit when compared to the status quo. Projected scenarios are (1) status quo ridership levels, (2) status quo technology use, (3) increased ridership, and (4) alternative technology adoption. The data supporting the model, presented in an Excel spreadsheet, can be accessed and downloaded via the transit calculator section of the website. Chapter 4 introduced the model and provided a summary of its projections in Table 4–1. A complete methodological report accompanies the spreadsheet and is included in Appendix B.

TRANSPORTATION EMISSIONS MAPS

The national, county, and household emissions maps that were introduced in Chapter 3 are intended to communicate the relationship between land-use patterns and GHG emissions. Supplementing the textual discussion of land use and GHGs, the maps use geographic imaging to make the link between the global problem of climate change and local factors that cause transportation emissions. Low emissions consistently coincide with geographic areas characterized by relatively high residential density and low auto ownership, and vice versa. Suburban, auto-oriented communities generally generate more CO_2 per household than do cities. The areas with lowest household emissions are, not coincidentally, often those well served by transit.

OUTREACH

The final phase of the project involves increasing attention to the dissemination of project tools and information as presented on the website and in the published report. This is a continuation of outreach activity that has informed the execution of the project tasks from an early stage. The objective of the final outreach strategy is to educate target audiences about the material contained in *Combating Global Warming Through Sustainable Surface Transportation Policy*, and its interactive website, www.TravelMatters.org. TravelMatters has been hyperlinked to the resource pages of relevant websites that inform the public about global warming, transportation planning and policy, and alternative transportation fuels and technology. In addition to publicizing TravelMatters through a host of nonprofit and government sites, partnerships with the APTA, FTA, and EPA, among others, have been established to publicize the website via electronic newsletters and newspapers.

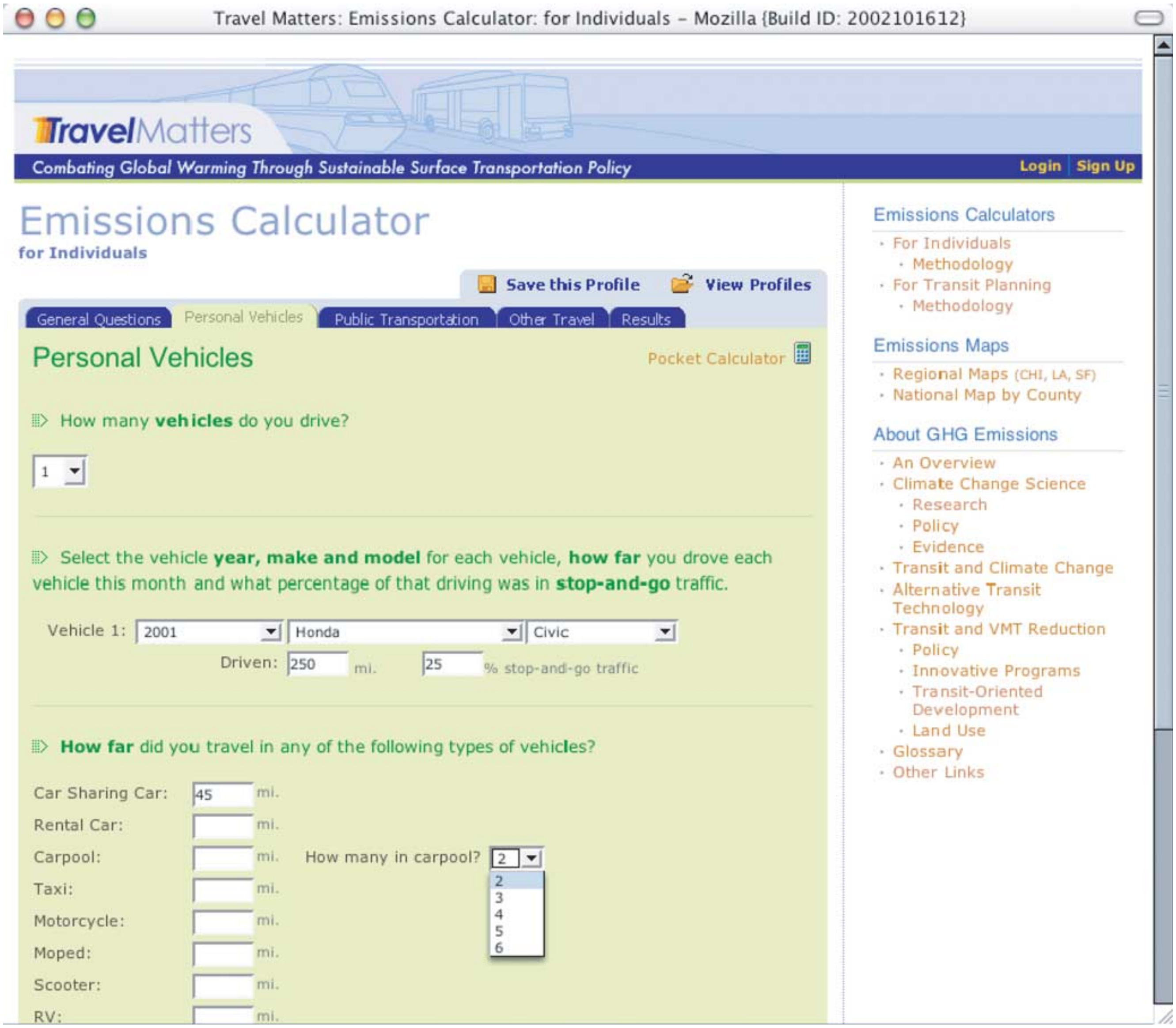


Figure 5-1. Individual calculator, personal vehicles form.

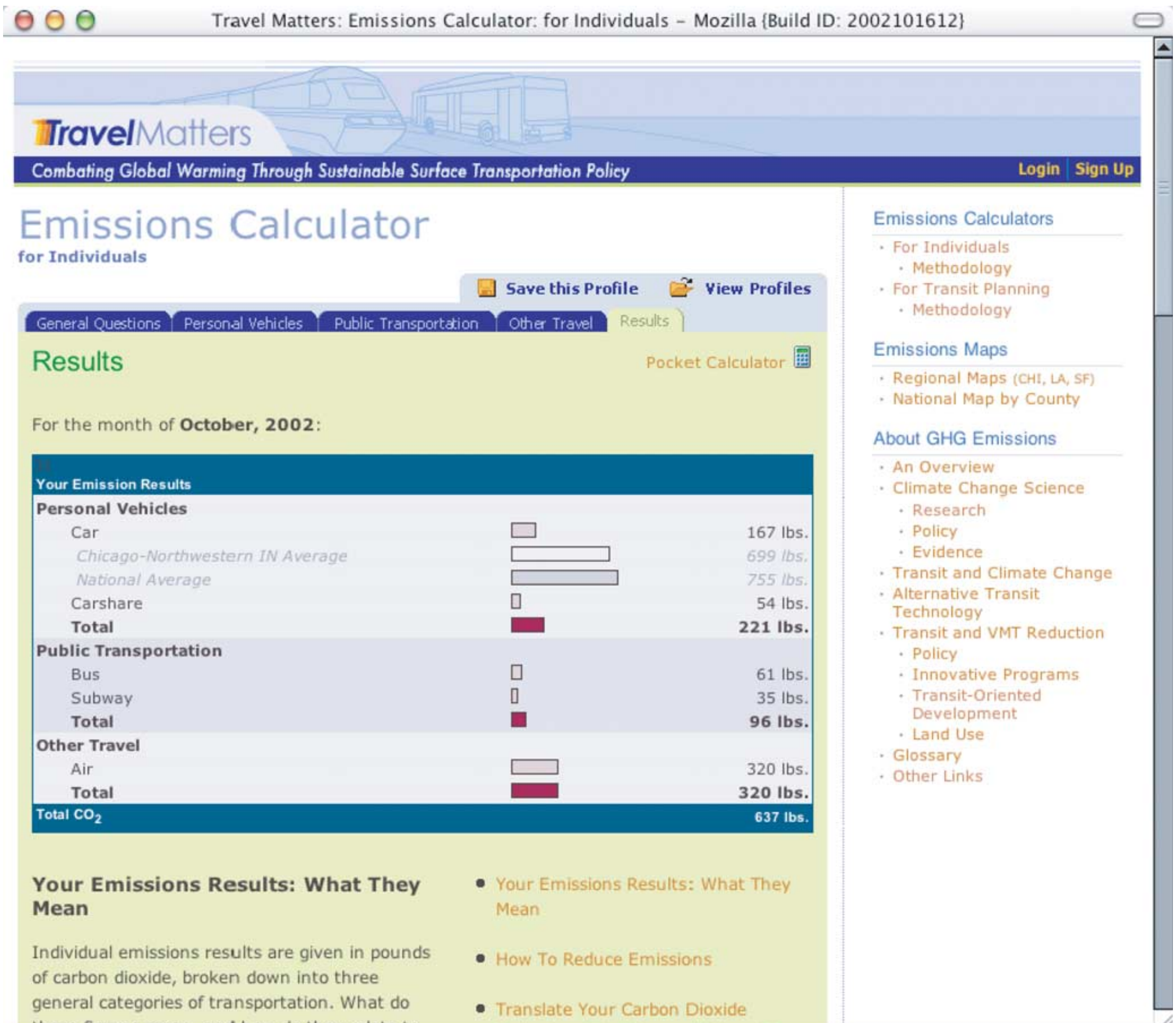


Figure 5-2. Individual calculator, results page.

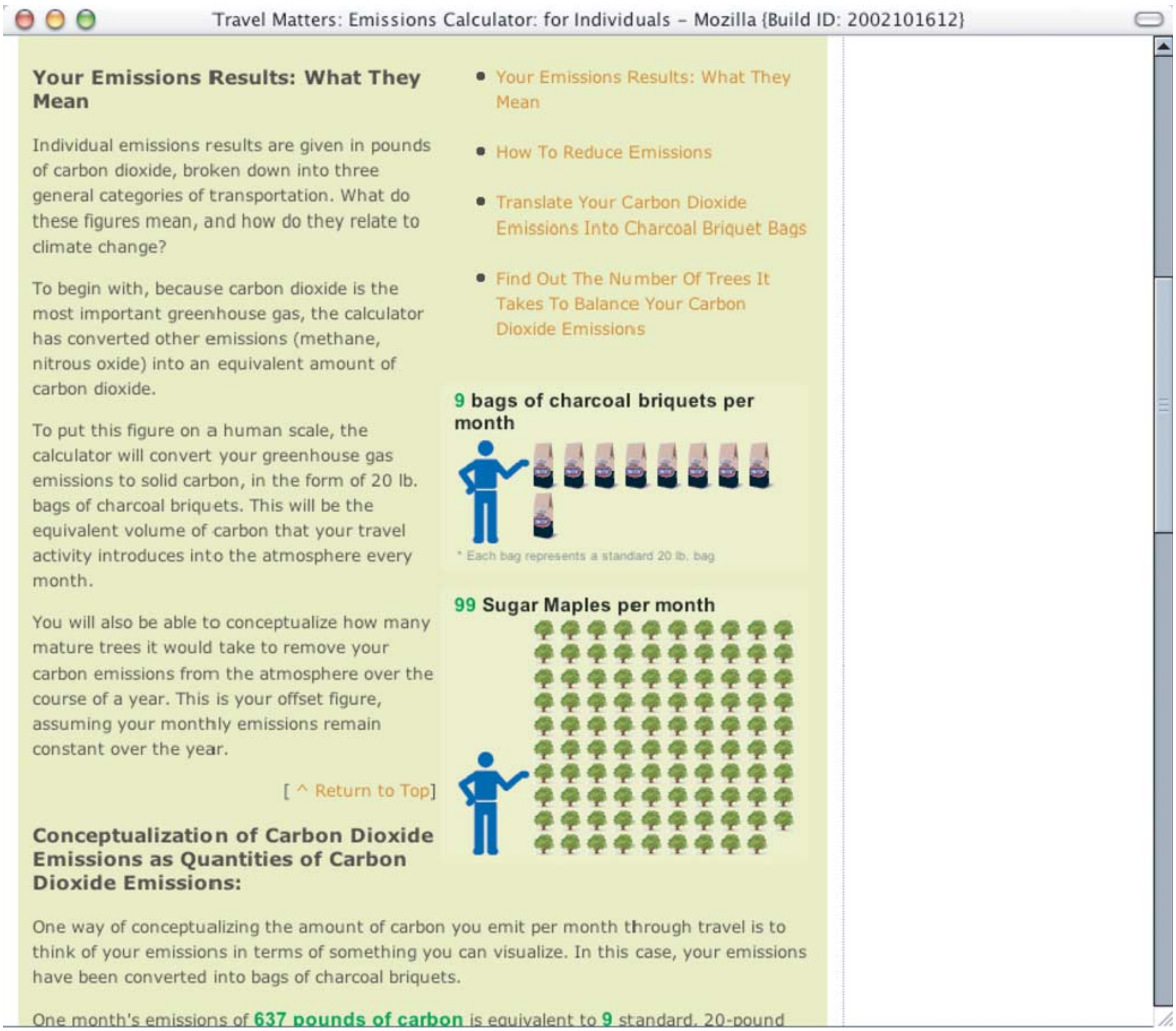


Figure 5-3. Individual calculator, second results page.

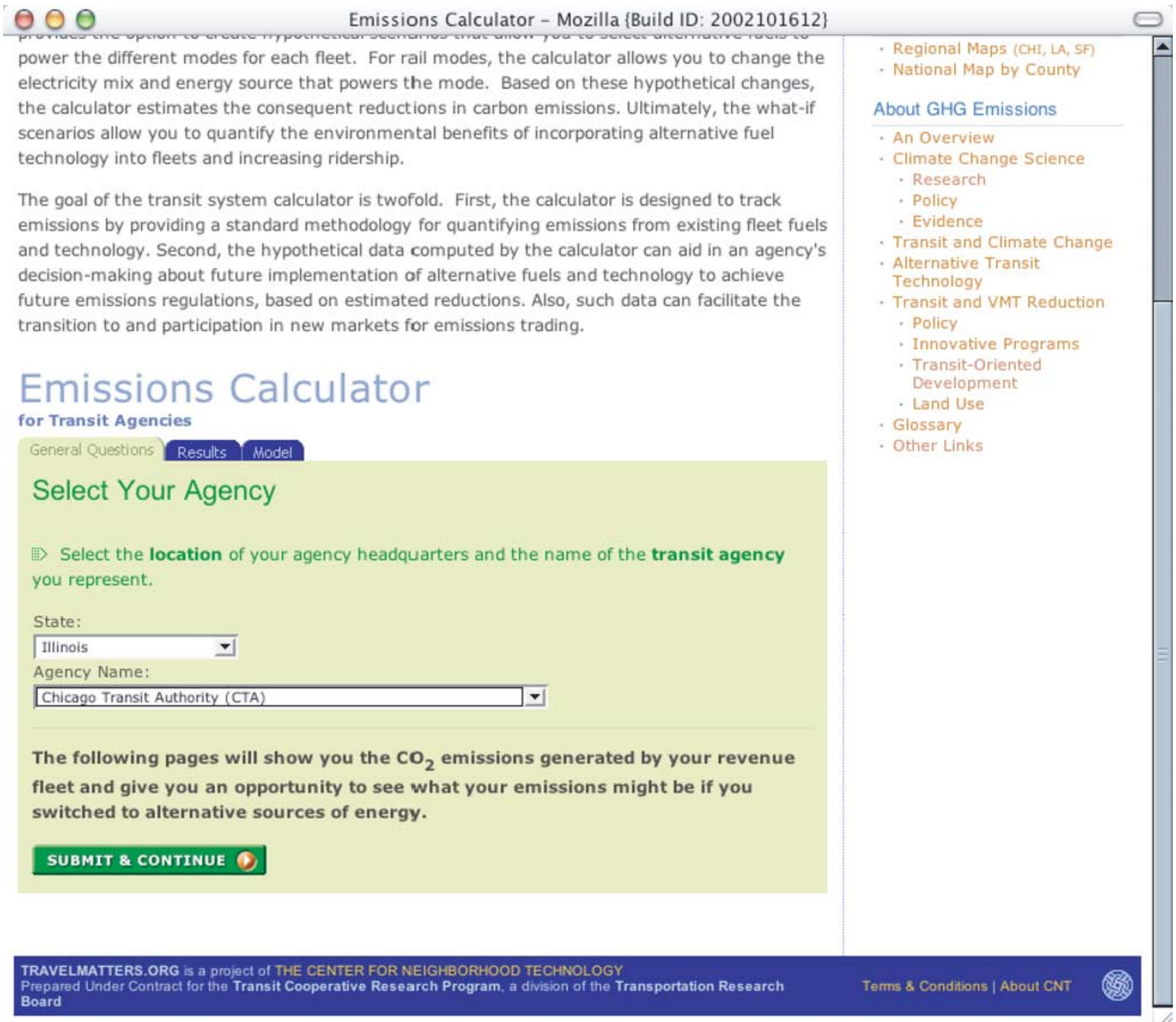
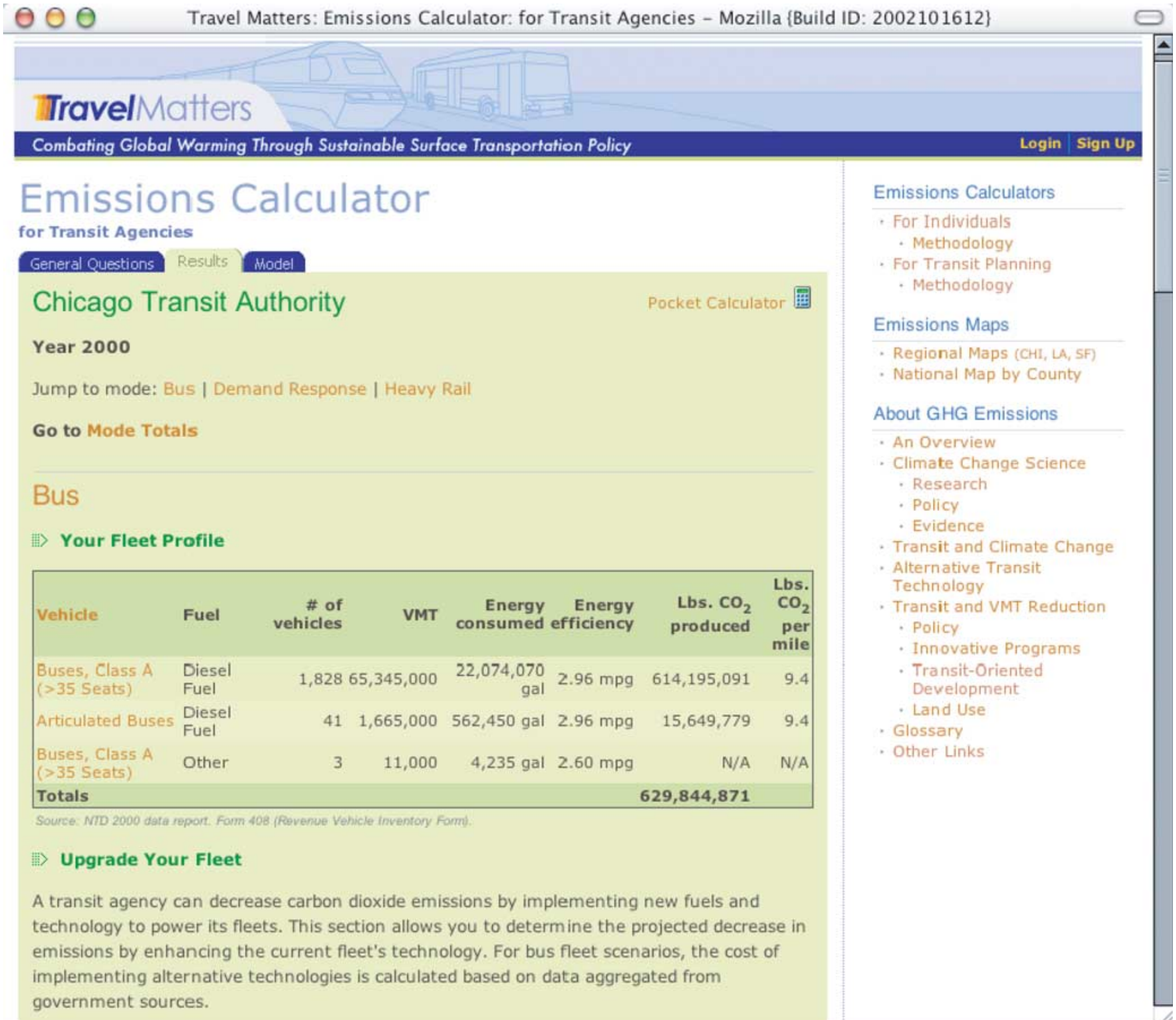


Figure 5-4. Transit planning calculator, introduction form.



Travel Matters: Emissions Calculator: for Transit Agencies – Mozilla {Build ID: 2002101612}

TravelMatters

Combating Global Warming Through Sustainable Surface Transportation Policy

Login | Sign Up

Emissions Calculator

for Transit Agencies

General Questions | Results | Model

Chicago Transit Authority

Pocket Calculator

Year 2000

Jump to mode: Bus | Demand Response | Heavy Rail

Go to Mode Totals

Bus

Your Fleet Profile

Vehicle	Fuel	# of vehicles	VMT	Energy consumed	Energy efficiency	Lbs. CO_2 produced	Lbs. CO_2 per mile
Buses, Class A (>35 Seats)	Diesel Fuel	1,828	65,345,000	22,074,070 gal	2.96 mpg	614,195,091	9.4
Articulated Buses	Diesel Fuel	41	1,665,000	562,450 gal	2.96 mpg	15,649,779	9.4
Buses, Class A (>35 Seats)	Other	3	11,000	4,235 gal	2.60 mpg	N/A	N/A
Totals						629,844,871	

Source: NTD 2000 data report. Form 408 (Revenue Vehicle Inventory Form).

Upgrade Your Fleet

A transit agency can decrease carbon dioxide emissions by implementing new fuels and technology to power its fleets. This section allows you to determine the projected decrease in emissions by enhancing the current fleet's technology. For bus fleet scenarios, the cost of implementing alternative technologies is calculated based on data aggregated from government sources.

Emissions Calculators
- For Individuals
  - Methodology
- For Transit Planning
  - Methodology

Emissions Maps
- Regional Maps (CHI, LA, SF)
- National Map by County

About GHG Emissions
- An Overview
- Climate Change Science
  - Research
  - Policy
  - Evidence
- Transit and Climate Change
- Alternative Transit Technology
- Transit and VMT Reduction
  - Policy
  - Innovative Programs
  - Transit-Oriented Development
  - Land Use
- Glossary
- Other Links

Figure 5-5. Transit planning calculator, tabulation of emissions.

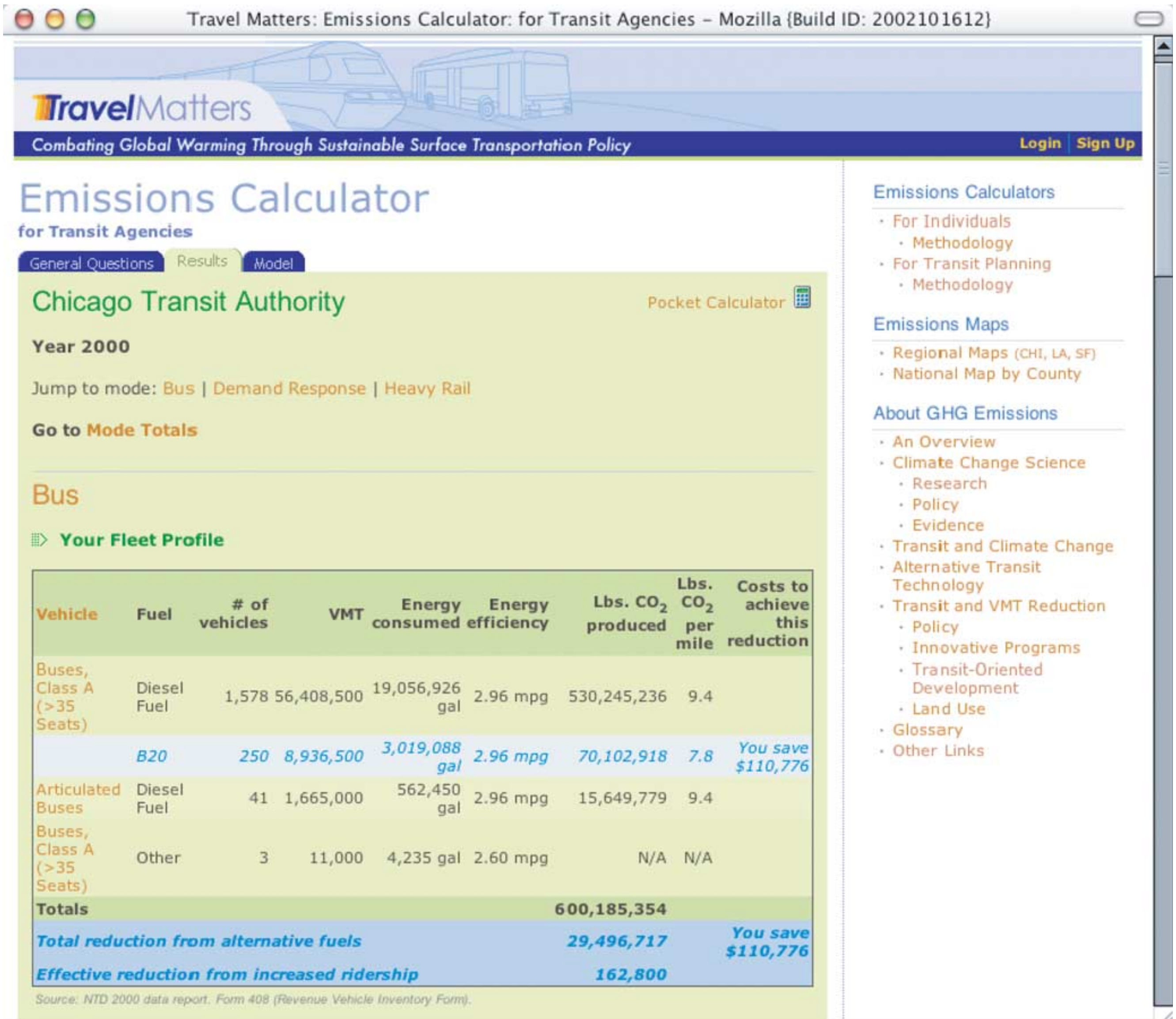


Figure 5-6. Transit planning calculator showing hypothetical scenarios.

CHAPTER **6**

CONCLUSIONS AND SUGGESTED RESEARCH

SUMMARY

Despite uncertainties regarding the measurement and forecasting of global climate change, scientists are in general agreement that human activities are generating GHG emissions in quantities sufficient to alter current climatic patterns. Since emissions from transportation in the United States accounts for over 8% of global, and 33% of national CO_2 emissions, and is rising at a higher rate (1.8%) than that of any other economic sector, the study team finds that reducing emissions from the transportation sector is one of the most urgent actions needed to stabilize U.S. emissions.

On the aggregate level, most CO_2 emissions from U.S. transportation originate in high-density urban areas. Although urban areas generate more emissions, mapping analysis found that emissions per household for those living in dense urban areas are well below that the emissions of households in less developed or rural areas. In other words, although cities generate more CO_2 collectively, suburban and rural residents generate more emissions individually. This is directly linked to land-use patterns and minimal transportation options in low-density regions. Cities often offer amenities, jobs, and other activities in close proximity to each other, thereby reducing dependency on the automobile, increasing the convenience of transit, and reducing VMT per household. Hence, in large, densely populated American cities, GHG emissions are maintained at a level that is lower than they would be outside urban areas and these environments are optimal for effective transit service. This finding, that in some places efficient land use and transit are *already* reducing GHG emissions relative to a per capita analysis, underpins the strategies pursued in this report.

Chapters 3 and 4, explored three strategies for lowering transportation sector emissions as follows: (1) identifying ways to reduce per capita miles driven by encouraging transit use and promoting transit-supportive land use patterns, (2) implementing energy-efficient transit fuels and technologies, and (3) developing tools to educate individuals, planners, and transit-agencies about the climatological consequences of travel decisions. The cities most effective at reducing demand for auto travel are those that have already invested heavily in dense central areas and existing, efficient transit systems that are competitive with the automobile. Successful systems tend to be linked to centers of employment or other major destinations, are easily accessible, and operate in neighborhoods rich in amenities. Other regions have achieved incremental increases in ridership through such program incentives as tax deductions for transit passes or employer-subsidized transit. Hallmarks of effective transit agencies are considerable attention to frequency of service, accessibility, vehicle cleanliness, and customer service.

Although the reform of land use is potentially the most effective means of reducing GHG emissions, practical barriers to rapid change in land use practices also make it wise to investigate other, short-term strategies. As discussed in Chapter 4, alternative fuels and technologies that reduce GHG emissions while also increasing fuel efficiency are attractive to cost-conscious transit agencies. An alternative technology program for reducing GHGs emitted from transit vehicles can be coupled with dramatic gains in fuel efficiency, reduced operating costs, and improved compliance with federal air quality regulations. Although this review is restricted to transit vehicle fuel and technology, the research team believes that our findings may be applicable to future markets in alternative automobile design as well. Despite current marketing and use of hybrid technology, several of the largest transit agencies have been converting fleets to CNG in order to improve emissions of smog-related pollutants. Data on the emissions-reduction potential of CNG is mixed, with some research suggesting that CNG does not reduce GHG emissions as aggressively as do other commercially available technology options, such as hybrid–electric engines or biodiesel fuel.

The fact that several transit agencies are making major investments in technology that is not necessarily optimal for GHG reduction is understandable, since CO_2 and other GHG emissions are not regulated and have emerged only recently as an area of concern to the public. Fortunately, hybrid–electric technology has the potential to reduce emissions of criteria pollutants and GHGs, providing a basis for future programs to coordinate the reduction of both sets of emissions. If and when emissions trading programs come into effect, financial incentives to quantify and track emissions reductions will make hybrid and other fuel-saving technologies even more attractive. It is anticipated that this report, and the emissions calculators it promotes, will demonstrate realistic procurement options available to transit agencies working to reduce GHG emissions while also meeting clean air standards.

Of the variety of alternative fuels and technologies examined in this report, studies indicate that vehicles fueled with

B100 can reduce CO_2 emissions over 80% when compared to emissions from conventional diesel buses. Hybrid–electric engines fueled with B20—that by itself reduces emissions over 14%—are probably the most cost-effective alternative currently available. In some cities, small battery-powered electric buses also have been used very effectively for certain specialized applications, such as Chattanooga's pedestrian-friendly downtown region. Structural changes to vehicles, such as integration or replacement of traditional metal frames with lightweight materials (e.g., fiber composite bodies) in the manufacturing of the vehicle can save up to 10% of a gallon of fuel per mile.

The hydrogen fuel cell that uses steam-reformed hydrogen is a very efficient propulsion technology, although it is currently expensive due to high production costs and an undeveloped market. When production costs drop sufficiently, widespread use of hydrogen fuel cells could substantially reduce CO_2 emissions from transit vehicles. In the absence of a market for hydrogen fuel cells or government subsidies, out-of-pocket expenses for transit agencies will undoubtedly slow the adoption of this alternative fuel.

All of the material discussed in this written report is presented in its online companion, www.TravelMatters.org. The website hosts two emissions calculators, conceived as information and planning tools to educate transit professionals and the public at large about the linkages between mobility and global climate. The calculators enable users to explore the emissions profiles of a variety of fuels and technologies as well as determine the effects of increased ridership. These tools can be used to help transit agencies and others understand possible CO_2 reduction outcomes from fuel choices and programs that increase ridership on transit.

FUTURE RESEARCH

Few existing studies have addressed the specific potential for greater use of public transportation and reformed land use practices to reduce CO_2 emissions. Although these issues are surveyed in Chapter 3, more work needs to be done to quantify the impacts of specific land-use policies on CO_2 emissions.

Mapping

As discussed in Chapter 3, the national maps depicting emissions by county are limited by the way in which VMT is counted by state departments of transportation, and the lack of a current national transportation survey that deals extensively with VMT generated by households within a particular place. Future research could attempt to differentiate between VMT contributed only by those living within the region being studied and the VMT that is contributed by drivers traveling through the study region on major highways. As a result, the credibility of current VMT figures, which currently capture interstate travel through survey findings, would be greatly enhanced.

The national and regional maps that overlay CO_2 emissions with VMT allow the overall emissions profiles of regions across the country to be viewed. Only micro-level analyses for Chicago, San Francisco, and Los Angeles were performed. Although the regional modeling for these three urban regions could act as a template for formulating models in other regions, it should be possible to tabulate these data in any nonattainment region where there is any type of smog-check program that tracks VMT at the household level and links these data to specific addresses.

A precursor to the national and regional maps, the location efficiency model (LEM) demonstrates that VMT declines due to the close proximity of homes, amenities, and markets to mass transit. Further research is still needed to identify how land-use patterns influence the increase or decrease in VMT. For example, land use research could focus on developing techniques that measure the benefits, limitations, and costs of designing pedestrian-friendly urban spaces. Specifically, studies could focus on how transit encourages or contributes to the development of pedestrian-friendly neighborhoods and, conversely, how existing pedestrian-oriented environments affect vehicle ownership. Research is needed to buttress studies that attempt to measure pedestrian behavior and the effects of walking on the health of both the individual and the local environment. Research should consider the factors that motivate people to walk instead of drive, as well as the social and environmental conditions that contribute to these decisions.

LEM emphasizes the need for researching strategies that effectively reduce the demand for travel. In other words, LEM data stress the need for quantifying the costs of strategies that reduce auto dependency while determining their social and economic efficacy. Research could, for example, establish the costs of shifting the number of personal vehicle trips to public transportation through various programs. Research also could identify the psychological barriers to greater public use of transit. Quantifying the real costs of car ownership and highway infrastructure could be a point of focus for future research seeking to establish the relative expense (to individuals, society, and the global environment) of public versus private transportation investments.

Transit

If emissions are measured by passenger miles traveled—(in terms of pounds of emissions per person per mile) a feasible way to reduce emissions is to encourage transit use. Hence, the greatest potential for reducing emissions in the transportation sector lies in transit's ability to attract riders. To make this conclusion more convincing, there is a need to measure the quantitative impacts of alternative transit fuels and technologies on ridership. Similarly, future research could quantify the effects of land-use changes, transit incentives, and other programs on personal VMT and transit ridership. Such research would make it possible to track net emissions reductions that result from these strategies.

One application for quantifying emissions from different initiatives would be to incorporate this potential into the TravelMatters transit calculator. Although the transit calculator will allow planners to learn more about the emissions profile of a transit fleet and the automobile emissions that the fleet could potentially offset, the calculator currently does not measure ridership changes directly influenced by land use developments. The study team would like to expand the measuring capacity of the calculator to allow for the creation of "what if" scenarios for land use and smart growth development. This would entail incorporating a range of possibilities that includes the effects of constructing additional sidewalks, increasing population density, and fostering retail development. The results, such as the socio-economic and environmental impacts of such research, may need to be measured before such expansion of the calculator.

Further, the quantification capacity of the calculator could be enhanced so that it provides additional emissions computations for transit vehicles and automobiles. Specifically, the calculator would measure currently regulated criteria pollutants such as NOx and SO_2 emissions. Since many regions are required to report these emissions based on the provisions of the Clean Air Act, appending this information would make the calculator a very useful source for emissions regulation. Once accomplished, the "what if" scenarios could be enhanced so that transit agencies could understand how to optimize reducing a broad range of pollutants.

The freight industry was not studied in this report, but it is a large contributor of emissions from the transportation sector. Future research could examine emissions standards for freight vehicles, the technologies and fuels for reducing emissions, and major strategies like mode split that affect emissions from the industry. Freight transportation should not be ignored as a contributor to climate change, local air quality, and health problems.

Emissions Trading and Tracking

As communities begin to strategize about how they can reduce GHG emissions and regulated pollutants, they will consider the financial incentives for implementing programs. Currently, there is an emerging emissions trading market for CO_2, although it is unclear how the market will fare without a regulatory federal cap and trade policy (the setting in which most emissions trading occurs). In order to participate in a market, communities or companies that reduce emissions would have to be able to document reductions from a baseline level of emissions. The regional and national emissions estimates given in this report attempt to provide a baseline for transportation emissions. Governments involved in GHG programs through the International Council of Local Environmental Initiatives are conducting surveys of GHG emissions in order to develop a comprehensive baseline. Future research could examine the evolving state of the CO_2 market and how local governments could fit into the trading market, including what would be required in terms of emissions tracking.

Transit agencies using electricity to power their vehicles (as is the case for most rail systems) may have little control over their emissions profiles, since their emissions levels are determined by their power provider's assigned electric generation mix. With the exception of the West Coast, which derives a considerable portion of its power from hydroelectric dams, renewable energy represents a small share of electric power in most parts of the United States. Other renewable energy sources, such as wind and solar power, have not received heavy investment throughout the United States. As a result, these alternative energy sources do not contribute a significant amount of power generation. Future research could study the details of these arrangements, the hindrances to investing in and building the infrastructure needed for renewable power, and the socio-economic, political, and environmental results of these programs.

CONCLUSION

Most scientists now agree that the Earth's climate is warming, as indicated by a rise in the average surface temperature of the Earth. Positive climate change (warming) is thought to be the result of human-generated emissions, principally CO_2. Greenhouse gases like CO_2, CH_4, and N_2O allow solar radiation to pass through the atmosphere, but prevent surface radiation from escaping to outer space, effectively "trapping" it. This process leads to an overall increase in surface temperature. The observational evidence for positive climate change is circumstantial but extensive: direct measurement has established that atmospheric CO_2 levels have increased since the industrial revolution and the related surge in fossil fuel consumption. The gas physics behind the heat-trapping greenhouse effect is not disputed, and the industrial exacerbation of the greenhouse effect is considered to be very likely. The ultimate effects, however, remain uncertain. Enough is now known, despite the uncertainties of measurement and forecasting, to warrant prudent actions to moderate or reduce emissions of GHGs. Much of what can be done in this regard will have the multiple effect of improving air quality and human physical health, as well as increasing fuel efficiency. Although improving personal and transit vehicle fuel efficiency is one tactic in any future GHG reduction strategy, another equally important tactic involves expanding the overall share of transit in U.S. transportation.

APPENDIX A

METHODOLOGY FOR ESTIMATING GHG REDUCTIONS RESULTING FROM USE OF PUBLIC TRANSPORTATION (*1*)

Actual calculations made according to the method outlined below are presented in Table A–1. The methodology and tables are taken directly from R. Shapiro, K. Hassett and F. Arnold, "Conserving Energy and Preserving the Environment: The Role of Public Transportation" (American Public Transportation Association, 2002).

1. Gather data on the number of passenger miles and VMT in the local or metropolitan area by each mode of public transit.
2. Calculate the energy use by the area's public transportation. Multiply the vehicle miles for each mode of public transit by the BTUs per vehicle mile for that mode provided in Table 10. Add the results to determine total energy use by the locality's public transit.
3. Calculate the pollution produced by public transportation. Multiply the vehicle miles for buses and diesel-powered rail public transit in the area by the mode's emissions in grams per vehicle mile provided in Table 16a, and multiply the total energy used by electrically powered rail public transit systems in the area by the emissions per megakilowatthour (MkW-h) in Table 16b. Add the results to determine the total pollution produced by the locality's public transit (*1*).
4. Calculate how much fuel would be used if private vehicles replaced public transit. Multiply the locality's total public transportation passenger miles by 5,254.8 (the BTUs per–passenger mile for replacement vehicles from Table 13.
5. Calculate how much pollution would be produced if private vehicles replaced public transit. Multiply the locality's total public transportation passenger miles by 0.826 (the ratio of the private vehicle replacement miles to the public transit passenger miles being replaced, from Table 19), and multiply by the weighted-average pollution emissions for private vehicles, in grams per vehicle mile, from Table 18.
6. Estimate the energy savings from the use of public transportation. Subtract the energy used by public transit (Step 2) from the energy needed if private vehicles replaced public transit (Step 4).
7. Estimate the environmental benefits of public transportation. Subtract the pollution produced by public transit (Step 3) from the pollution that would be produced if private vehicles replaced public transit (Step 5).

ENDNOTES

1. The calculations for CO_2 offsets required a slight alteration in the APTA methodology outlined above. What follows are the steps taken in addition to those prescribed by APTA.
    1. In Step 3, we are to multiply the total energy used by electrically powered rail public transit systems in the area by the emissions per MkW-h in Table 16b.
    2. However, in Step 2, we are to multiply the vehicle miles for each mode of public transit by the BTUs per vehicle mile for that mode, including electrically powered rail in Table 10.
    3. Therefore, we assume that in Table 10, heavy and light rail energy efficiency would be given in terms of MkW-h per vehicle mile instead of BTU per vehicle mile, or Table 16b's emissions by electricity-powered rail systems would be converted to grams per BTU instead of grams per MkW-h to make the multipliers in Step 3 consistent.
    4. Our assumption is that since Table 10 gives energy efficiency in terms of BTU per vehicle mile, we can make a simple conversion of the figure given in Table 16b (618,499,055) from grams per MkW-h to Grams per BTU for CO_2, giving us 0.18 grams of CO_2 per BTU as the multiplier in Step 3 for electric rail.
    5. We made the conversion as follows:
    6. 1BTU = $2.93 \times 10 - 4$ kW-h
    7. 1 kW-h = $1/2.93 \times 10 - 4 = 10000/2.93 = 3412$ BTU/kW-h
    8. 1MkW-h = 3.412×10 9 BTU
    9. 0.618×10 9 grams of CO_2/MkW-h [Table 16b]/3.412×10 9 grams /MkW-h = .618/3.41 = 0.18 grams of CO_2/BTU

TABLE A-1 Calculations of emissions savings resulting from use of public transportation

Case Study Areas	Transit Agency(ies)	Mode	Annual Passenger Miles
Washington, D.C.	Washington Metropolitan Area	Bus	452,855,175
	Transit Authority	Heavy Rail	1,190,448,841
		Demand Response	2,498,629
		TOTAL	1,645,802,645
Los Angeles, California	Los Angeles County Metropolitan	Bus	1,271,169,585
	Transportation Authority	Heavy Rail	74,729,093
		Light Rail	208,824,385
		TOTAL	1,554,723,063
	Santa Monica Big Blue Bus	Bus	72,740,223
		Demand Response	51,309
		TOTAL	72,791,532
Chattanooga, Tennessee	Chattanooga Area Regional	Bus	9,422,636
	Transportation Authority	Demand Response	281,895
		TOTAL	9,704,531

Source: Columns 1 through 5, FTA's National Transit Database, 2000.
Source: Columns 6 through 11, Calculations based on APTA's Methodology for Estimating Energy Savings and Environmental Benefits of Public Transportation. Shapiro, R., K. Hassett, & F. Arnold. "Conserving Energy and Preserving the Environment: The Role of Public Transportation." American Public Transportation Authority. July 2002.

TABLE A-1 (*Continued*)

Annual Vehicle (Revenue) Miles	[Step 2] Energy Used by Public Transportation (BTUs)	[Step 3] CO_2 Produced by Public Transit (Grams)	[Step 4] Fuel Used if Private Vehicles Replaced Public Transit (BTUs)
34,192,726	1,413,458,907,388	81,618,036,962	2,379,753,944,625
48,243,553	954,691,670,317	171,844,500,657	6,255,808,659,455
3,643,119	26,572,909,986	1,901,708,118	13,130,295,395
86,079,398	2,394,723,487,691	255,364,245,737	8,648,692,899,475
85,655,002	3,540,806,472,676	204,458,489,774	6,679,996,169,175
3,567,756	70,602,323,484	12,708,418,227	392,701,383,715
4,658,489	138,301,221,432	24,894,219,858	1,097,372,143,175
93,881,247	3,749,710,017,592	242,061,127,859	8,170,069,696,065
4,581,067	189,372,147,646	10,935,006,929	382,249,871,865
74,056	540,164,464	38,657,232	269,628,795
4,655,123	189,912,312,110	10,973,664,161	382,519,500,660
1,724,068	71,269,522,984	4,115,350,316	49,515,952,180
197,896	1,443,453,424	103,301,712	1,481,358,225
1,921,964	72,712,976,408	4,218,652,028	50,997,310,405
		*0.18 grams of CO_2/BTU = Conversion of grams of CO_2/MkW-h to grams of CO_2/BTU	

TABLE A-1 (*Continued*)

[Step 5] CO_2 Produced if Private Vehicles Replaced Public Transit (Grams)	[Step 6] Environmental Benefits of Public Transportation (Grams of CO_2 Saved)	[Step 6] Environmental Benefits of Public Transportation (Tons of CO_2 Saved)
169,448,443,671		
445,439,766,428		
934,932,002		
615,823,142,101	360,458,896,364	396,981
475,643,692,976		
27,961,982,561		
78,137,490,731		
581,743,166,267	339,682,038,408	374,099
27,217,791,162		
19,198,699		
27,236,989,861	16,263,325,700	17,911
3,525,743,093		
105,478,907		
3,631,222,001	-587,430,027	-647

TABLE 10 Energy Efficiency of Public Transportation, by Fuel Source Per Mile and Per Passenger Mile, 1998

Transit Mode by Fuel	Btu/ Vehicle Mile	Btu/ Passenger Mile
Bus Total	41,338	4,415.2
Commuter Rail Total	54,071	1,612.1
Heavy Rail– Electric	19,789	911.3
Light Rail– Electric	29,688	1,152.8
TOTAL (weighted average)	**38,251**	**2,740.8**

TABLE 13 Values for Determining the Energy Benefits of Public Transportation, 1998

Btus per private-vehicle mile: Weighted Average	6,348.2
Miles driven by "replacement" vehicles	35,089,895,556
Total Btus consumed by "replacement" vehicles	223,203,124,495,867
Passenger miles for "replacement" vehicles	42,476,000,000
Btus per passenger mile for "replacement" vehicles	5,254.8

TABLE 16a Emissions by Buses and Diesel-Powered Trains, Grams/Vehicle Mile, 1999[31]

	Volatile Organic Compounds (VOCs)	Carbon Monoxide (CO)	Nitrogen Oxides (NOx)	Carbon Dioxide (CO2)
Buses	2.3	11.6	11.9	2,386.9
Diesel Rail	9.2	47.6	48.8	9,771.0

TABLE16b Emissions by Electricity-Powered Rail Systems, Grams/MKWH, 1999[32]

VOCs	CO	NOx	CO2
137,987	1,772,125	17,365	618,499,055

TABLE 18 Pollution Emissions by Private Vehicles, Grams Per Vehicle Mile, 1999[33]

	VOCs	CO	NOx	CO2
Automobiles	1.88	19.36	1.41	415.49
SUVs, light trucks	2.51	25.29	1.84	521.63
Weighted Average	2.10	21.45	1.56	452.92

TABLE 19 Private Vehicle Miles Driven in Shift from Public Transportation, 1999[34]

Private Vehicle Occupants	Share	Passenger Miles – Number of People	Vehicle Miles Driven
Driver	70 percent	30,855,300,000	30,855,300,000
Driver + 1 passenger	19 percent	8,375,010,000	4,187,505,000
Driver + 2 passengers	6 percent	2,644,740,000	881,580,000
Driver + 3 or more	5 percent	2,203,950,000	489,766,667
Total	**100.0 percent**	**44,079,000,000**	**36,414,151,667**

APPENDIX B

METHODOLOGY FOR TRANSIT EMISSIONS PROJECTION MODEL (*1–4*)

MODEL INPUTS

The model is based on VMT and fuel consumption data for most major modes of public transportation: bus, heavy rail, light rail, commuter rail, and trolley bus. The data was collected from the APTA *2001 Fact Book*,(*44*) which reports data collected from transit agencies by the U.S. Department of Transportation's FTA. Information about alternative fuel vehicles in use was only available for buses, and was not very detailed. Data on the quantity of alternative fuel consumed was not accessible either, except in a general category of "other." The study team also collected the number of unlinked passenger trips and the number of active vehicles, although this data was not significant in the actual projection. All of the above data was collected for the years 1990 to 2000, and annual rates of change were computed in order that we could witness any recent trends or shifts that might indicate future trends.

A typical rate of growth for VMT was estimated based on the average rate of growth from 1990 to 2000. An average fuel consumed per mile of travel (for both liquid fuels and electricity) was calculated by estimating the percentages of national VMT totals driven by vehicles of each fuel type and dividing the total fuel consumed for the mode by the appropriate percentage of miles traveled by vehicles of each mode.

The emissions produced per unit of fuel also were considered in the model. Diesel, gasoline, and electricity were the only fuels whose quantities of consumption were specified in the FTA and APTA dataset. Using the GREET Model discussed in Chapter 4, the study team calculated that burning a gallon of diesel results in the emission of 27.824 pounds of carbon equivalents (CE) and a gallon of gasoline results in the emission of 24.116 pounds CE. EIA estimates that the national average emissions of CE from a kilowatthour (kW-h) of electricity results in the emission of 1.384 pounds of CE. These numbers were used to calculate the emissions generated from burning the amount of fuel consumed by each mode each year.

MAKING PROJECTIONS

There are four scenarios of projections calculated for each mode. The four projections are as follows:

1. Typical VMT growth and technology,
2. High VMT growth with typical technology,
3. Typical VMT growth with advanced technology, and
4. High VMT growth with advanced technology.

For each scenario, the end calculation is the amount of emissions generated up to 2020 and 2040 for each mode. The emissions for each mode within each scenario are then summed. Because the team is projecting the amount of emissions reduced with the use of advanced technologies, the advanced technology total emissions for 2020 and 2040 were subtracted from the typical technology emissions. The result is an estimate of the amount of emissions that could be avoided if there was widespread adoption of advanced transit technologies in both typical VMT and high-VMT growth scenarios.

As an example, here are the first 5 years of projections for bus emissions are presented in Table B–1.

The 1999 and 2000 values are from data gathered, not modeled. Beginning in 2001, however, all of the fields are calculated using basic assumptions. The formulas, using 2001 as an example, are as follows:

2001 VMT = 2000 VMT ∗ (1 + 1.5% growth)

2001 fuel consumption = 2001 VMT ∗ 93% diesel fleet ∗ 0.30 gal/mi traveled

2001 electricity consumption = 2001 VMT ∗ .009% electric fleet ∗ 5.42 kW-h/mi traveled

2001 pounds of carbon equivalents = (gallons of diesel ∗ 27.824 lbs CE/gal) + (kW-h electricity ∗ 1.384 lbs CE/kW-h)

2001 Mt (mega tons) or Tg (tera grams) = 2001 lbs CE ∗ 4.54E-10 Tg/lb

The same method is used to calculate all of the fields up through 2040. The Mt of CE are then summed from 2000 to 2020 and 2000 to 2040.

The same process is used to calculate VMT for each of the four scenarios with changes in the percent of annual growth. In the high-growth VMT scenarios, the rate of growth is double the typical growth rate. For buses, then, the high growth rate is 3%, making the multiplier 1.03.

The other variable in the projection is the implementation of technologies or fuels that would decrease GHG emissions. For this variable it is necessary to make assumptions about the potential use of fuels and technologies for up to 40 years in the future. Because the task is to compare a best-case scenario

TABLE B-1 Typical VMT growth and technology for buses

lbs CO_2/gal or kW-h		27.824	1.3484	3.39		
Percent of 2000 fleet VMT		93.0%	0.009%	6.991%		
	Annual Growth	**Gal/Mi**	**kW-h/Mi**	**Gal/Mi**		**Tg/lb**
	1.5%	0.30	5.42	0.42		4.54E-10
Year	**VMT (Millions)**	**Diesel Consumption in Gallons**	**Electricity Consumption per kW-h**	**CNG Consumption in Gallons (Includes Other Fuels)**	**CE Emissions (lbs CE)**	**CE Emissions (Tg or Mt CE)**
1999	2275.900	618204000	965000	52070000	17378726602	7.885
2000	2314.780	635160000	1128500	67361000	17902567299	8.123
2001	2349.502	644687400	1145428	68371415	18171105809	8.245
2002	2384.744	654357711	1162609	69396986	18443672396	8.368
2003	2420.515	664173077	1180048	70437941	18720327482	8.494
2004	2456.823	674135673	1197749	71494510	19001132394	8.621
2005	2493.675	684247708	1215715	72566928	19286149380	8.751

to a no-change scenario, the team made optimistic assumptions about the availability and market penetration of fuels and technologies, and also assumed that transit agencies would be quick to implement low-emissions vehicles.

A number of technologies and fuels for buses that reduce GHG emissions are both currently available and in development. The challenge for buses (as well as demand-response and vanpool vehicles) is in estimating the relative market share of each new type of vehicle or fuel. The assumptions we use in the model are listed below.

Buses

The model projects that increases in diesel and electric efficiency due to light-weight frames, hybrid engines, regenerative braking, and green-power purchases result in a 25% relative decrease in fuel consumption (hybrids can reduce fuel consumption by 15 to 30%). In addition, the increased adoption of electric buses to 1.5% of the national VMT is projected in 2002 to 2004, 5% in 2005 to 2016, and 20% in 2017 to 2040. The adoption of biodiesel, in the form of B20, is projected as starting in 2003 and continuing at 10% of the national VMT through 2040. The increased use of CNG buses is projected to increase to 7.5% of the national VMT in 2001 to 2003 and 10% in 2004 to 2016, at which time CNG is projected to be completely replaced by other alternatives. Finally, a 5% adoption rate is projected for hydrogen fuel cells (in which hydrogen is generated by electrolysis) in 2010 to 2016, increasing to 20% in 2017 to 2027 and increasing again to 40% in 2028 to 2040. The adoption of these alternative technologies displaces fossil fuel diesel as a percentage of VMT.

Rail

Emissions-reducing technologies for rail are still in the early stages of development, and there are no studies that estimate the potential market availability of new technologies for transit rail. One emissions-reducing option that is available to transit agencies today, however, is the purchase of electricity that is generated from renewable, no-emissions sources such as wind, solar power, and hydroelectricity. For this model, the team assumed that starting in 2015 rail systems will be operating in a way that reduces emissions by 25%, either through fuel-saving technologies or powering by green electricity. This assumption is based on the absence of any technology for rail transit that will be widely available in the next 10 years. However, it is possible that regenerative braking and energy storage research being done on freight rail could be adapted for transit rail. The freight rail technologies are predicted to be available starting in 2010. An additional 5 years of research and development is an appropriate estimate for applying technology for transit rail. In order to minimize the impact of an inaccurate estimate of technology introduction, the team assumed that transit agencies operating rail will either adopt technologies that cut electric consumption by 25% or purchase 25% of their power from green sources, or a combination of the two, adding to a 25% decrease in net emissions beginning in 2015.

ENDNOTES

1. Vyas, A. D., H. K. Ng, D. J. Santini, and J. L. Anderson, *Electric and Hybrid Electric Vehicles: A Technology Assessment Based on a Two-Stage Delphi Study,* Argonne National Laboratory, Illinois 1997. Online version at www.transportation.anl.gov/ttrdc/publications/papers/evstudy.html.
2. Interlaboratory Working Group on Energy-Efficient and Clean-Energy Technologies, U.S. Department of Energy, *Scenarios for a Clean-Energy Future,* 2000. Online version at www.ornl.gov/ORNL/Energy_Eff/CEF.htm.
3. *Annual Energy Outlook 2002 with Projections to 2020, 2001*, U.S. Energy Information Administration, Washington, D.C. Online version at www.eia.doe.gov/oiaf/aeo/.
4. *The Transportation Sector Model of the National Energy Modeling System. Model Documentation Report, 2001*, U.S. Energy Information Administration, Washington, D.C. Online version at tonto.eia.doe.gov/FTPROOT/modeldoc/m0702001.pdf.

APPENDIX C

COMPARISONS OF EMISSIONS AND COSTS OF EMISSION REDUCTION FOR ALTERNATIVE FUELS

The interactive, web-based emissions calculator, www.TravelMatters.org, accompanying this report is intended for use by transit agencies interested in determining the quantity of greenhouse gases emitted by a given fuel, or fuel-technology combination. The objective of the effort described in this appendix is to establish a standard for the comparison of fuel emissions based on the best currently available information. One of the challenges faced by transit agencies wishing to compare fuel emissions is the variety of existing information sources and the disparities among them. The most comprehensive fuel emissions model, Argonne National Laboratory's Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model, provides the formulas used by the TravelMatters website. Comparative emissions of selected fuels according to the GREET model are presented in Table C-1. Emissions figures from GREET are compared to those of several other sources in Table C-3. Table C-2 presents a cost analysis of use of and conversion to alternative fuels.

Most important to understanding the discussion below are two definitions and a qualification.

- Emission Coefficient—This is the term used by the Energy Information Administration (EIA) to compare the GHG emissions for the different fuels. It is defined as the pounds of carbon dioxide equivalent GHG emissions for a given fuel per million BTUs of energy available to the vehicle.
- Bus emissions per mile—This is the term used below to compare the emissions for the different fuels per mile of bus travel. It is defined as the Emission Coefficient multiplied by the energy use of the bus in BTU per mile, divided by one million. This accounts for the differences among fuels of both their emissions and their efficiencies.
- The qualification is that all of the values related to emissions of alternative fuels are estimates that are subject to continual change. Assumptions of future fuel efficiencies, a range of assumptions in the models, changes in technology, manufacturing and distribution processes, in addition to other factors make it imperative that all figures be treated as approximations. (Even a relatively simple, yet important, data point such as the heating value of gasoline or diesel fuel will vary because the formulations of these and other fuels are changed in response to expected climate conditions.)

EMISSIONS FROM ALTERNATIVE FUELS

Table C–1 contains information from the GREET model that is necessary to compare emissions from eight fuels. Seven of the fuels are currently being used in buses while the eighth, gasoline, is familiar as a fuel for passenger cars, and is presented for the sake of comparison with alternative fuels and technologies as a family. (The section below, "Results of GREET-Based Analyses," contains additional data on the fuels and explains in detail the steps and assumptions used to develop the data.)

The results from the GREET portion of Table C–1 are based on calculations generated by the GREET 1.6 Fuel-Cycle Model for Transportation Fuels and Vehicle Technologies. (GREET stands for Greenhouse-Gases, Regulated Emissions, and Energy Use in Transportation.) GREET was developed by Argonne National Laboratory, under the U.S. Department of Energy, Office of Transportation Technologies. The model can be found at: [www.transportation.anl.gov/ttrdc/greet].

GREET is structured to calculate the fuel-cycle energy consumption and the fuel-cycle emissions of greenhouse gases, and the fuel-cycle emissions of five criteria pollutants. The greenhouse gas emissions are based on the sum of the greenhouse warming potentials of three gasses:

- Carbon dioxide (CO_2) with a global warming potential (GWP) of 1,
- Methane (CH_4) with a GWP of 21, and
- Nitrous oxide (N_2O) with a GWP of 310.

(The emissions of criteria pollutants, while calculated by the GREET model, are not considered in this analysis.)

Stages in the fuel-cycle analysis that are calculated separately in the GREET model are:

- Feedstock (production, transportation, and storage)
- Fuel (production, transportation, distribution, and storage)
- Vehicle operation (vehicle refueling, fuel combustion/conversion, fuel evaporation, and tire/brake wear).

The BTUs per mile and grams per mile are calculated for a prototypical passenger car in the GREET model. The results of the calculations are shown as Rows 1 through 8 of Table C-1. The Emission Coefficient of each fuel is calculated in the table by dividing the Total GHG Emissions by the Energy Consumption for Vehicle Operation and then changing the units from grams per BTU to pounds per million

TABLE C-1 Emissions from alternative fuels
All emissions are total CO_2 equivalents

	Source	Units	Gasoline	Petroleum Diesel	Biodiesel from Soybeans	B20	Ethanol from Corn	Compressed Natural Gas	Hydrogen from NG	Hydrogen from electrolysis[a]
Results of GREET-based Analysis										
Energy Consumption										
Feedstock	(1)	BTU/mile	171	143	336	179	433	265	97	0
Fuel	(1)	BTU/mile	893	582	1,030	667	1,834	300	1,142	1,101
Vehicle Operation	(1)	BTU/mile	4,115	3,397	3,407	3,407	3,828	3,886	1,741	1,741
Total Energy Consumption	(1)	BTU/mile	5,179	4,122	4,773	4,253	6,095	4,451	2,980	2,842
GHG Emissions										
Feedstock	(1)	gram/mile	24	20	-247	-30	-158	37	9	0
Fuel	(1)	gram/mile	68	43	59	46	142	22	180	33
Vehicle Operation	(1)	gram/mile	321	280	283	280	299	243	0	0
Total GHG Emissions	(1)	gram/mile	413	343	95	296	283	302	189	33
Emission Coefficient		lb.CO_2/mmBTU	221	222	61.4	191	163	171	239	42
Energy Consumption - Automobile Operation		BTU/mile	4,115	3,397	3,407	3,407	3,828	3,886	1,741	1,741
Energy Consumption vs. Petroleum Diesel		Comsump./Diesel	1.21	1	1.00	1.00	1.13	1.14	0.51	0.51
Bus Energy Usage per Mile [b]		BTU/mile	72,600	60,000	60,000	60,000	67,800	68,400		30,600
Bus Emissions per mile		lb.CO_2/mile	16.1	13.3	3.7	11.5	11.0	11.7	7.3	1.3

Notes: a Assumes electricity generated by hydropower at off-peak or by solar or wind technologies
b 60,000 BTU/mile is equivalent to approximately 2 miles per gallon
Source: (1) Argonne National Laboratory website www.transportation.anl.gov/ttrdc/greet

TABLE C-2 Costs of reducing GHG emissions in buses with alternative fuels
Steps to get to $ per ton of GHG reduction (as equivalent CO_2) for alternate fuels

	Emission Reduction									
1	Bus Energy Usage per Mile (See Table C-1)	BTU/mile	72,600	60,000	60,000	60,000	67,800	68,400	30,600	30,600
2	Bus Emissions per Mile (See Table C-1)	lb.CO_2/mile	16.1	13.3	3.7	11.5	11.0	11.7	7.3	1.3
3	Bus Emissions less Petroleum Diesel Emissions	lb.CO_2/mile	+2.8	--	-9.6	-1.8	-2.3	-1.6	-6.0	-12.0
	Fuel Cost									
4	Cost of Fuel per mmBTU (1),(2),(3)	$/mmBTU	$9.91	$9.11	$17.34	$10.76	$16.35	$7.93	$7.39	$15.83
5	Cost of Fuel per mile	$/mile	$0.72	$0.55	$1.04	$0.65	$1.11	$0.54	$0.23	$0.48
6	Cost of Fuel less Cost of Petroleum Diesel	$/mile	+$0.18	--	+$0.49	+$0.10	+$0.56	-$0.01	-$0.32	-$0.07
	Vehicle Costs									
7	Cost of Bus less Cost of Diesel Bus - Capital (4)	$/bus		standard	$0	$0	$20,000	$50,000	$[illegible]000	$60,000
8	Bus Life	miles		1 million	1 million	1 million	1 million	1 million	1 [illegible]lion	1 million
9	Cost of Bus less Cost of Diesel Bus - Capital	$/mile			$0.00	$0.00	$0.02	$0.05	$0.06	$0.06
10	Cost of Bus less Cost of Diesel Bus - Total	$/mile	NA[2]	standard	$0	$0	$0.02	$0.05	$0.06	$0.06
	Costs of Emission Reduction									
11	Cost of Fuel less Cost of Petroleum Diesel	$/mile		--	+$0.49	+$0.10	+$0.56	-$0.01	-$0.32	-$0.07
12	Cost of Bus less Cost of Diesel Bus - Total	$/mile		--	$0	$0	+$0.02	+$0.05	+$0.06	+$0.06
13	Cost less Cost of Diesel	$/mile		--	+$0.49	+$0.10	+$0.58	+$0.04	-$0.26	-$0.01
14	Bus Emissions less Petroleum Diesel Emissions	lb.CO_2/mile		--	-9.6	-1.8	-2.3	-1.6	-6.0	-12.0
15	TOTAL COST OF EMISSION REDUCTION	$/lb. CO_2			+$0.051	+$0.055	+$0.252	+$0.025	-$0.043	-$0.001
16	**Scenario 1 - Cost of Emission Reduction**	**$/ton CO_2**	**NA**	**Standard**	**+$102**	**+$110**	**+$504**	**+$50**	**-$86**	**-$2**
17	Cost of Fuel less Cost of Petroleum Diesel	$/mile						-$0.01	-$0.32	-$0.07
18	**Scenario 2 - Avail. $ to Pay for Alternative Bus**	**$**						**$10,000**	**$320,000**	**$70,000**
19	$ Gained by Trading CO^2 at $10/ton	$/mile						$0.008	$0.030	$0.060
20	$ Gained by Trading CO^2 at $10/ton	$						$8,000	$30,000	$60,000
21	**Scenario 3 - Avail. $ to Pay for Altrenative Bus**	**$**						**$18,000**	**$350,000**	**$130,000**

Sources:

(1) www.gaspricewatch.com (gasoline), www.eia.doe.gov/pub/oil_gas/
(2) Alternative Transportation Fuels and Vehicles: Energy, Environment, and Development Issues, (CRS).
(3) Hydrogen Fuel (www.eren.doe.gov/consumerinfo/refbriefs/a109.html)
(4) Alternate Fuel Transit Buses - Final Results, NREL, 1996.(CNG, Ethanol, Biodiesel), H_2Gen Innovations, Inc. (Hydrogen)

TABLE C-3 Emission coefficients for alternative fuels
All emission coefficients are total CO_2 equivalents

	Source	Units	Gasoline	Petroleum Diesel	Biodiesel from Soybeans	B20	Ethanol from Corn	Compressed Natural Gas	Hydrogen from NG	Hydrogen from electrolysis[a]
Chemical Properties of Fuels										
Chemical Formula	(1)		Hydrocarbons 4 to 12 carbons	Hydrocarbons 3 to 25 carbons	Fatty acids/alcohol 12 to 22 carbons	80%diesel/20%bio 3 to 25 carbons	C_2H_5OH	CH_4	H_2	H_2
Molecular Weight	(1)		100-105	approx. 200			46.07	16.04	2.02	2.02
Lower Heating Value	(1)	BTU/lb.	18,000-19,000	18,000-19,000	15,700-16,700		11,500	21,300	51,532	51,532
Lower Heating Value per Volume	(1)	BTU/gal.	115,000	128,400	119,000	121,000	76,000	19,800[b]	12,600[c]	12,600[c]
Results of GREET-based Analysis										
Assumed Car Mileage (gas.equiv.)		mpg (geg)	27.5	33.2	33.2	33.2	27.5	27.5	60.5	60.5
Energy Consumption										
Feedstock	(2)	BTU/mile	171	143	336	179	433	265	97	0
Fuel	(2)	BTU/mile	893	582	1,030	667	1,834	300	1,142	1,101
Vehicle Operation	(2)	BTU/mile	4,115	3,397	3,407	3,407	3,828	3,886	1,741	1,741
Total Energy Consumption	(2)	BTU/mile	5,179	4,122	4,773	4,253	6,095	4,451	2,980	2,842
GHG Emissions										
Feedstock	(2)	gram/mile	24	20	-247	-30	-158	37	9	0
Fuel	(2)	gram/mile	68	43	59	46	142	22	180	33
Vehicle Operation	(2)	gram/mile	321	280	283	280	299	243	0	0
Total GHG Emissions	(2)	gram/mile	413	343	95	296	283	302	189	33
Emission Coefficient		lb.CO_2/mmBTU	221	222	61.4	191	163	171	239	42
Car Mileage[d]		mpg	27.9	37.8	34.9	35.5	20.0	5.1	7.2	7.2
Results from EIA Sources										
Tailpipe Emissions	(3)	lb.CO_2/mmBTU[e]	156.4	161.4				117.1		
Weighted Quantity of GHG	(4)	Moles/VMT	10.71				13.88	9.03		
Emission Coefficient		lb.CO_2/mmBTU	271				351	229		
Results from NREL Sources										
Emission Coefficient	(5)	lb.CO_2/mmBTU[e]		548	118	462				
Emission Coefficient	(6)	lb.CO_2/mmBTU[e]		209	48.5					
Emission Coefficient	(7)	lb.CO_2/mmBTU							230.7	
Selections for Use in Calculating Emissions (Table C-1)										
Emission Coefficient		**lb.CO_2/mmBTU**	**221**	**222**	**61.4**	**191**	**163**	**171**	**239**	**42**

Notes

[a] Assumes electricity generated by hydropower at off-peak or by solar or wind technologies.
[b] Assumes compressed gas at 2400 psi.
[c] Assumes compressed gas at 5000 psi
[d] Calculated by dividing Lower Heating Value by Vehicle Operation Energy
[e] Includes only CO_2, not all GHGs

Sources

(1) Alternate Fuels Data Center website www.afdc.nrel.gov/altfuels.html
(2) Argonne National Laboratory website www.transportation.anl.gov/ttrdc/greet
(3) Energy Information Administration website www.eia.doe.gov/oiaf/1605/factors.html
(4) Alternatives to Traditional Transportation Fuels 1994, Energy Information Adminstration, 1996
(5) Life Cycle Inventory of Biodiesel and Petroleum Diesel for Use in an Urban Bus, NREL, 1998
(6) Biodiesel for the Global Environment, NREL, 2000
(7) Life Cycle Assessment of Hydrogen Production via Natural Gas Steam Reforming, NREL, 2001

BTU by multiplying by 1,000,000, and dividing by 454 (Row 9). Row 3 is brought down as Row 10. Row 11 is calculated by dividing the BTU/mile of each fuel by the BTU/mile of petroleum diesel. This ratio is assumed to apply to buses as well as passenger cars, but given that the ratio may vary under different driving conditions for the same bus the assumption leads only to a first approximation.

Row 12 is calculated by multiplying the ratios in Row 11 by an assumed energy consumption for a diesel bus of 60,000 BTU/mile, which is equivalent to approximately 2 miles per gallon. Row 13 is calculated by multiplying the Emission Coefficient (Row 9) by the Energy Consumption (Row 12) and dividing by 1,000,000. The bottom two rows of Table C-1 provide information needed to consider costs of emission reduction.

COSTS OF REDUCING GHG EMISSIONS IN BUSES WITH ALTERNATIVE FUELS

An important factor in the selection of alternative fuels is cost. Table C-2 contains a sequence of calculations that can be used to approximate the costs of using alternative fuels to reduce emissions. The rough estimations in Table C-2 should not be used to make decisions in the absence of other considerations, but they may be the basis for an ongoing refinement of cost estimations.

Sources of data are included in the notes at the bottom of the table. The same bus energy consumption of 60,000 BTU/mile assumed in Table C-1 is carried forward to C-2. Because petroleum diesel is the standard fuel in buses at this time, it is used as the standard for comparisons made in Table C-2.

Rows 1 and 2 are carried forward from Table C-1. Row 3 is calculated by subtracting the emissions per mile for petroleum diesel from each of the other fuels to get the reductions of emissions that can be gained from alternative fuels, in pounds per mile.

Rows 4 through 6 present comparable Costs of Fuel per mile for each of the fuels. Current price estimates are used. (See the sources cited in Table C-2.) By using the lower heating values of each fuel shown in Table C-3, the costs are converted to dollars per million BTUs.

Rows 7 through 10 add costs of the buses to the fuel cost of emission reduction. A number of assumptions are made to arrive at a demonstration of the process, all of which are subject to question and refinement for decision-making. A major assumption regards the scale and maturity of the system that is replacing diesel buses. For example, the fuel cell buses that have been operated to date cost in excess of $1 million, or four to five times the cost of a diesel bus. However, the Cost of Bus less Cost of Diesel Bus—Capital amounts shown in Table C-2 for hydrogen, are one estimate of costs at a future time when fuel cell buses are under mass production.

Assumptions of a million-mile bus life were made for every fuel. While these are very rough estimates, in the context of a mature transit system they are reasonable. It is further assumed that maintenance and fuel infrastructure costs would be no different from those of a petroleum diesel system.

The Costs of Emission Reduction were calculated in Rows 11 through 15 for each fuel, using the assumptions discussed above, and are shown as Scenario One (Row 16). The results are shown as dollars per ton of CO_2 equivalent GHG reduction. Due to the comparatively high fuel costs shown, reduction of emissions using biodiesel, B20 and ethanol would be very expensive. CNG is a less costly option. Under the initial assumptions of a mature, full-scale system, hydrogen yields even greater savings.

Because these assumptions do not describe current market conditions, and it may be some time before hydrogen fuel cells are cost-competitive, another perspective on the substitution of alternative fuels is presented in Scenario Two. The same cost of fuel is assumed in both Scenario One and Two. However, in Scenario Two, it is assumed that savings from lower fuel costs can be invested in the bus. The operating costs saved from lower fuel costs over the million-mile life of a bus could, however, be substantial. Row 17, which is the same as Row 11, shows the savings on fuel per mile for the three feasible alternatives. Row 18 shows savings over the typical bus life. Savings with CNG only amount to $10,000, a fraction of the estimated $50,000 needed for conversion of a bus from diesel to CNG fuel. Assuming hydrogen fuel and fuel cell bus technology become affordable at some point in the future, hydrogen's significant fuel economy would make up for higher capital costs, thus making it competitive with conventional technology.

The same costs are assumed in Scenario Three as in Scenario One. Scenario Three also assumes that emissions savings will eventually be valued by carbon markets at a price of $10.00 per ton. These revenues to the transit agency, of up to $60,000 over the million-mile life of a bus, could increase the funds available for more expensive buses beyond what is available in Scenario Two.

These scenarios only begin to illustrate the possible uses of the tables to analyze the costs and benefits of alternative fuel options. The costs of the fuels, the buses and the fuel infrastructure are all complex variables, as are vehicle performance and emissions reductions. The GHG calculator is designed to standardize various emissions calculations, and to simplify explorations of emissions reduction strategies.

EMISSION COEFFICIENTS FOR ALTERNATIVE FUELS

Table C-3 contains more information on the emission coefficients for alternative fuels. The fuels selected for inclusion in Table C-3 are those that are most commonly considered for use in transit vehicles. Methanol and propane are not on the list because they are no longer being considered as practical fuels. Seven different sources of data were used to create Table C-3. (See Table C-3, *Sources*). All sources are branches of the U.S. Department of Energy. However, each source presents its data differently. The following paragraphs explain how the components of Table C-3 were assembled from these sources, each of which is referenced in the notes at the bottom of the table.

Properties

The chemical formulas and molecular weights are included in the table in order to clarify similarities and differences among the fuels. Both gasoline and petroleum diesel are mixtures of hydrocarbons (compounds containing only carbon and hydrogen) and significant amounts of impurities, which contain sulfur, oxygen and nitrogen. The two fuels are separated from crude petroleum by fractional distillation processes that condense the specified mixture of hydrocarbons within specific ranges of boiling points. While both gasoline and diesel contain many compounds within the same range of numbers of carbon atoms, the molecular weights show that diesel consists primarily of compounds having higher numbers of carbon atoms. Biodiesel also has a mixture of hydrocarbons, but it is refined from the fatty acids contained in soybeans or other organic materials. B20 is the most common mixture of petroleum diesel and biodiesel: 20 percent of the mixture is biodiesel, 80 percent is petroleum diesel.

The lower heating value of each fuel is the heat generated by combustion less the heat required to bring the liquid fuel to the combustion temperature. (The higher heating value is not used, because it would include the heat released when water vapor in the combustion products condenses. No vehicles in use, or currently being developed, would capture this heat, so the lower heating value is used for comparisons between fuels.) The lower heating value is expressed in both BTUs per pound and BTUs per gallon. Interestingly, the BTUs per pound for gasoline and diesel show the same 5 percent range for both fuels, while the BTUs per gallon show a precise number that is different for the two fuels. This illustrates that these two fuels can vary considerably in composition, and therefore heating values for them must be considered approximations.

Results of GREET-Based Analyses

As mentioned above, the GREET model is structured to calculate the fuel-cycle energy consumption, the fuel-cycle emissions of greenhouse gases, and the fuel-cycle emissions of five criteria pollutants. The greenhouse gas emissions are based on the sum of the greenhouse warming potentials of three gasses:

- Carbon dioxide (CO_2) with a global warming potential (GWP) of 1
- Methane (CH_4) with a GWP of 21
- Nitrous oxide (N_2O) with a GWP of 310.

The emissions of criteria pollutants, while calculated by the GREET model, are not considered in this analysis. Fuel-cycle stages that are calculated separately in the GREET model are:

- Feedstock (production, transportation, and storage)
- Fuel (production, transportation, distribution and storage)
- Vehicle operation (vehicle refueling, fuel combustion/conversion, fuel evaporation, and tire/brake wear)

Using the example of gasoline for the selected fuel, the sequence of decisions required by the GREET model is as follows:

1. A choice must be made about vehicle type. Only passenger cars and light trucks are options.
2. A fuel type must be selected, and a choice is made about options. Conventional, federal reformulated and California reformulated gasoline are the options.
3. An oxygenate (a compound added to gasoline to get cleaner burning) must be selected.
4. A vehicle technology must be selected.
5. Assumptions about the efficiency of petroleum and electrical production are shown and defaults are offered.
6. Assumptions about the transportation modes for the fuel are shown, including pipeline lengths, tanker or barge mileage, and tanker size. Again, defaults are offered.
7. A baseline vehicle is shown, and criteria pollutant emissions characteristic of that vehicle are shown. (Criteria pollutants were not considered here.)

Upon making these selections, the model calculates a range of data. The data that are of interest here are shown in Tables C-1 and C-3 as the Energy Consumption and GHG Emissions for Feedstock, Fuel and Vehicle Operation for each fuel. The Total Energy Consumption and Total GHG Emissions in the two tables for each fuel are sums of these data. These calculations can all be made using the GREET website. The results of the calculations are also tabulated in the publication *GREET 1.5—Transportation Fuel-Cycle Model, Volume 2: Appendices of Data and Results.* The values in Tables C-1 and C-2 are those given in *GREET 1.5—Volume 2.* Identical results for these fuels are obtained from GREET 1.6.

The vehicle technology is chosen by GREET to match the selected fuel. The spark-ignition engine and the compression-ignition engine are considered both near-term and long-term technologies. The dedicated spark-ignition engine and fuel cell are considered long-term technologies. The Calculated MPG (Row 14 in Table C-3) is the result of dividing the Lower Heating Value per Volume by the Vehicle Operating Energy Consumption to get miles per gallon. While the MPG does not enter into the emissions calculations, it is illustrative of the relative volume of each fuel that needs to be stored in the vehicle.

The Emission Coefficient is a term that is used by the Energy Information Administration (EIA), but not by the GREET model. It seems, however, to be the most appropriate measure of comparison among the fuels. It is calculated by dividing the Total GHG Emissions by the Vehicle Operation Energy Consumption. Pounds of carbon dioxide equivalent per million BTUs of fuel in the tank have been selected for use in Tables C-1 and C-3 as the units for the Emission Coefficient—the same units used by the EIA.

Results from EIA

The first "Results from EIA Sources" section (Row 15 of Table C-3) is based on data provided by the Energy Information Administration's Office of Coal, Nuclear, Electric and Alternative Fuels, within the U.S. Department of Energy (DOE). The source data may be accessed on-line at www.eia.doe.gov/oiaf/1605/factors.html. Only tailpipe—rather than fuel-cycle—emissions are included in this source. The website considers a variety of fuels, but the only fuels in Table C-3 for which data is included are motor gasoline, distillate fuel (diesel), and natural gas.

Another EIA source consulted (Rows 16 and 17) is the publication, "Alternatives to Traditional Transportation Fuels 1994—Volume 2: Greenhouse Gas Emissions." Here, the Weighted Quantities of Greenhouse Gas Emissions are expressed in moles per vehicle mile traveled (VMT). These units were selected by the EIA because greenhouse gas heat absorption is directly related to the number of molecules of a gas. (A mole of a gas is equal to the amount of the gas that contains 6.023×10^{23} molecules. A mole is equal to the molecular weight of the gas expressed as grams. For example, the molecular weight of carbon dioxide (CO_2), is approximately 44, so a mole of CO_2 weighs approximately 44 grams.) The VMT estimate for each fuel is derived by the EIA assuming a vehicle with a gasoline efficiency of 30 miles per gallon. (Thus, the fuel amount is that with the same lower heating value as $^1/_{30}$ gallon of gasoline.) Weighted GHG emissions are equal to the quantity of each GHG emitted multiplied by the global warming potential per mole of each gas, relative to carbon dioxide. (The same definition used in the GREET model, although the "global warming potentials" are not specified by the EIA.)

Only three of the fuels being considered in this report are included in the above publication: gasoline, ethanol from corn, and compressed natural gas. Table C-3 shows the values in Moles/VMT for these fuels in Row 16 labeled Weighted Quantity of GHG. Row 17 shows the same values in pounds per million BTUs. The conversion requires an assumption for the pounds of GHG per mole. The publication reports (p. 17) that carbon dioxide and water vapor account for more than 97 percent of alternative and traditional transportation fuel production products; the remaining three percent is a mixture of gases. For purposes of estimation, it was assumed that the average molecular weight of the GHG components is that of CO_2—44 grams per mole, or 0.097 pounds per mole. The emission coefficients resulting from this conversion are shown.

Results from NREL Sources

Two sources of data on biodiesel are available from the U.S. Department of Energy. The DOE's National Renewable Energy Laboratory (NREL) prepared a "Life Cycle Inventory of Biodiesel and Petroleum Diesel for Use in an Urban Bus" in 1998. Unfortunately, the life cycle inventory apparently only accounts for CO_2 emissions, not for total GHG emissions. That discrepancy is acknowledged in Table C-3.

The NREL report presents a material balance of the biomass carbon flows (in grams) associated with the delivery of 1 brake horsepower-hour (bhp-h) of engine work. Biodiesel is analyzed and then diesel is compared with biodiesel and with B-20. The carbon that is absorbed in the agricultural stage from atmospheric CO_2 is credited to biodiesel as a reduction in the tailpipe CO_2. Conversion to our units for Table C-3 requires determining that one bhp-h equals 2,544 BTU. The resulting net CO_2 emissions (Row 18) are:

- Petroleum diesel: 633.28 grams CO_2/bhp-h or 548 lb. CO_2/mmBTU
- Biodiesel: 136.45 grams CO_2/bhp-h or 118 lb. CO_2/mmBT
- B-20: 534.10 grams CO_2/bhp-h or 462 lb. CO_2/mmBTU

Another source of data about biodiesel and petroleum diesel is the NREL publication "Biodiesel for the Global Environment." The statement is made that "biodiesel produces 78% less CO_2 than diesel fuel. Biodiesel produces 2,661 grams of CO_2 per gallon, compared to 12,360 grams for gallon for petroleum diesel fuel." (Other GHGs are apparently not included.) The following values are also included in the publication:

	Diesel	**Biodiesel**
• Lower heating value (BTU/gal)	130,250	120,910

Calculation yields (Row 19):

• Emission coefficient ($lbCO_2$/mmBTU)	209.0	48.5

An NREL report, "Life Cycle Assessment of Hydrogen Production via Natural Gas Steam Reforming," concludes that the overall global warming potential of the production of hydrogen is 11,888 grams CO_2/kg of hydrogen produced. If it is assumed that no GHG is produced by the hydrogen-fueled vehicle (an assumption confirmed by the GREET analysis) the NREL emission coefficient can be compared to the others in Table C-3. The conversion requires a lower heating value for hydrogen, which in Table C-3 is shown as 51,532 BTU/pound. The conversion results in an Emission Coefficient of 230.7 lb CO_2/mmBTU for hydrogen (Row 20).

Row 21 in Table C-3 shows the values of Emission Coefficients selected for use in Table C-2, Costs of Reducing GHG Emissions with Alternate Fuels. The GREET values were selected because the methodology to estimate them was consistent, and because they tended to be in the mid range of other estimates.

APPENDIX D

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Abbreviations used without definitions in TRB publications:

AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
IEEE	Institute of Electrical and Electronics Engineers
ITE	Institute of Transportation Engineers
NCHRP	National Cooperative Highway Research Program
NCTRP	National Cooperative Transit Research and Development Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
SAE	Society of Automotive Engineers
TCRP	Transit Cooperative Research Program
TRB	Transportation Research Board
U.S.DOT	United States Department of Transportation