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COMBATING GLOBAL WARMING THROUGH SUSTAINABLE SURFACE TRANSPORTATION POLICY

FINAL REPORT

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ABSTRACT

The objective of *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 greenhouse gas emissions from transportation may be reduced. Both the print and web-based versions of the project review the capacity of public transportation to mitigate greenhouse gas emissions, and present this material in a format accessible to lay individuals and transit professionals. Key strategies for reducing transportation emissions are identified in the report: increasing the use of public transit and reforming corresponding land use practices, adopting energy-efficient technologies and fuels in transit fleets, and disseminating this information to a broad public. The TravelMatters website includes two on-line calculators that track travel 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 versions of the project present information on the land use factors that generate demand for travel; how 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.

SUMMARY OF FINDINGS

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 (warming) climate change 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, leading 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. Much of what can be done in this regard will have the multiple effect of improving air quality, in addition to improving human physical health and increasing fuel efficiency. While improving personal and transit vehicle fuel efficiency is one tactic in any future greenhouse gas reduction strategy, another equally important tactic involves expanding the overall share of transit in U.S. transportation. It is with such transit-related strategies that this report is most concerned.

THE TRANSPORTATION SECTOR AND GREENHOUSE GASES

The United States produces one quarter of global greenhouse gas emissions. The transportation sector accounts for a third of U.S. emissions, making American transportation a substantial factor in the global climate change equation, and therefore 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 about 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 broader, 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, customer service training for personnel, or providing 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, greenhouse gas emissions will be highest. Where these local characteristics support mass and non-motorized forms of transportation, greenhouse gas emissions will be lower – as can be seen in the maps of household greenhouse gas emissions in Chapter 3 of this report. This linkage, 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, available to regional planners, developers, community groups, and transportation agencies, that will make public transportation a more competitive mobility option.

FUEL-EFFICIENT AND LOW-EMISSIONS TRANSIT TECHNOLOGY

Transit agencies in larger urban areas are often 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. While there is currently no regulatory requirement to reduce greenhouse gas emissions from transit vehicles, increasing the fuel efficiency of transit vehicles effectively cuts back on 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 GREET emissions model, the comparative CO_2 benefits of alternative fuels have been compiled and included in a chart in Appendix A of this report. The Appendix also 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 in the case of natural gas. 100% biodiesel, on the other hand, eliminates virtually all regulated and greenhouse gas 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, achieves dramatic greenhouse gas reductions when used in a hybrid electric, or fuel cell engine. Using currently available fuels and technologies (a hybrid-electric powered bus, for example) it is possible to cut operating costs, and to dramatically lower regulated and greenhouse gas emissions. Using technologies and fuels still in development (such as hydrogen fuel cells) it will be possible to reduce regulated and greenhouse gas emissions even further.

EDUCATIONAL TOOLS

Most people are little aware of how much carbon dioxide and other greenhouse gases their daily activities cause to be emitted into the atmosphere. The emissions calculators designed for this project and hosted at the URL 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, are user-friendly tools with which to quantify greenhouse gas 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 will allow transit agencies to measure their greenhouse gases and provide them with information on alternative technologies and fuels.

CHAPTER 1

INTRODUCTION AND RESEARCH APPROACH

THE 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 greenhouse gases (mostly carbon dioxide) into the atmosphere at a rate higher than at any time in at least the last 20,000 years. Currently, around 8 per cent 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.

The potential benefits of reducing GHGs are substantial enough, if properly understood, to induce municipal, regional, and state authorities to take action on climate change independently of a larger 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 there are currently 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 GHG, 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, the municipal construction of new rapid transit or commuter rail, or community development of affordable housing or employment near transit. All of these have the potential to reduce carbon emissions by dropping the demand for automobile use.

PROJECT OBJECTIVE

The objective of *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 greenhouse gas emissions from transportation may be reduced. Both the print and web-based versions of the project review the capacity of public transportation to mitigate greenhouse gas emissions, and present this material in a format accessible to lay individuals and transit professionals. Three strategies for reducing transportation emissions are identified in the report: increasing the use of public transit, reforming corresponding land use practices, and adopting energy-efficient technologies and fuels in transit fleets. The TravelMatters website includes two on-line calculators that track travel emissions for individuals or transit fleets, and a series of Geographic Information Systems 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; how 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.

RESEARCH APPROACH

The scope of *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 greenhouse gas 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. In order to better understand the factors that shape the heavy automobile use (and resultant high emissions) characteristic of the American urban landscape, the research team reviewed the ways in which land use and urban form condition travel demand. Echoing the findings of several other recent studies on transportation and emissions, (discussed in Chapters 2 and 3) strategies for smart growth in urban areas and increased use of public transportation emerged as feasible ways to lower transportation sector emissions. CNT then conducted case studies of three cities 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, helping thereby to revitalize a struggling city center. Santa Monica, California was studied for its celebrated and heavily used bus system. Arlington County, Virginia, is an example of effective and prosperous transit oriented development in a suburban location, 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, and synthesizing the latest emissions-testing data to which of the currently available fuels and technologies are most likely to reduce GHGs. The result of this research is both a narrative and a tabular comparison of the emissions reduction potential of a variety of transit fuels and technologies, as well as the costs associated with their implementation.

On the basis of the above research, a model is included in the report, estimating GHG transit emissions between 20 and 40 years in the future. The model is designed to illustrate total transit emissions based on several different scenarios, taking into account the greater or lesser 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 not only the results of the project research, but a variety of exclusively on-line decision-support tools intended to help individuals, transit agencies, and municipal planners understand how greenhouse gases are generated, by both individuals and transit systems, and options for minimizing emissions from the transportation sector. The tools, hosted on the website www.TravelMatters.org, consist of two emissions calculators, one for transit agencies and one 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 on both the county and household levels, and maps of regional and household carbon emissions for Chicago, Los Angeles, and San Francisco. All of these maps are intended to illustrate the lower household carbon emissions associated with higher-density urban areas, in contrast to the higher household emissions found in sprawling or rural areas.

The final task of the project is to disseminate the results, and market the decision-support tools to target audiences. The research team will attend conferences, disseminate brochures, and use the internet to increase public awareness of the impacts of travel behavior on global warming, and encourage action to sustainably reduce greenhouse gas emissions from transportation.

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: mechanized human industry. 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 fifty 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 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 greenhouse gases. The primary greenhouse gases are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), are chlorofluorocarbons (CFC-11, 12, 113, CCl_4).

Greenhouse gases are emitted locally, but 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 towards an overall reduction of greenhouse gases. The United States, for example, is responsible for a quarter of the annual worldwide carbon dioxide emissions. Any substantial emissions reduction measures taken by the U.S. would have significant global consequences.

A SECTORAL 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, and therefore emit carbon dioxide. 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: the number of vehicle miles traveled in passenger and freight vehicles has steadily increased over the past two decades. Gas prices have decreased since the late 1970s, and Americans have been driving farther each year. As the number of light trucks and SUVs in use has risen precipitously, the average fuel efficiency of cars on the road has dropped, despite technological advances over the last twenty 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 denser, mixed use urban development, can all 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 define the determine the range of travel options available to local residents. A person living in a residential sub-division with cul-de-sac streets and few sidewalks has little choice but to drive to the hardware store or to a job. A person living in an area laid out in a grid of interconnecting streets and 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 therefore 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, a short-term strategy for greenhouse gas reduction would optimally be based on existing programs, such that reductions in greenhouse gases would come as collateral benefits of efforts improve air quality, reduce pollution in non-attainment 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 purposes of reducing emissions of carbon dioxide. 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 in fact helping to reduce greenhouse gases by decreasing the need 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 without negative effects on the environment and social equality.

LOW-EMISSION TRANSIT TECHNOLOGIES

Reducing personal automobile 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 thirty years ago. A number of alternative fuels and technologies have been developed for public transportation, but have not been widely implemented. Much can still be done to make low greenhouse gas 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 greenhouse gas emissions, but save money on fuel, while delivering performance on a par with diesel. Not only do such fuel-efficient vehicles benefit air quality and human health, they also work for the bottom line.

SUMMARY

This report examines the ways in which individuals, communities, transportation planners, and transit systems can locally reduce greenhouse gas emissions from transportation. Even in the absence of federal policy that regulates greenhouse gas emissions, the benefits of the actions that reduce GHGs are so great that implementing them is 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 and achieve a more active lifestyle, improving their own health. 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 greenhouse gas emissions can also work towards 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: clean air, and the physical and economic health of communities, to only name a few.

CHAPTER 2

AN INTRODUCTION TO CLIMATE CHANGE RESEARCH

It is now widely accepted within the scientific community that the quantity of carbon dioxide and other greenhouse gases present in the atmosphere has increased steadily since the Industrial Revolution, and particularly since the mid-20th century. Levels of atmospheric carbon dioxide are currently higher now than at any point during the past 420,000 years. It is also widely accepted that the average surface temperature of the earth has increased by a significant fraction of a degree Celsius over the last century. Determining the causal relation between these two sets of empirical observations -- increasing concentrations of greenhouse gases 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 carbon dioxide and regulating global surface temperatures, climate researchers have determined with greater certainty than only a decade before that the warming of the last fifty years is a result of human, greenhouse gas-generating activities.

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: 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 more 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 computers. Though less well established than the observational evidence, computer-simulated climate projections have improved tremendously over the last fifteen 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 they contradict or reinforce one another. Significantly, in the time between the First and Third IPCC Assessments, research has strengthened agreement between various fundamental data sets, partly in response to criticisms leveled at the integrity of time-series data. 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 U.N. IPCC concluded in 2001 that "the effect of anthropogenic greenhouse gases is detected."[1] A subsequent report issued by the U.S. Environmental Protection Agency, in fulfillment of U.S. treaty obligations under the United Nations Framework Convention on Climate Change, did not dispute the analyses or findings of the IPCC report, though it emphasized the provisional state of scientific knowledge in the field.[2] The IPCC report was reviewed by the U.S. National Academy of Sciences in 2001, which found "the body of the…report…scientifically credible and…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] 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 – coal in particular – that was transforming European economies at the end of the 19th and the beginning of the 20th centuries. As early as the 1850's, such industrial centers as Manchester, England were notorious for surrounding themselves and 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 1880's. To the Swedish chemist Svante Arrehnius in 1896, such sights represented 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, Arrehnius observed, was historically unprecedented.[4] When this observation was linked to the well-established heat-trapping property of carbon dioxide 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.[5] 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.[6]

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.[7] It was not until the 1950's, a period of innovation in the geophysical and atmospheric sciences, that concerted research began on the subject of greenhouse gases. 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 carbon dioxide 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.[8] It was under his supervision that the carbon dioxide monitoring station on Mauna Loa, Hawaii, was established. Readings from this station and another in Antarctica established that atmospheric carbon dioxide has increased steadily since 1957, and that this is the result of human activities.[9] (Figure 2.1)

Focused research on climate science gathered momentum in the 1970's, when the issues of world population growth and the oil-related energy crisis became issues of primary concern for both the public and policy makers.[10] 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 United States government dealing with carbon dioxide emissions addressed the economic, political, and environmental impacts of increased fossil fuel consumption both in the developed and developing worlds.[11] Although awareness of the role of greenhouse gas emissions in climate change was increasing at this time, the energy and environmental legislation of the 1970's and 1980's was motivated largely by an interest in reducing U.S. dependency on foreign oil and in cutting acid rain-causing emissions from cars and power plants.

The upsurge of interest in fossil fuel combustion and climate change during the 1980's prompted governmental and non-governmental organizations to begin sponsoring research in climate science. Central to this effort was the establishment by the United Nations of the Intergovernmental Panel on Climate Change (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 the climate warming "signal" from the background noise of 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 (1990, 1995, 2001) for improvements in computer simulation capabilities, an increase in the range and accuracy of observational evidence, and further international efforts to monitor climate. 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 1990's, 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 greenhouse gas emissions. One report that relates global climate change directly to emissions from specific economic sectors, including transportation (second only to industry as a source of carbon dioxide), is the 1997 "Five Labs Report." 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 U.S. 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. [12]

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 are likewise 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 carbon dioxide emissions are likely to further global warming."[13]

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 carbon dioxide is indeed altering the climate, an unmistakable warming trend should appear in the 1990's."[14] Such has indeed been the case. Long-term temperature data establish the 1990's as the warmest decade, and 1998 as the warmest year, since reliable records have been kept beginning in 1861.[15] Paleoclimatological data go further and establish the 1990's 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 sudden, unforeseen regional atmospheric changes, on the scale of the sudden appearance of the ozone hole over Antarctica in the 1980's.[16]

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 – between 66-90 per cent 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."[17] 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 100,000 years.[18] Conversely, efforts to explain recent warming with recourse to natural causes alone are less and less promising, the IPCC suggesting that it is "bordering on unlikely" (just under 90 per cent certainty) that human activity has played no role in the general warming of the climate.[19] 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."[20] 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," 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.[21]

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 Third Assessment, most of these concerns have been addressed, resulting in an overall increase in certainty regarding the human causes of a warming climate. To quote the Third Assessment: "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 20th century." The exceptionally consistent global warming observed during the years between the Second and Third Assessments (including 1998, the warmest year of the century) further substantiate the general warming trend observed over the last fifty years.[22]

The Evidence: Carbon Dioxide Emissions

The primary greenhouse gases in the earth's atmosphere are water vapor (H_2O), carbon dioxide (CO_2), methane (CH_4), chlorofluorocarbons (CFC-11, 12, 113, CCl_4), nitrous oxide (N_20), ozone (O_3), and aerosols. After water vapor, which is not directly affected by human activities, carbon dioxide is the greenhouse gas most prevalent in the atmosphere. Because carbon dioxide circulates throughout the biosphere in such large volumes, it plays a primary role in the thermal regulation of the earth's atmosphere. Methane, though it is the second most prevalent gas by volume, is four times as powerful as a heat trapping gas, and has more than doubled its pre-industrial concentration, has a shorter residence time in the atmosphere and is generated in much smaller quantities than carbon dioxide.[23] 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 man-made carbon dioxide 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* (human-made) to naturally produced carbon.[24] 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 carbon dioxide emissions due to human activity during the second half of the 20th 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 carbon dioxide levels. This paleoclimatological evidence, corroborated by ice cores drilled at a number of sites around the world, establishes that the present concentrations of carbon dioxide in the atmosphere are the highest in nearly half a million years (much longer than any individual cycle of glaciation and deglaciation), up 31 percent 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."[25] Similar evidence has been obtained for the other greenhouse gases (though some, such as chlorofluorocarbons (CFCs), have actually begun to diminish at global levels). Thus, based on historical evidence and given the known properties of carbon dioxide as a heat trapping gas, steadily rising levels of carbon dioxide should lead to a detectable rise in average global temperature over a long enough time span.

The 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 beginning 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 period, over 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 somehow preserved, can extend the temperature record several thousand years into the past.[26] 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 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," and that "the current rate of increase is unprecedented during at least the past 20,000 years."[27]

It is acknowledged, however, that mean temperatures alone are insufficient for the attribution of human-induced climate changes.[28] To bridge the inferential gap, throughout the 1990's researchers called for a wider array of experimental measurements of such phenomena as heat absorption by the oceans and the cooling potential of ocean cloud cover and atmospheric aerosols.[29] 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.[30] This recent effort 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. The results from this record, again, indicate a 20th century warming that is the greatest in 500 years.[31]

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 fifty years. For example, questions arose in the 1990's 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: borehole temperatures, reduced terrestrial snow and ice cover, and changes in temperature of the ocean.[32]

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 1960's. The recent NAS 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 20th 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."[33]

Measurements from submarines and satellite data both suggest that the thickness and extent of Arctic sea ice have diminished since these readings first became available in the 1970's. In Antarctica, the IPCC Third Assessment documents the retreat of five ice shelves over the course of the 20th century; the National Snow and Ice Data Center put the number at seven since 1974. Less than a year after the *Third Assessment* 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.[34]

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 1980's and early 1990's, that the earth's atmosphere is indeed warming: "The effect of anthropogenic greenhouse gases is detected," as the IPCC concludes in its Third Assessment.[35] It also suggests the sorts of dramatic and rapid ecological changes that further warming might accentuate.

Cloud Cover and Atmospheric Feedbacks

The two fundamental elements of climate change science – greenhouse gases, primarily carbon dioxide, 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, result 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 carbon dioxide 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.[36]

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.[37] 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 greenhouse gases. Mainstream climate researchers, however, point to evidence contradicting Lindzen's convection model – "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-blown, alternative model of climate systems, the bulk of circumstantial evidence still points towards the probability of positive climate change.[38]

Computer Simulated Climate Forecasts

Climate science research in the 1980's and 1990's 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, 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 that is 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 previously. The IPCC now considers climate simulations capable of providing "credible simulations of both present annual mean climate and the climatological cycle," as well as "stable, multi-century simulations."[39] If a simulation, incorporating all known atmospheric feedbacks, can faithfully reproduce several centuries of recorded climate variation, the odds of the same simulation running an accurate forecast well into the future increase.

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."[40] 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."[41] Though the report acknowledges that such an initiative would require a major federal and private commitment to research and development, 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 transportation sector. 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 greenhouse gases vary according to geographical region and economic sector. CO_2 emissions can therefore be traced to specific, regional economic and social practices, helping 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 carbon dioxide emissions.[42] The transportation sector is a major contributor to the total U.S. volume of CO_2 emissions, at 33 percent of the total.[43] Thus, emissions from the U.S. transportation sector make up 8 percent of world CO_2 emissions. For the decade of the 1990's, transportation sector emissions averaged the greatest rate of growth, at 1.8 per cent, outpacing an average 1.25 per cent growth in all other sectors.[44] "Transportation," reports the Energy Information Administration in its 2000 inventory of U.S. greenhouse gas emissions, "is the largest contributing sector to total emissions" (Figure 1).[45]

Of the various *modes* of transportation that generate emissions, by far and away the largest segment consisted of the combined emissions of both automobiles and light trucks; almost 60 percent of transportation-related carbon emissions come from motor fuel consumed by these two classes of vehicle. For year 2000, cars generated 38.6 per cent of the U.S. transportation sector CO_2 emissions; light trucks, 20.6 per cent; and buses, 13.7 per cent. 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.[46]

From a purely statistical point of view, then, a strategy for reducing global carbon dioxide emissions would do well to reduce emissions originating in the use of automobiles and light trucks in the United States.[47] 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, bicycles, or to walk instead. With such a large proportion of greenhouse gas 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 greenhouse gas emissions from the transportation sector overlaps with the aims of a variety of programs in urban planning, public policy, and within federal, state, and municipal transit agencies, all directed towards increasing public use of mass transportation. 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. While the third chapter offers illustrations of the conditions necessary for optimal transit efficiency, the fourth chapter illustrates the concrete economic advantages that new low-emissions technologies can bring to a transit agency itself. The case of alternative transit technologies will illustrate a larger principle on a smaller scale: how multiple ends can be achieved through programs of energy efficiency. Reducing transportation sector greenhouse gas emissions by increasing transit use has the positive consequence of reducing regulated pollutants, and reducing transit agency operating costs.

CHAPTER 2 ENDNOTES

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[1] U.N. Intergovernmental Panel on Climate Change, Third Assessment Report. Climate Change 2001: The Scientitic Basis. "Summary For Policymakers," (2001), 12.6, "Concluding Remarks." [http://www.grida.no/climate/ipcc_tar/wg1/index.htm]

[2] U.S. EPA, U.S. Climate Action Report 2002. Third National Communication of the United States of America Under the United Nations Framework Convention on Climate Change. [http://www.epa.gov/globalwarming/publications/car/index.html]

[3] Committee on the Science of Climate Change, Climate Change Science. An Analysis of Some Key Questions, (Washington, D.C.: National Academy Press, 2001), 22. [http://books.nap.edu/html/climatechange/climatechange.pdf]

[4] Arrhenius, Svante, "On the Influence of Carbonic Acid in the Air upon the Temperature of the Ground," *Philosophical Magazine*, vol. 41 (1896); Worlds in the Making, (New York: Harper, 1908).

[5] Ausuble, Jesse H., "Historical Note," in Changing Climate. Report of the Carbon Dioxide Assessment Committee, (Washington: National Academy of Science, 1983), 488-491.

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[8] Revelle, Roger, "Carbon Dioxide Exchange Between Atmosphere and Ocean and the Question of an Increase of Atmospheric CO_2 During the Past Decades," *Tellus*, 9 (1957).

[9] Carbon that is a byproduct of human activities, such as fossil fuel combustion or slash and burn deforestation, is identifiable on the basis of a chemical structure than is distinct from that of naturally occurring carbon.

[10] "Because of continuing population growth, however, the world's rate of energy use will need to be greater in the future than it is now in order to maintain a constant supply of energy to each person." Revelle, "Carbon Dioxide and World Climate," 42; "Forward," in Changing Climate, ix-xii.

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[12] Interlaboratory Working Group on Energy-Efficient and Low Carbon Technologies, Department of Energy, "Scenarios of U.S. Carbon Reductions. Potential Impacts of Energy-Efficient and Low Carbon Technologies by 2010 and Beyond," (1997). This document, known informally as the "Five Labs Report," is the culmination of a number of different initiatives on energy policy sponsored by the Clinton Administration. [http://www.ornl.gov/ORNL/Energy_Eff/labweb.htm].

[13] U.S. Transportation Research Board, "Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards," (Washington, D.C.: National Academy of Sciences, 2001).

[14] Revelle, "Carbon Dioxide and World Climate," 38.

[15] Third Assessment Report. Climate Change 2001: The Scientitic Basis, "Technical Summary," 28-29.

[16] "It is…possible that climate could undergo a sudden large change in response to accumulated climate forcing. The paleoclimatic record contains examples of sudden large climate changes, at least on regional scales." Climate Change Science, 7.

[17] Third Assessment Report. Climate Change 2001: The Scientitic Basis. "Summary for Policymakers," 61.

[18] For a survey of paleoloclimatology, see the NOAA website: [http://www.ngdc.noaa.gov/paleo/globalwarming/home.html].

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[21] Scientific Assessment of Climate Change, 256.

[22] Third Assessment Report. Climate Change 2001: The Scientitic Basis, Chapter 12, "Executive Summary." [http://www.grida.no/climate/ipcc_tar/wg1/index.htm]

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longer-term issue of global carbon dioxide levels. Hansen, "Global warming in the twenty-first century: An alternative scenario," *Proceedings of the National Academy of Sciences*, 97 (2000): 9875-9880.

[24] John Houghton, Global Warming. The Complete Briefing, (Cambridge: Cambridge University Press, 2nd ed. 1997), chapter 3.

[25] Third Assessment Report. Climate Change 2001: The Scientitic Basis, "Technical Summary," 39.

[26] For an introduction to *dendroclimatology*, or the study of past climates through tree rings, see the overview provided by University of East Anglia's Climate Research Unit: [http://www.cru.uea.ac.uk/cru/annrep94/trees/index.htm]

[27] Third Assessment Report. Climate Change 2001: The Scientitic Basis, "Summary for Policymakers," 7.

[28] Ibid., 246.

[29] Hansen, James, "The Global Warming Debate," *NASA Goddard Institute for Space Studies*. [http://www.giss.nasa.gov/edu/gwdebate/]; Lindzen, Richard S., "Can Increasing carbon dioxide cause climate change?" *Proceedings of the National Academy of Sciences*, vol. 94 (August 1997): 8335-8342.

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[33] Climate Change Science, 16.

[34] See the briefing on Larsen B at the University of Colorado, Boulder's National Snow and Ice Data Center: [http://nsidc.org/iceshelves/larsenb2002/].

[35] Third Assessment Report. Climate Change 2001: The Scientitic Basis, Chapter 12 "Detection of Climate Change and Attribution of Causes." [http://www.grida.no/climate/ipcc_tar/wg1/index.htm]

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[39] Third Assessment Report. Climate Change 2001: The Scientific Basis, Chapter 8, "Model Evaluation." [http://www.grida.no/climate/ipcc_tar/wg1/index.htm]

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[41] Scenarios of U.S. Carbon Reductions, 1.17.

[42] U.S. Department of Transportation, Transportation Energy Data Book, ed. 22 (for year 2000): [http://www-cta.ornl.gov/data/Index.html]

[43] Ibid., Table 3.4, Chapter 3, "Greenhouse Gas Emissions." As with all measurements of aggregate emissions, numbers vary slightly according to different sources. According to the U.S. EPA, transportation made up 27% of the U.S. total. U.S. EPA, Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2000, (2002). [http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2002.html]

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CHAPTER 3

LOCAL STRATEGIES FOR REDUCING CO_2 EMISSIONS

Because the transportation sector is such a sizeable contributor to total U.S. greenhouse gas emissions, reducing transportation emissions will be a primary objective for any comprehensive U.S. greenhouse gas mitigation policy. Of the three strategies for reducing GHG emissions outlined in Chapter 1, this chapter focuses on the adoption of land-use practices that are more transit-supportive, and on policies that may increase the use or expand the service of already existing transit systems. While the reform of land-use practices prevailing in the United States is the most challenging of the two approaches, it is perhaps the most important for the long-term stabilization of CO_2 and other greenhouse gas 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 relation 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 greenhouse gases. How we build cities, therefore, has atmospheric consequences; those consequences also have an economic impact on the budget of typical urban households. Households in higher density neighborhoods coupled with frequent and accessible transit incur significantly lower transportation expenses because they are freed of the costs of auto ownership – the second greatest expense for American households.[1] 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.[2] 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 greenhouse gases, 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 relation between transit services and the markets that support them since the early days of public transportation. Formal modeling of travel demand, or the concrete conditions that influence individual decisions whether, where, and how to travel, however, began with the large-scale transportation construction of the 1950's. Until quite recently, one of the greatest barriers to studies attempting to isolate the true causes of what is known as "trip generation" 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 of transit travel demand carried out by Boris Pushkarev and Jeffrey Zupan in the 1970's 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 begin their study of travel demand with the observation that, today, transit functions in competition with the automobile. With the exception of neighborhoods within 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 1920's, and even into the early days of the 1950's 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.[3] 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 the First World War.

The expansion of the automobile market from the 1920's 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 functionally 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 the Second World War, transit has been compelled to extend its operations into areas laid out not 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 20th century, of financing itself in the absence of comparable levels of municipal and federal assistance available for the creation and maintenance of auto infrastructure.[4] This led to a considerable reduction in transit service as early as the 1940's. 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 Boris S. Pushkarev and Jeffrey M. Zupan produced a founding text of modern travel demand theory in the 1970's. 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."[5] 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 they summarize in the conclusion to *Public Transportation and Land Use Policy*,

> 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 1 and 7 dwellings per acre, transit use is minimal…A

> density of 7 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.[6]

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 ten, for example, is found to drop the level of auto ownership by 0.4 percent.[7] 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 percent 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."[8] 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.[9] 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.[10]

As revealing as were earlier studies of travel demand, 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 more closely scrutinize the same relationships with fine-grained, neighborhood-level data. This has necessarily involved the laborious compilation of new information. John Holtzclaw, in a 1994 paper, "Using Residential Patterns and Transit to Decrease Auto Dependence and Costs," developed a methodology for predicting household automobile travel from density and transit access in 28 California communities.[11] 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, calculating the transportation value, or "location efficiency," of a given place.[12] The Center For Neighborhood Technology, in cooperation with the Natural Resources Defense Council and the Surface Transportation Policy Project, developed a model to predict vehicle miles traveled in the Chicago, San Francisco and Los Angeles metropolitan areas in 1997. While earlier work, such as that carried out by Pushkarev and Zupan, looked at metropolitan regions on a city-wide scale, the LEM and subsequent modeling was able to predict vehicle miles traveled 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. "Direct comparison of neighborhoods is necessary," Holtzclaw writes, "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."[13] 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), vehicle miles traveled, 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: 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.

The location efficiency model (LEM) predicted household vehicle ownership and vehicle miles traveled 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: Geographic Information Systems unavailable prior to the 1980's allowed land use patterns and their effects to be made plainly visible; 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 the relative cost to households having to make more trips. By incorporating into statistical analysis the travel habits of different income groups, 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," thus refining the twenty-five 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.[14]

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 usage. 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 4 auto trips for every 1 trip by transit.[15] In further research on "transit leverage," John Holtzclaw found a reduction of VMT in San Francisco of 9 miles for every passenger mile of service.[16] If a single passenger mile on transit equals multiple passenger miles in an automobile, then increasing transit use emerges as a substantial tool for greenhouse gas reduction. Recognizing this, the American Public Transit Association calculates that, if only 7 percent of daily trips in the United States were shifted to transit, CO_2 emissions equivalent to more than 20 percent those of the commercial sector would be eliminated.[17] Taking the 1999 CO_2 emissions from transit, APTA calculates what the equivalent emissions would have been had those trips occurred on other modes, and obtains a figure representing a near doubling of the transit value. [18] (Table 3.1. For the APTA methodology as applied to case studies included in this chapter, see Table A-1)

SEGREGATED LAND USE, VMT, AND GREENHOUSE GAS EMISSIONS

Trends characteristic of the post-war period, such the absence of coordination between local land use and federal transportation planning, various subsidies and 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. Though this was done for a variety of reasons, some of them still justifiable, it is increasingly clear that the extreme segregation of land uses leads to greater VMT, and by extension, higher levels of greenhouse gas emissions. Less intentional factors have produced similar effects: 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 greenhouse gas 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 denser, more mixed-use areas. Low transportation costs and low greenhouse gas emissions, therefore, go together, a correspondence that highlights the economic benefits of greater transportation efficiency. To take Chicago for an example: in its study of the higher 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 than households in more distant, transit-poor communities.[19] (Table 3.2)

The emissions maps in Figures 3.2-3.7 provide a geographic illustration of this relationship: on a per household basis, central Chicago, Los Angeles, and San Francisco generate fewer emissions than outlying areas. Greater transportation efficiencies, rather than imposing a financial burden to urban residents, would in fact free up significant funds on a per household basis. In the older, denser parts of cities, even 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 more sprawling cities such as Houston, Atlanta, and Dallas-Ft. Worth still spend more on transportation than do residents of denser, more transit-oriented cities like Chicago, Honolulu, or New York -- on the order of $2,500 annually.[20] Taken in the aggregate, such sums can reach large magnitudes.

While households make the daily choice of which travel mode to use, local and regional planners have the potential to reshape metropolitan regions in a way that could sustainably and systematically reduce the demand for automobile travel, and 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 greenfield development. And, as the examples above suggest, land use patterns that lower local CO_2 emissions would necessarily build in energy efficiencies that would, over the long-run, save money from household transportation expenses, and the cost to society of auto oriented infrastructure.

Neighborhood Travel Emissions

Figures 3.2 to 3.7 map carbon dioxide emissions from automobiles in three cities of differing geography and history.[21] In each case, remarkable parallels emerge. Figure 3.2, 3.4, and 3.6 illustrate aggregate CO_2 emissions generated on a per square mile basis in each city. These images conform to conventional expectations regarding cities and pollution: high concentrations of people and industry generate high concentrations of pollutants. While this is true in general terms, it masks the effect of urban form and land use on the emissions of individual households, which is often much less than that of rural or less dense equivalents. Figures 3.3, 3.5, and 3.6 illustrate CO_2 emissions generated per household in each of the three cities. In this case, one sees a virtual inversion of the emissions values mapped in the first set of figures.

While the more densely populated areas of Chicago, Los Angeles, and San Francisco produce higher aggregate emissions than less densely populated outer suburbs and hinterlands, this relation 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 denser urban areas emerges 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 measurements of vehicle miles traveled in each city, offer visual confirmation of several decades' worth of literature describing 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 lower-density, sprawling urban areas to total greenhouse gas emissions.

Travel Emissions Across the Country

Similar relationships may be observed at the national level. Measuring emissions by county, the smallest geography for which household, vehicle ownership, and vehicle miles traveled 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 the larger American cities. At the household level, however, this relationship reverses, and precisely those regions that emit the most GHGs per unit area, emerge as the most efficient in terms of emissions per household. (See Figures 3.8 and 3.9)

The United States Environmental Protection Agency collects data on criteria pollutants generated by vehicle travel in the United States per county. Maps generated with this data do not include carbon dioxide or other greenhouse gases, because they are not regulated by current pollution control measures. The Center For Neighborhood Technology has utilized the EPA's vehicle miles traveled data to map carbon dioxide emissions from automobile use for each county in the U.S. The EPA obtains VMT estimates that the U.S Federal Highway Administration collects from state bureaus of transportation. The states formulate the estimates by conducting traffic counts in each county and projecting those figures to arrive at an estimated miles traveled per year in each county. Motor gasoline converts to a known amount of carbon dioxide, and so the carbon dioxide emissions from vehicle miles traveled in each county can be estimated by using an average fuel consumed per miles traveled.

Emissions from travel can been 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. But how far are those urban drivers traveling each day compared to drivers in rural areas where smog is never a problem? Analysis of county VMT figures indicate that, though 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 less 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 larger area. So, while more carbon dioxide 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 been 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. Though 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-state. While this suits the EPA's purpose of tracking the total quantity of auto pollution in the U.S., it allows small distortions to appear in mapping at the county level. Some rural counties may appear darker 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 vehicle miles traveled 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 is a 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 multiple transportation options for a given trip. Transit is much more prevalent in urban areas: density increases transit's economic viability. When distances are closer together, people have the additional option of walking or biking to destinations instead of traveling by car. Making regional planning decisions based on principles of sustainable development and the importance of public transportation is one way of contributing towards climate stabilization and improving the health of communities.

TRANSIT AND SUSTAINABLE SURFACE TRANSPORTATION POLICY

The essence of sustainability is the integration of economic development and environmental improvement. As the Task Force for the President's Council on Sustainable Development (1997) described it, sustainable communities are those that "flourish because they build a mutually supportive, dynamic balance between social well-being, economic opportunity, and environmental quality."[22] 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 linkage of sustainability with mass transit now informs a range of policies intended to make more efficient use of urbanized land, reduce traffic congestion, cut back vehicle emissions, and improve pedestrian mobility. The examples that follow each illustrate how the use of transit or other non-motorized transportation options are enhanced when travel demand factors are taken into consideration in the planning, marketing, design, and operation of transit. Aside from the potential economic benefits 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 greenhouse gas emissions in America's large urban centers. Global issues like climate change can be addressed by very local, very 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 1990's were a record decade for transit, with ridership figures growing by 21 percent nationwide from 1995 to 2000, approaching levels not reached since the early 1960's.[23] With more people using transit, a strong rationale exists for capitalizing on this trend as a key strategy in the effort to reduce U.S. greenhouse gas emissions from the transportation sector. Looking beyond the success of already-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 20th 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 feasible and desirable mobility option for urban residents. Planning for transit-supportive land use, reducing the provision of parking spaces near 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 stitch transit together with the modern urban fabric. Taken together, these tools amount to models of urban design that differ fundamentally from the auto-oriented development predominant since WWII.

State and FederalPolicy

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 21st 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

SUSTAINABLE SURFACE TRANSPORTATION PROGRAMS:

Intermodal Transit Passes. Commuters are more likely 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.

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.[24] At the state level, Maryland in 1997 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 something that links many things together: surface transportation. Maryland hopes to save its remaining open spaces and make its urban areas more livable by making existing surface transportation infrastructure more efficient. The state more recently established an “Office of Smart Growth” to help coordinate efforts mandated under the new law.

The State of Georgia recently established an administrative body, 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 2003-2005 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 in the union to formulate a greenhouse gas reduction policy in its 2002 “Energy Plan.” The plan sets itself the goals of a 10 percent reduction of greenhouse gas emissions below 1990 levels by the year 2020, a 50 percent increase in the use of renewable energy in the state by 2020, and the reduction by 25 percent of primary energy use per unit of gross state product by 2010.[25] While these and other initiatives intended to reform the urban environment of the United States are not intended to reduce emissions of greenhouse gases, it should be emphasized that any measure that reduces vehicle miles traveled will simultaneously reduce the amount of carbon dioxide and other greenhouse gases released into the atmosphere.   Increasing 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

There are hundreds of organizations in the United States working locally and regionally to encourage planners and policy makers to create sustainable transportation systems that would provide real mobility options for residents, and produce collateral benefits such as lower greenhouse gas emissions, improved air quality, better physical health, and neighborhoods rich in services and amenities. In order for planners and policymakers to consider these options, however, there must be a perceived market demand for sustainable development. Incentive products for individuals to take advantage of the assets and convenience of a place are a way of encouraging a reshaping of 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 non-motorized forms of transportation with enhanced bicycle and pedestrian facilities, encouraging 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) downtown shuttle bus service, car sharing, and commuter station 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 has recently experienced a dramatic upsurge in pass sales, as a result of a year 2000 executive order mandating that tax-free transit benefits be made available to all federal employees.[26] Projects, like the Los Angeles Neighborhood Initiative (LANI), build on the presence of transit as an essential dimension of a neighborhood's pedestrian friendliness.[27] Transit use may also be encouraged through the use of innovative financial instruments. The location efficient mortgage can reduce the cost of home ownership anywhere that lenders recognize the transportation savings accruing to households located near transit service.

In some instances, simple urban design improvements can work in favor of transit. The city of Portland 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 percent. 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.[28] By correcting for the lack of urban design elements such as pocket parks, pedestrian walkways, or pedestrian friendly transit stops, and working to increase the pleasantness of the transit experience, such projects improve the livability of neighborhoods – a concept given wide circulation since the middle 1980's by New Urbanist architects. A crucial part of neighborhood livability is a reduced dependency on automobile transport.[29]

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-serviced with 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 to reduce dependency on automobiles means doing more than simply linking up existing urban and suburban areas with transit networks, but actually reconfiguring 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, consistent application of sustainable surface transportation policies "could result in measurable reductions in vehicle travel and air pollutant emissions" by the year 2010.[30] 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 those…places…which have high shares of rail commuting and high concentrations of housing and offices within walking distance of stations."[31] 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.[32]

Scholars sympathetic to transit oriented development are careful to point out that transit in the United States cannot be effective absent a range of supporting 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.”[33] In a national context where transit planning is not always coordinated with the growth of urban areas, there is nonetheless 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. Altogether, 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 in fact encourage single occupant vehicle use by hiding the true market costs of free parking.[34] 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 commuting to work by 20 percent.[35] Zoning restrictions on the density of station area development can disrupt what is perhaps the most well established correlation in transit policy research: that between high urban density and increased transit ridership.[36] 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. 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) was as high as 63 percent in one case, and 74 percent in another. A 1992 study suggesting that density influences trip generation compared transit use in older, denser neighborhoods, with more auto oriented neighborhoods in Maryland's Montgomery County: "The study found that residents of the TOD's patronized transit between 10 percent and 45 percent more than residents of nearby auto-oriented neighborhoods."[37] 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 usage is walking distance to transit stations.[38]

Not all density is conducive to increased transit usage, however. The most well conceived transit oriented development 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.[39] Density that emphasizes one land use to the exclusion of others – commercial districts that empty out in the evening, or exclusively residential areas that offer no amenities or destinations, can discourage pedestrian activity and access to transit. Many of the urban design principles of the New Urbanism, such as public plazas, grid street design, a variety of pedestrian scale 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 higher ridership levels and higher 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.[40]

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 by car. On the basis of a transportation model developed in Portland, Oregon, the evaluation of transit usage in different so-called pedestrian environments demonstrates that "[z]ones 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."[41] This approach has recently been taken up 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 lighting fixtures, and lighted bus shelters.[42]

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 vehicle miles driven, or VMT. In each case, additionally, transit infrastructure operates in the context of some form of transit oriented development, 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 usage. Chattanooga has managed to reinvigorate its local industry, its 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 it made. The success of Washington, D.C. transit authorities in building over 100 miles of rail system since the 1970's is due to the substantial land use authority of Arlington County, Virginia, and Maryland county governments, 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 more than most has been shaped by America's relationship with the automobile, is haltingly engaged in one of the most massive infrastructure investments in the nation – a thirty year project to make modern L.A. the transit capital it was in the first decades of the 20th 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 greenhouse gas emissions.

Case Studies: 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.[43] 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, to encourage a mixture of downtown commercial activities and housing options, and to provide an intrinsically pleasant experience. Transit innovation in Chattanooga also benefited from the local community's commitment to maintaining the region's hard-won air quality.[44]

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 federal 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 which began to affect the livability of the region. This was manifested in disinvestment in Chattanooga's historic core, as residents and the

GREENHOUSE GAS REDUCTION BENEFITS OF CHATTANOOGA TRANSIT PROGRAM:

Alternative Technology. Electric shuttle buses reduce emissions of regulated pollutants and GHGs and draw riders; cut auto trips downtown.

Reduced Parking in city center encourages transit use, reducing vehicle miles traveled.

Mix of Land Uses in city center encourages walkability, a low-greenhouse gas mobility option.

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 1970's, together with many industrial cities it suffered a major setback later in that decade as heavy industry quit the region. Economic conditions reached a low point in the early 1980's, when the largest mall in Tennessee was built fifteen minutes outside the historic city center, gutting downtown of small business. Chattanooga's community leaders decided at this point that the city must reinvent itself. This led to a change in governmental structure, in which a city commissioner system was replaced by a more inclusive mayor-council system, and the drawing up of a twenty-year regional plan based on extensive community involvement in shaping the new face of Chattanooga. Among the many objectives agreed to in the over 100 public consultations that went into the 1984 Vision 2000 plan, the community agreed to reduce congestion in the downtown area, to provide for some form of public transportation, to make downtown commutes more efficient, and to draw visitors to several of the areas' anticipated attractions.

Chattanooga's reinvention was well on its way 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 -- comprising 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. “The concept,” says CARTA Planning Director Frank Aron, “was to have people who live, work, play and visit the downtown to 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.”[45] 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 into operation a fleet of electric powered buses. A local industrialist, Joe Ferguson, was hired as a consultant by the City of Chattanooga to investigate the feasibility of the plan, concluding 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.[46] AVS would custom manufacture the type of buses needed in Chattanooga, and in so doing, make a long-term investment in the vitality of the local economy.

With assistance from the Federal Transit Authority, 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, combined with the export of AVS buses to other cities nationally and internationally, have made AVS a thriving for-profit enterprise, and its buses a well received amenity. Since the early 90's, 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."[47] Once stigmatized as the dirtiest city in America, with a downtown hollowed out by a local 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."[48]

Case Studies: Washington, D.C.

Washington, D.C. presents a much different case than Chattanooga. The presence of the federal government as a major employer guarantees that the city will not face the same sort of profound economic crisis as did Chattanooga. Nor does it face 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 1980's.[49] Washington's present traffic congestion, not to mention the region's carbon emissions, would undoubtedly be much worse if Metrorail's approximately 300,000 riders, or the 250,000 weekday commuters using Metrobus, had no choice but to drive to their destinations.[50] (See Table 3.3, Table A-1.)

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.

With 103 miles of track, Washington is home to the largest rail transit network built in the United States since the Second World War. From its inception in the 1960's, the Metrorail system was designed to extend outward from the city core along projected corridors of development, to concentrate growth in proximity to transit. Since then, stations have opened at intervals of 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."[51] The Washington area is indeed more hospitable than many to transit oriented development. 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 edge city of Tyson's Corner. Despite this, the realization of Washington's original transit goals has been substantial, with higher urban densities than would have otherwise been the case. Arlington County, Virginia is, in fact, one of the most densely populated jurisdictions in the United States, at 7,326 persons per square mile, more dense than Seattle or Pittsburgh. The Arlington County Department of Public Works estimates that the presence of Metro stations attracted nearly 3 billion dollars of real estate development between 1973 and 1990, and that the annual system-wide commercial activity attributable to Metro area development comes to half a billion dollars annually.

Arlington County's high density helps make the Orange Line -- the Rosslyn-Ballston corridor -- one of the most heavily used lines in the Metrorail system, accounting for 30% of Metrorail's ridership. Of Arlington's 11 stations, five 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, to an average weekday passenger volume of 20,634 by 1999. During the decade of the 1990's the Ballston station area underwent intensive development, with a combined total of 2,297,147 square feet of office and retail space, and 2,475 housing units, going up on 1,314,847 square feet of site area.[52] Urban densities such as these are most likely the reason why over half (64.5 percent) of Ballston's riders access the 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."[53] 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 have recently commissioned a study on the possibility of a network of pathways and pedestrian friendly improvements throughout the Orange Line corridor.[54]

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 the Metro Red Line, benefited from a strong real estate market in the 1980's, and zoning favorable to high-density development. Ridership in the county overall is up sixteen percent from 1995 to 2000, but it is not clear that the design of the 1980's era development is optimal for encouraging transit usage at the station.[55] As one assessment put it, Silver Spring "suffers from…lack of street life, and poor urban design."[56] 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 1980's, 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."[57] This turnaround results, in part, from closer involvement with the Silver Spring community in the planning process. "The developers spent a lot of time talking to the community, figuring out after the [1980's] failed attempts, what the community really wanted," reported a local planner. "To a very large extent [people] wanted to see the mix of the local things being addressed."[58] 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. Though 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's experience shows that transit oriented development 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, itself 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 greenhouse gas emissions (see emissions maps, Chapter 5), the success of transit oriented development in Washington stands as a prototype for future strategies of VMT reduction across the country.

Case Studies: Los Angeles and Santa Monica, California

No other city in the United States represents 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. Up until the 1920's and 1930's, 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 geographical 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 Los Angeles as a new type of city, one interlacing urban and rural spaces together to avoid the real and perceived ill effects of 19th century urban density, that laid the groundwork for a city that so easily accommodated the arrival of the automobile. Los Angeles and transit are not as antithetical as they might seem at first.[59]

By the mid 1920s, Los Angeles 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 a year.[60] L.A.'s conversion to automobile transportation, beginning in the 1920's and peaking with the construction of the interstate freeway system in the 1950's and 1960's, 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.[61]

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 fast-growing region.

Following the methodology for converting transit passenger miles to equivalent personal vehicle emissions, L.A.'s high ridership results in considerable CO_2 savings. (See Table 3.4, and Table A-1.)

Beginning in 1990, Los Angeles began a massive, controversial program of infrastructure investment, a thirty-year project to rebuild LA as the transit capital of North America. 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.[62] Currently, subcenters such as Long Beach and North Hollywood are linked by trains to downtown LA, with a link between Pasadena and downtown projected for 2003. Linkages to West and East L.A., however, together with a line into the San Fernando Valley, are in limbo. Despite difficulties in moving forward with the original 400-mile system, several developers have built, or plan to build, TOD's in close proximity 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 its residents use public transportation to get to work -- "nearly a third more than the countywide average for employed residents."[63] The developer of Pacific Court has also put up a TOD in Pasadena, anticipating the arrival of the Blue Line there in 2003; a transit village is also planned for the commuter rail, MetroLink station at Sylmar, in the San Fernando Valley.

Although the continued extension of the L.A. Metro Rail system faces major obstacles, 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 system provides ready accessibility for Santa Monica residents – "almost everyone in the city of Santa Monica lives within two blocks of a bus stop."[64] 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.[65] (See Table 3.5 for CO_2 savings from Santa Monica's ridership, 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.[66] Both trade publications and the 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 percent 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 with one of the key Blue Bus customer segments, the UCLA community, it has recently set up a pass-fare system, which lets UCLA students, faculty, and staff use their identification cards as debit cards at the fare box, thus reducing total boarding time.[67]

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 the buses come out of one yard, Santa Monica incurs comparatively lower administrative expenses than the L.A. MTA, which operates over a much larger area, and out of multiple bus yards. It has also paid close attention to rider preferences. After a steady decline in ridership into the early 1990's, 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.[68] 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.

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 it remains to be seen how the Blue Bus will perform as overall surface congestion continues to increase in West Los Angeles.

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 not inconceivable 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 suggests that the five county Los Angeles Consolidated Statistical Metropolitan Area is densifying – consuming land more efficiently than its northeastern peers, thereby raising its density as a function of population over aggregate urbanized land.[69] 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 densifying trend; in the long term, the potential is there for Los Angeles bus and rail systems to do likewise.

Greenhouse gas emissions from the U.S. transportation sector can be significantly lowered by reducing passenger vehicle miles traveled. One of the most immediate and practical ways of reducing this figure is by filling buses and trains with people who would otherwise take 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 advantage in terms of speed, convenience, and desirability, urban planning and design are required to support the development of cities defined by frequent use of transit for work trips, and the greater choice of mobility options for personal ones. As travel demand research has demonstrated, the key to an expanded range of mobility options is a higher density of land use that is coupled with a transit and pedestrian friendly environment. In highly transportation efficient locations, auto trips are lower because higher density makes it more economical to make trips on foot, by bicycle, as well as 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 subway system, people are willing to use transit. The case of Chattanooga's downtown revitalization project highlights the growing popularity of the mixed-use, high-density urban environment that is served by better transit, rather than automobiles. Indeed, the Chattanooga experience lends much weight to the argument that transit may be effectively used 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, greenfield development, but rather reinvestment in older, already dense areas, and densification of newer, more suburban ones. In both cases, a key ingredient is the provision of mass transit, pedestrian and bicycle-friendly built environments, and a desirable effect is the reduction of personal automobile greenhouse gas and smog-forming emissions.

CHAPTER 3 ENDNOTES

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[1] "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." Center for Neighborhood Technology, "Changing Direction: Transportation Choices for 2030," (2002), 4. Data drawn from 1990 LEM study.

[2] 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 hypothetically 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 + 12.7 cents per mile driven, was used to derive an annual cost per household.

[3] Boris Pushkarev and Jeffrey Zupan, <u>Public Transportation and Land Use Policy</u>, (Bloomington, Indiana: Bloomington University Press, 1977), 5.

[4] See Paul Barrett, <u>The Automobile and Urban Transit. The Formation of Public Policy in Chicago, 1900-1930</u>, (Philadelphia: Temple University Press, 1983).

[5] Ibid., 37.

[6] Ibid., 172-173.

[7] Ibid., 173.

[8] Ibid., 174.

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[9] Reid Ewing, Transportation and Land Use Innovations. When You Can't Pave Your Way Out of Congestion, (Chicago: Planners Press, 1997), 43.

[10] Apogee/Hagler Bailly. "The Effects of Urban Form on Travel and Emissions: A Review and Synthesis of the Literature," (1998).

[11] Hotzclaw, John, "Using Residential Patterns and Transit to Decrease Auto Dependence and Costs," (Natural Resources Defense Council, 1994).

[12] Holtzclaw, Clear, Dittmar, Goldstein and Haas, "Location Efficiency: Neighborhood and Socio-Economic Characteristics Determine Auto Ownership and Use – Studies in Chicago, Los Angeles, and San Francisco," *Transportation Planning and Technology*, vol. 25 (2002): 1-27.

[13] Holtzclaw, et al, "Location Efficiency," 2.

[14] Ibid., 25.

[15] Boris S. Pushkarev, Jeffrey M. Zupan, Urban Rail in America. An Exploration of Criteria for Fixed-Guideway Transit, (Bloomington, Indiana: Indiana University Press, 1982), 25. The regions compared were New York-northeastern New Jersey, Chicago, Philadelphia, San Francisco, Boston, and Cleveland.

[16] John Holtzclaw, "Explaining Urban Density And Transit Impacts on Auto Use," (San Francisco: Natural Resources Defense Council, January 1991); "Does a Mile in a Car Equal a Mile on A Train? Exploring Public Transit's Effectiveness in Reducing Driving," (Sierra Club, n.d.): [http://www.sierraclub.org/sprawl/articles/reducedriving.asp].

[17] Robert J. Shapiro, Kevin A. Hassett and Frank S. Arnold, "Conserving Energy and Preserving the Environment: The Role of Public Transportation," (APTA: July, 2002), 3. [http://www.apta.com/info/online/shapiro.pdf]

[18] Ibid., 9.

[19] Data in Table 2 taken from Center for Neighborhood Technology, "Changing Direction: Transportation Choices for 2030," (2002), 4.

[20] Surface Transportation Policy Project, and the Center for Neighborhood Technology, "Driven to Spend. A Transportation and Quality of Life Publication," (2000), 14.

[21] Values mapped in Figures 3.2 through 3.7 were created by dividing the VMT in quarter-section by an average miles per gallon, and multiplying this figure by the pounds of CO_2 produced by each gallon of gasoline consumed. The emissions represented here are for a typical Chicago household with 2.6 people and $43,000 in annual income. The geographic unit is a quarter-section, a half-mile by half-mile square.

[22] President's Council on Sustainable Development, <u>Sustainable Communities Task Force Report</u>, (Washington, D.C.: 1997), vi.

[23] American Public Transportation Association, "National Monthly Totals for Last 9 Years – 2nd Quarter 2001." [http://www.apta.com/stats/]

[24] For a list of other state programs addressing greenhouse gas emissions, see the Pew Center on Global Climate Change website: [http://www.pewclimate.org/states/all.cfm]

[25] New York State Energy Research and Development Authority, "New York State Energy Plan 2002," [http://www.nyserda.org/sep.html]

[26] 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. Lorraine Taylor, Assistant Sales Manager, WMATA, Personal Communication, October 29, 2001.

[27] See Michael Baker Corporation, The Potential of Public Transit as a Transportation Control Measure. Case Studies and Innovations, (1998).

[28] Cases drawn from Project for Public Spaces, Inc., Transit-Friendly Streets: Design and Traffic Management Strategies to Support Livable Communities, (Washington, D.C.: National Academy Press, 1998).

[29] The most recent general statement of this school of thought may be found in Duany, Andres, Elizabeth Plater-Zyberk, and Jeff Speck, Suburban Nation: The Rise of Sprawl and the Decline of the American Dream, (New York: North Point Press, 2000).

[30] Apogee/Hagler Bailly, "The Effects of Urban Form on Travel and Emissions," i.

[31] Robert Cervero, "Transit-based housing in California: evidence of ridership impacts," *Transport Policy*, vol. 1, no. 3 (June 1994): 181.

[32] Michael Bernick and Robert Cervero, Transit Villages in the 21st Century, (New York: McGraw Hill, 1997).

[33] "An Evaluation of the Relationship Between Transit and Urban Form," *Research Results Digest*, no. 7 (June 1995): 5.

[34] Donald C. Shoup, "The High Cost of Free Parking," *Journal of Planning Education and Research*, 17 (1997): 3-20; "The Trouble with Minimum Parking Requirements," *Transportation Research*, Part A, 33 (1999): 549-574.

[35] Cervero, Ridership Impacts of Transit-Focused Development in California, (Berkeley: University of California Transportation Center,1993), 129.

[36] "On balance, research consistently shows density to be one of the most important determinants of transit modal choice." "An Evaluation of the Relationship Between Transit and Urban Form," 25.

[37] Studies cited in Cervero, Ridership Impacts of Transit-Focused Development in California, Chapter 2.

[38] D. Loutzenheiser, "Pedestrian Access to Transit: A Model of Walk Trips and their Design and Urban Form Determinants around BART Stations," *Transportation Research Board Paper No. 971424*, (1997); Cervero, Ridership Impacts of Transit-Focused Development in California.

[39] This is the principal conclusion of Cervero in Ridership Impacts of Transit-Focused Development in California.

[40] S.B. Friedman & Company, Metra Rail Service and Residential Development Study. Summary of Findings, (Chicago: July 2000), 41.

[41] Apogee/Hagler Bailly, "The Effects of Urban Form on Travel and Emissions," 34-35.

[42] Dean Kubani, City of Santa Monica Environmental Programs Division, personal communication, October 31, 2001.

[43] Information on Chattanooga was synthesized from the following sources: Thomas Dugan, "Electric Buses in Operation: The Chattanooga Experience," *Transportation Research Record*, no. 1444, (1994): 3-9; Chattanooga Area Regional Transportation Authority,

(CARTA) "The Chattanooga Story"; "Chattanooga's Electric Bus Story" [http://www.carta-bus.org]; City of Chattanooga, "About Chattanooga" [http://www.chattanooga.gov].

[44] Following the methodology developed by APTA and outlined in Appendix A, carbon savings deriving from public transportation ridership in Chattanooga is, unlike the other cases studies in this chapter, 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.

[45] Aaron Frank, CARTA Planning Director, personal communication, September 25, 2001.

[46] Details on AVS corporate history are provided courtesy of Kirk Shore, Advanced Vehicle Systems, personal communication, October 22, 2001.

[47] Ibid.

[48] Curtis Moore, "Smart Growth and the Clean Air Act," *Northeast Midwest Economic Review* (March/April, 2001), 5.

[49] Garreau, J., Edge City: Life on the New Frontier, (New York: Doubleday, 1991).

[50] Washington Metropolitan Area Transit Authority figures indicate all entries through the fare box; ridership is estimated to be half this number. This and other figures pertaining to Arlington County Metrorail ridership, are taken from James Hamre, "ABC Development Forum," Arlington County Department of Public Works, (March 12, 2001). [http://www.co.arlington.va.us/dpw/planning/images/abc.pdf]; and James Hamre, personal communication, October 10, 2001.

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[51] Bernick and Cervero, Transit Villages, 216.

[52] Statistics in this paragraph are drawn from: "Development in the Metro Corridors, 1960-2000," Arlington County Department of Community Planning, Housing and Development.

[53] Seattle Strategic Planning Office, "Transit Oriented Development Case Studies. Washington, D.C. Metro," (1998). [http://www.cityofseattle.net/planning/transportation/SAP/Reports/TOD_Case_Studies.htm]], 6.

[54] See Arlington Greenway Core Walking Group, "Walk Arlington. Places for Walking in the Rosslyn-Ballston Corridor," (2001) [http://www.commuterpage.com/pdfdocs/WALKArlington. pdf].

[55] Silver Spring ridership figures are taken from Montgomery County Planning Board, "Local Area Transportation Review Congestion Standards by Policy Area." [http://www.mc-mncppc.org/planning/development/policy/issue3.pdf]

[56] Seattle Strategic Planning Office, "Transit Oriented Development. Washington, D.C."

[57] Ibid.

[58] Niemela, Kathryn, "Silver Spring renaissance: Phase 2 is entertainment," *Washington Business Journal*, (July 9, 1999). [http://washington.bcentral.com/washington/ stories/1999/07/12/focus6.html].

[59] Bernick and Cervero, "Los Angeles, 1910," in Transit Villages, 19-23.

[60] Ibid.

[61] American Public Transit Associatoin, "Largest Bus Agencies – Transit Ridership Report Second Quarter 2002." [http://www.apta.com/stats/]

[62] American Public Transit Association, "Heavy Rail Transit Ridership Report – Fourth Quarter 2000"; "Commuter Rail Transit Ridership Report – Fourth Quarter 2000." L.A.'s Metro Rail system led the way with a ridership increase of 60.56 percent, following the opening of a new line; MetroLink, Southern California's commuter rail system, was among the fastest growing, with a ridership increase of 11.5 percent. [http://www.apta.com/stats/]

[63] Seattle Strategic Planning Office, "Transit Oriented Development Case Studies. Los Angeles Metropolitan Transit Authority," (1998). [http://www.cityofseattle.net/planning/ transportation/ SAP/Reports/ TOD_Case_Studies.htm].

[64] Transit Cooperative Research Program, The Role of Transit in Creating Livable Metropolitan Communities, vol. 22, (National Academy Press, 1997), 86.

[65] David T. Hartgen, "Comparative Performance of Major U.S. Transit Systems, 1998." (University of North Carolina at Charlotte: Department of Geography, Transportation Studies, 1998).

[66] Ibid.

[67] Paul Casey, Senior Transit Programs Analyst, Santa Monica Municipal Bus Lines, personal communication, October 12, 2001. Details on the operation of the Blue Bus in this and the following two paragraphs are provided courtesy of Mr. Casey.

[68] Dean Kubani, personal communication, October 31, 2001.

[69] "[A]lthough it is still auto-oriented, Los Angeles is "densifying" dramatically and is developing quite densely even at the fringe. As a result, the overall statistical profile of the two metropolitan areas [Los Angeles and New York City] looks quite similar at a gross

scale." Fulton, William, Rolf Pendall, Mai Nguyen, and Alicia Harrison, "Who Sprawls the Most? How Growth Patterns Differ Across the U.S," (The Brookings Institute, 1991), 14. The authors arrive at their density ratio by considering population over *urbanized land* -- as defined by the National Resource Inventory of land uses -- rather than population density in an *urban area* determined by a threshold number of inhabitants established by the census.

CHAPTER FOUR

TRANSIT TECHNOLOGIES FOR REDUCING GREENHOUSE GASES

As shown in the preceding chapter's case studies of transit-oriented development, increasing ridership means taking account of a wide variety of factors in the transportation planning process. A similar logic applies to greenhouse gas reduction: the most effective strategy will likely be one that is comprehensive, and approaches the problem from multiple avenues. Improved transit service and transit-friendly urban planning, examined in the previous chapter, are two such avenues; conversion of transit fleets to cleaner and more efficient technologies represent still another. As with transit-oriented development, no single factor will, by itself, significantly reduce automobile usage at a regional or local level. Emissions reducing technology, it should be stressed at the outset, will only have a significant impact if it is bundled together with policies that make transit competitive with the automobile.

This chapter examines the 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 greenhouse gas 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 today considered alternative 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 1930's.[1] Nor is natural gas a new technology, but one that has only recently – like the others – come into wider use as a pollution abatement measure. None of these fuels were 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 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 considerable expense. At the same time, its 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 (see below, "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 less 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.[2] Since virtually no North American transit agencies base procurement decisions solely on the basis of greenhouse gas emissions, the challenge is to identify technologies that reduce emissions of regulated pollutants, and at the same time generate significantly fewer greenhouse gases. 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 transit vehicles (AFV's) in the United States.[3] As clean air mandates have toughened over the 1990's, many transit agencies have run demonstration projects involving commercially available alternative fuels, as well as 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

AFV's is also growing among a handful 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 will also be substantially expanding its fleet of 10 hybrid-electric buses, with standing orders for an additional 325, and funding for 50 more.[4] New York's investment in AFV bus technology is part of a comprehensive pollution reduction strategy, involving the use of newer, low-sulfur fuels in all diesel buses, the advanced retirement of older diesel buses, and the purchase of newer 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 newer CNG buses, making it the largest AFV transit fleet in the nation.[5]

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 smaller ones. Though the CO_2 contribution of transit buses is slightly more than 1 percent (6.3 million metric tonnes) of the total CO_2 produced by the transportation sector, this share could increase if transit is able to significantly reduce automobile VMT by capturing single occupant drivers.[6] (See Emissions Projection Model, Appendix B) Transit and other fleets are also 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.[7] This means taking into account the GHG's generated at every stage of a fuel's production, transportation, and end-use, or *life* 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."[8] 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 determining, from existing sources, the quantities of GHG emissions from alternate fuels.

While Table 4.1 suggests that buses powered by ethanol and natural gas 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: much depends on the engine technology being used.[9] On the basis of year 2000 vehicle emissions testing by the Northeast Advanced Vehicle Consortium, compressed natural gas (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.[10] Thus, while transit bus fleets, under regulatory or public pressure, are converting diesel-powered vehicles to a combination of cleaner burning 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.[11] Though 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 is not the only alternative, however. Any of the conventional or alternative fuels become much more efficient (and significantly reduce GHG emissions) when used in a hybrid electric engine, though 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 higher 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 percent 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 1/10 of a gallon per mile, a considerable savings in fuel and costs when considered over the lifetime of a vehicle. As an ancillary strategy for certain niche applications, such as promoting service in downtown business areas and airport shuttles, battery powered electric buses are more fuel-efficient than diesel and less polluting. 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 their 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 FOR WHICH MARKETS HAVE EMERGED

Compressed Natural Gas

Based on the recent procurement activity and successful demonstration programs of the nation's two largest transit operators, CNG (followed by hybrid-electric technology) is emerging as the most likely successor to the conventional diesel engine. In the early 1990's, liquefied petroleum gas (propane, or LPG) was the fuel of choice for AFV's; since then, the market preference has decisively switched to natural gas.[12] 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 compressed natural gas. 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.[13]

The emissions profile of natural gas, however, is mixed. While CNG comes out 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 higher GHG emissions. (See Appendix C) As the Northeast Advanced Vehicle Consortium (NAVC) reports in their emissions testing of AFV's, "CNG buses consume more fuel for the same output [as diesel]…canceling out nearly half of the CO_2 benefit."[14] CNG buses also suffer a "weight penalty" due to the larger and heavier fuel tanks required to maintain natural gas in a pressurized state, and in volumes sufficient 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 diesel buses, which emit virtually none of the gas. 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.[15] As NAVC reports, "even though the CNG buses emit less CO_2, the impact from the released methane creates a larger GHG impact."[16]

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 greenhouse gas emissions. While trends indicate a clear shift to natural gas by major transit agencies, those involved in alternative fuel programs at the nation's two largest transit agencies view CNG as a step in the direction of still different technologies. "Natural gas will have outlasted its usefulness in the near future," says New York City Transit's Dana Lowell; "CNG is ultimately a transitional strategy," echoes LA's John Drayton.[17] 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. The other likely competitor with CNG, both agencies anticipate, 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, though inherent limitations on battery technology make the electric bus an unlikely successor to the diesel engine for the majority of heavy-duty, urban applications. Where conditions are appropriate, however, electric, battery powered buses have proven themselves to be economical, reliable, and very popular with the public. Electric buses emit nothing 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 1/3 less CO_2 to be emitted than would an equivalent diesel fleet.[18] 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.[19]

For geographical conditions of low relief and a temperate climate, with short distance routes and frequent-stop duty cycles, electric buses are an optimal technology.[20] 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."[21] The first to adopt battery electric technology, Santa Barbara put its first two electric buses in operation in January and May 1991. The two prototypes, which went into operation on routes formerly served by diesel buses, then captured 75 percent of Santa Barbara's 300 percent ridership increase for 1991.[22]

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 well as cars. The greater efficiency of hybrids comes from regenerative braking. In real-world operation, regenerative braking is estimated to recuperate 25 percent 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 Assistant Chief Maintenance Officer Dana Lowell, "are the only technology that reduces regulated and non-regulated emissions at the same time." Judging New York's ten-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 commercially viable.[23] 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."[24] "The number of [hybrid-electric] vehicles," the report concludes, "is expected to quadruple in the U.S. alone during the next couple of years. In another several years, the worldwide hybrid bus fleet may well reach in to the thousands or even tens of thousands."[25]

In the meantime, 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 such groups as the Southern Coalition for Advanced Transportation, the Northeast Advanced Vehicle

Consortium, 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."[26] 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 15-30% more efficient than a conventional diesel vehicle…Hybrids are going to make a big impact over the next decade."[27]

Biodiesel

A transit bus, running on 100% biodiesel, would reduce CO_2 emissions per mile by nearly 72% across the life cycle of the fuel, in comparison with diesel. A transit bus running on the more commonly used mixture of 20 percent biodiesel and 80 percent diesel, called "B20," would reduce CO_2 emissions per mile by about 14 percent in comparison with diesel.[28] (See Table 4.1) For both the pure form of biodiesel, and the 20 percent mix, the greatest percentage of biodiesel's reduction of greenhouse gas 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 the other fuels. (See Table C-1)

Biodiesel is an organically produced fuel, made either from the oil of vegetables such as soybeans, or recycled cooking greases.[29] 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."[30] Biodiesel has the added advantage of reducing methane emissions, together with all regulated pollutants except oxides of nitrogen (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.[31] Using B20 requires no modification of conventional diesel burning engines; higher blends of biodiesel require replacement of rubber with synthetic engine seals. Aside from the seals, biodiesel actually increases engine lubricity, and helps to clean out the fuel system.

Biodiesel, like the alcohol fuels, is currently at a competitive disadvantage with diesel due to its relatively high cost of production. Pure biodiesel, or "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 two to three years, with municipal school districts and the U.S. military two of the biggest consumers.[32] 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."[33] 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. 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. 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."[34] 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 1990's, and cooking-oil/animal fat-based biodiesel in 2000. It is currently nearing the end of a 2001 trial running 150 buses on B20.[35] 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 GHG emissions per mile from ethanol is 17 percent lower than that of petroleum diesel.[36] (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 LA's John Drayton. "We were paying more for the fuel and getting less mileage."[37] After a period of demonstration programs ending in the late 1990's, 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, several 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.[38]

A number of cities ran demonstration programs with ethanol or methanol buses in the 1990's: 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 1990's, when New York ran the program, according to Lowell, methanol engines were prohibitively expensive, hard to get a hold of, and too difficult to maintain.[39] 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.[40] At the time of Peoria's program (1992-1998), ethanol cost 18¢ more than diesel on a per mile basis. At the time of Los Angeles' program (1989-1997), ethanol cost 35¢ more. 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.[41] Despite ethanol's advantage for reducing GHG emissions compared to conventional fuels, mechanical difficulties and high costs make it an unlikely resource in the effort to reduce vehicular emissions.

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 will be 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 1990's, 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, which led to immediate savings; Houston also expected future savings from reduced brake and tire wear and better mileage.[42]

Between 1992 and 1999, Los Angeles MTA operated 6 much less expensive, 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 put it, that "everything works better." "We are 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.[43]

ALTERNATIVE TRANSIT FUELS AND TECHNOLOGIES STILL IN DEVELOPMENT

Energy Storage Systems

Most of the research and development 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.[44] 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 improving rail technology is "improving, but without revolutionary breakthroughs," according the David Phelps, a Senior Project Manager at the American Public Transportation Association.[45]

Given that 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 comprise 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 are not beyond the performance range of conventional technology. For a system of rail cars, however, the technical 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 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. [46]

Regenerative braking, according to APTA's David Phelps, is "the most exciting area in rail technology advance currently."[47] 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 Pueblo, Colorado, in 2004. Looking further ahead, UT Austin expects the "commercialization phase of flywheel technology to be about 8 to 10 years away" for high-speed applications.[48] More relevant for urban transit is "wayside energy storage" in which a flywheel or ultracapacitor is located, not on the locomotive, by 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.[49] With the technology as it currently stands, recuperated energy in an electrified system is useless unless there is a second train accelerating at just the moment 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 research and development in hydrogen increased substantially over the 1990's, 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 the auto consortium, together with the California Air Resources Board, and the California Fuel Cell Partnership, hydrogen transit buses were put into trial operation in three different locations in the 1990's: Chicago, Vancouver, and Georgetown University. 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."[50] 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 you have a compressor on the bus, you just adjust the lines to use hydrogen as well as natural gas…it's one change."[51]

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 a photovoltaic array, a truly zero-GHG method of making hydrogen. SunLine expects that, in less sunny parts of the U.S., hydrogen will most likely be made from methane, in a process called natural gas reforming. Though 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 the carbon in CH_4 as CO_2. However, the extremely high efficiency of a hydrogen fuel cell 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 continually changing as companies compete in a limited market and products undergo a rapid evolution. Appendix C contains a methodology for comparing estimated costs, based upon the current costs of alternative fuels. As they evolve, 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 are first calculated using data in Table C-1. All of the technologies are compared with the current standard – petroleum diesel. Fuel costs are based on the current costs as reported by government research institutions (see sources in 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 AFV buses. As the costs of these buses become lower over time, low fuel prices could make them more attractive to transit agencies.

Scenario Two assumes the same costs of fuels as in Scenario One, 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. 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 compare with bus costs in the near future

Scenario Three also assumes the same costs of fuels as in Scenario One, and that the investments of Scenario Two are feasible. It also 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 Two. By itself, CNG fuel substitution appears to offer relatively modest emissions reductions. In combination with a fuel cell, however, considerable emissions reductions and cost savings can both 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 higher public visibility, which has often been accompanied by higher ridership. Experience has shown that hybrid-electric and battery powered buses are especially popular with the public, and this may go far towards 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 greenhouse gas 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 percent. In and of itself, introduction of low-emissions technology into this sector will not significantly contribute to a reduction of greenhouse gas emissions. If such technology can help transit agencies to reduce costs and improve customer satisfaction, however, 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 describes the potential for transit vehicles to reduce greenhouse gas 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 in 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 U.S. Energy Information Administration's "Greenhouse Gases Regulated Emissions and Energy Use in Transportation" (GREET) transportation emissions 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 the 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 a relative increases in transit ridership experienced over the past five years.

Potential reductions in GHG emissions are projected from 2000 to 2020 and 2040. The model estimates the reductions of GHG emissions, in metric tons of carbon dioxide equivalent per year, that would be achieved over a 20- and 40-year period by converting the technologies used by transit and rail fleets to emit cleaner by products and lower GHG emissions.

The graph in Figure 4.1 shows four possible scenarios for future greenhouse gas emissions from U.S. transit— buses, light rail, trolleybus, heavy rail, and commuter rail. In the graph, the blue line represents hypothetical national emissions if transit were to continue to increase vehicle miles traveled at the rate it has for the past few years – from 1.5% for buses up to 6% for light rail and trolleybus. As Figure 4.1 shows, under this "continued growth" scenario, transit's GHG emissions will continue to rise at a steady rate, having over twice as much of an impact over the next 40 years.

Alternative technologies that increase the efficiency of transit vehicles can help mitigate the impact of this growth in emissions. The green line in Figure 4.1 shows the impact of alternative technologies on transit emissions at today's rate of growth in VMT. The model thus estimates that the adoption of alternative technologies and fuels by transit agencies could prevent a total of 30 Teragrams (Tg) of Carbon equivalent (CE) emissions between now and 2020 and 170 Tg CE by 2040. In other words, if transit agencies across the county were to begin adopting alternative technologies, they could reduce their emissions by 23% between now and 2040 as compared to if they continued using the current transit technologies.

The yellow line in Figure 4.1 represents a model of transit emissions with high growth in vehicle miles traveled by transit. Under this high-growth scenario – assumed as double today's growth rate – the importance of alternative technologies will be even greater. The red line in the graph depicts the expected emissions from transit with high growth in transit VMT and the adoption of alternative technologies for transit vehicles. 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.

CHAPTER 4 ENDNOTES

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[1] U.S. Department of Energy, Energy Information Administration, "Developments in U.S. Alternative Fuel Markets," Mary Joyce, (2000). [http://www.eia.doe.gov/cneaf/alternate/issues_trend/altfuelsmarkets.html]

[2] "Near-term technologies are those already or almost available in the marketplace. Long-term technologies are those that require further research and development." M. Q. Wang, Greet 1.5 – Transportation Fuel-Cycle Model. Volume 1: Methodology, Development, Use, and Results, (Argonne National Laboratory, Transportation Technology R&D Center, 1999), 93.

[3] "Developments in U.S. Alternative Fuel Markets," op. cit.

[4] Dana Lowell, Assistant Chief Maintenance Officer, Bus Department, New York City Transit, personal communication, March 21, 2002; *Making Score. Newsmagazine for Employees, Retirees and Families of the Department of Buses*, vol. 1, no. 2 (Fall 2000). [http://www.mta.nyc.ny.us/nyct/bus/score.pdf]

[5] Los Angeles County Metropolitan Transit Authority, "MTA's State of the Bus System Report," (March, 2001). [http://www.mta.net/ press/ pressroom/ images/ SBR.pdf]

[6] Sources for this calculation are statistical information taken from APTA, and the Energy Information Administration.

[7] See Michael Wang, "Impacts on Greenhouse Gas Emissions of Using Alternative Transportation Fuels with Advanced Vehicle Technologies," Global Climate Change and Transportation: Coming to Terms, (Washington, D.C.: Eno Transportation Foundation, 2002), 75.

[8] Energy Information Administration, "Alternatives to Traditional Transportation Fuels 1999." [http://www.eia.doe.gov/]

[9] See Argonne's GREET model at the URL:

[http://www.transportation.anl.gov/ttrdc/greet/index.html].

[10] M. J. Bradley & Associates, and Northeast Advanced Vehicle Consortium, Hybrid-Electric Drive Heavy-Duty Vehicle Testing Project. Final Emissions Testing Report, (Boston: 2000), section 6.

[11] "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." Wang, "Impacts on Greenhouse Gas Emissions of Using Alternative Transportation Fuels with Advanced Vehicle Technologies," 75.

[12] EIA, "Developments in U.S. Alternative Fuel Markets," 1.

[13] When sold as a fuel, favorable tax treatment makes natural gas economical compared to other fuels. The capital costs of converting a transit *facility* to natural gas, 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 diesel to CNG bus total $50,000 (compared to $20,000 for an ethanol bus.) Capital costs for converting a diesel transit facility (including buses) to CNG total $3.75 million 1994 dollars for a 50-bus facility (compared to $0.10 million for ethanol.) Source: Motta, Robert, Norton, Paul, et al., "Alternative Fuel Transit Buses. Final Results from the National Renewable Energy Laboratory (NREL) Vehicle Evaluation Program," (Golden, Colorado: NREL, 1996), 18, 20.

[14] M. J. Bradley, op. cit., 38. Findings in this report are based on tests done by UWVA's Transportable Emission Testing Laboratories.

[15] Energy Information Administration, "Alternatives to Traditional Transportation Fuels 1999."

[16] M. J. Bradley, op. cit. NAVC found in testing that, on a certain duty cycle, a CNG bus "actually had higher total GHG emissions" than a comparable diesel bus.

[17] Dana Lowell, personal communication, November 27, 2001; John Drayton, Manager, Los Angeles MTA Alternative Fuels Program, personal communication, December 4.

[18] Zail Coffman, Analyst, Santa Barbara Electric Transportation Institute, personal communication, December 5, 2001.

[19] Zail Coffman, personal communication.

[20] Paul Griffith, and Gary Gleason, "Six Years of Battery-Electric Bus Operation at the Santa Barbara Metropolitan Transit District," in vol. 1, Symposium Proceedings. The 13th International Electric Vehicle Symposium, (1996).

[21] Ibid., 1.

[22] Gary Gleason, Santa Barbara Electric Transit Institute (SBETI), "Seven Years of Battery-Electric Bus Operations." [http://www.sbeti.com/seven_ years2.html]

[23] Dana Lowell, personal communication.

[24] M.J. Bradley & Associates, Hybrid-Electric Transit Buses: Status, Issues, and Benefits. TCRP Report 59. (Washington, D.C.: National Academy Press, 2000), iii.

[25] Ibid., 48.

[26] Kevin Shannon, Southern Coalition for Advanced Transportation, personal communication, December 10, 2001.

[27] Zail Coffman, personal communication.

[28] U.S. Department of Energy, National Renewable Energy Laboratory, "Life Cycle Inventory of Biodiesel and Petroleum Diesel for Use in an Urban Bus. Final Report," (1998). [http://ott.doe.gov.biofuels/lifecycle_pdf.html]

[29] U.S. Department of Energy, National Renewable Energy Laboratory, “Biodiesel – The Clean, Green Fuel for Diesel Engines.” [http://www.nrel.gov/docs/fy00osti/28315.pdf]

[30] Ibid., v.

[31] Shaine Tyson, Renewable Diesel Project Manager, National Renewable Energy Laboratory, personal communication, December 12, 2001.

[32] Shaine Tyson, personal communication.

[33] U.S. Department of Energy, Office of Transportation Technologies, Alternative Fuels Data Center, “Biodiesel General Information.”[http://www.afdc.doe.gov/ altfuel/ bio_general.html] At the time of this writing, federal subsidies for biodiesel do exist, though their continuance is uncertain. Production of biodiesel is subsidized by the USDA as part of its Bioenergy Program. (Federal Register, November 13, 2000. 7 CFR Part 1424) 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 of 2000. The two 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 of 2002, biodiesel producers who use animal fats and oils produced in the US to make biodiesel are also eligible to participate in the program.

[34] Brent D. Yacobucci, “Alternative Transportation Fuels and Vehicles: Energy, Environment, and Development Issues,” Congressional Research Service Report, December 5, 2000.

[35] Sallie Hilvers, Director Public Affairs, Cincinnati Metro, personal communication, January 2, 2002.

[36] For methanol, life cycle emissions are higher than those of petroleum diesel. See Energy Information Administration, “Alternatives to Traditional Transportation,” (1999).

[37] John Drayton, personal communication.

[38] Motta, Robert, "Alternative Fuel Transit Buses."

[39] Dana Lowell, personal communication.

[40] Dana Lowell, personal communication.

[41] John Drayton, personal communication; George Stout, Greater Peoria Mass Transit, personal communication, December 5, 2001.

[42] John Franks, Senior Director of Bus Maintenance, Houston Metro, personal communication, January 2, 2002.

[43] John Drayton, personal communication.

[44] Research 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. Austin's CEM is also looking at supplementing the turbine with flywheel technology to increase energy efficiency. Richard Hayes, University of Texas Austin Center for Electromechanics, personal communication, December 12, 2001.

[45] David Phelps, Senior Project Manager, Rail Programs, American Public Transportation Association, personal communication, December 14, 2001.

[46] "Urenco Power Technologies – Flywheel Energy Storage System." [http:// theflywheel.com /flycylinder /regeneration.htm] Flywheels and supercapacitors are also being tested for use in transit buses.

[47] David Phelps, personal communication.

[48] Richard Hayes, personal communication.

[49] The Urenco Flywheel. "Urenco Power Technologies – Flywheel Energy Storage System."

[50] Richard Cromwell, SunLine Transit Agency, personal communication, January 23, 2002. See also: U.S. Department of Energy, National Renewable Energy Laboratory, "Hydrogen Fuel Cell Bus Evaluation," Leslie Eudy and Richard Parish, (2001). [http://www.eren.doe.gov/hydrogen/pdfs/30535bo.pdf]

[51] Richard Cromwell, personal communication.

CHAPTER 5

TOOLS FOR REDUCING GREENHOUSE GAS EMISSIONS. A WEB-BASED STRATEGY

INTRODUCTION

The substance of *Combating Global Warming Through Sustainable Surface Transportation* will be posted on a website, www.travelmatters.org, designed in conjunction with the published report. The site content is tailored to both individuals seeking information on global warming, and to transit and planning professionals who are poised to make significant decisions about the climate change impact of local and regional transportation systems. These individuals may take advantage of a trio of resources provided by the website – two interactive emissions calculators, eight on-line emissions maps, and accessible educational content -- to emphasize the close relationship between efficient transit systems and mitigated GHG emissions. The published report provides detailed references to technical and research literature on climate change science, land use and transportation planning, and alternative transit technologies. The website contains nearly identical content, and is supplemented with a glossary, and links to related websites.

The two calculators together are the centerpiece of the website. 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 the use of 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 their emissions totals. Together, the calculators serve to inform individuals, transit professionals, urban planners and public interest groups about greenhouse gas emissions resulting from transportation, and identify ways to for them to reduce their respective emissions. As the issue of climate change gains prominence on the policy horizon, TravelMatters will be available to the above audiences as a resource for the enrichment of public discourse on the moderation of greenhouse gas emissions from the transportation sector.

While the emissions calculators offer a quantitative description of greenhouse gas emissions, TravelMatters hosts several colored maps of the geographic distribution of emissions in urban and rural areas. These maps offer striking visual support for the argument in Chapter 3, concerning the ways in which land use and transportation infrastructure directly affect greenhouse gases emissions. Text from the body of the published report is also presented as educational content for users interested in learning about the science of climate change, the definition and role of GHGs, the various factors that influence the demand for automobile and transit trips, and alternative transit technologies and fuels.

CHANGING BEHAVIOR

One of the goals of the project has been 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. The TCRP H-21 oversight panel has from the beginning provided many fruitful suggestions concerning user interface with 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 also 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 at the annual American Metropolitan Planning Organizations conference in March, 2002. Here we presented the basic idea of the project: that surface transportation systems can be designed to cost-effectively reduce GHG emissions. CNT 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 carbon dioxide regulation in mind. At the same time, CNT was advised to link GHGs with emissions that are currently regulated by the Environmental Protection Agency, and therefore of more immediate concern to transit agencies and municipal planning organizations (MPOs). In response to this last suggestion, the next generation of TravelMatters (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 the American Public Transportation Association (APTA), the Federal Transit Administration (FTA) and the Energy Information Administration (EIA). Functionality of the site was tested internally at the Center for Neighborhood Technology. In each instance, feedback from these tests has been crucial to the development of the final TravelMatters product.

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 Federal Transit Administration's National Transit Database for 2000. In the next version of TravelMatters, CNT anticipates the transit vehicle database being 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 carbon dioxide 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 about the greenhouse gases generated in the course of their daily travel, and encourage them to shift to modes generating comparatively fewer emissions. The individual calculator profiles every 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 likewise unique in its comprehensiveness. The TravelMatters database contains information on the vehicle type, fuel consumption, annual ridership, and vehicle 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 greenhouse gas 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 governmental officials. Planning agencies can use it to establish a baseline of emissions from which to set emissions reductions targets or simulate emissions from varying procurement scenarios. Establishing a baseline emissions level will also position transit systems to take advantage of emerging carbon dioxide trading markets, and any future regulatory trading and reduction programs. As with the individual calculator, the transit or planning professional will be encouraged to set up an account and track emissions over time, recording 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" (2002) (See Appendix A, Table A-1). Greenhouse gas emissions, unlike regulated pollutants such as particulate matter and oxides of nitrogen, are strictly a function of the amount of fuel combusted. In fact, emissions of carbon dioxide are much easier to estimate than emissions of criteria pollutants because carbon dioxide 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 carbon dioxide at a particular rate, and so the fuel efficiency of a vehicle -- the amount of fuel consumed per distance traveled, determines the GHG efficiency of transit vehicles. While 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. By the end of 2003, the calculator will be programmed to compute criteria pollutants.

The calculator can determine the annual GHG emissions of almost any U.S. transit agency, broken down 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. Users may determine the emissions benefits deriving from the substitution of 10 hybrid electric for 10 petroleum diesel buses, for example.

PROJECTION MODEL

The emissions projection model estimates different rates of emissions growth over a 20- and 40-year period, in metric tons of carbon dioxide 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 introduces the model, and provides a summary of its projections; a complete methodological report accompanies the spreadsheet, and is included in Appendix B.

TRANSPORTATION EMISSIONS MAPS

The national county and household emissions maps, introduced in Chapter 3, are intended to communicate the relationship between land use patterns and greenhouse gas 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 the very local factors behind 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 older, central 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 in fact 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 internet version, TravelMatters. 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 non-profit and government sites, partnerships with the American Public Transportation Association, the Federal Transit Administration, and the Environmental Protection Administration, among others, have been established to publicize the website via electronic newsletters and newspapers.

CHAPTER 6

CONCLUSIONS AND SUGGESTED RESEARCH

REPORT SUMMARY

Despite uncertainties regarding the measurement and forecasting of global climate change, scientists are in general agreement that human activities are generating greenhouse gas emissions in quantities sufficient to alter current climatic patterns. Since emissions from transportation in the United States accounts for over one-eighth of global, and one-third of national carbon dioxide emissions, and is rising at a rate (1.8 percent) higher than that of any other economic sector, we argue that reducing emissions from the transportation sector is one of the most urgent actions needed to stabilize U.S. emissions. Three strategies for accomplishing this have been outlined in the report: modifying the factors of travel demand to better support transit and shift auto trips to transit, and increase existing transit service and performance, adopting low- or no-emissions transit fuels and technologies, and disseminating this information to the general public.

On the aggregate level, most carbon dioxide emissions from U.S. transportation originate in high-density urban areas. While urban areas generate more emissions, mapping analysis found that *per household* emissions for those living in dense urban areas are well below that of households in undeveloped or rural areas. In other words, while cities generate more CO_2 collectively, suburban and rural residents generate more emissions individually. This is directly linked to land use patterns and the minimal transportation options in low-density regions. Cities often offer amenities, jobs, and other activities in close proximity to each other, thereby reducing auto-dependency, increasing the convenience of transit, and thus reducing the vehicle miles traveled per household. Hence, in larger, denser American cities, greenhouse gas emissions are maintained at a level lower than they would be otherwise; these environments are also optimal for effective transit service. This finding, that in some places efficient land use and transit are *already* reducing greenhouse gas emissions relative to a per capita analysis, underpins the strategies pursued in this report.

In Chapters Three and Four, we explored three strategies for lowering transportation sector emissions: encouraging transit use and reforming land-use practices; implementing energy-efficient transit technology to accommodate increased transit use; and developing tools to educate individuals, planners, and transit professionals 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. Overall, effective transit agencies pay considerable attention to frequency of service, accessibility, vehicle cleanliness, and customer service.

Though the reform of land use is potentially the most effective means of reducing GHG emissions, practical barriers to rapid change in land-use practices make it wise to also investigate other, shorter-term strategies. As discussed in Chapter Four, alternative fuels and technologies that reduce greenhouse gas emissions while also increasing fuel efficiency, making them attractive to cost-conscious transit agencies. An alternative technology program for reducing greenhouse gases emitted from transit vehicles can be coupled with dramatic gains in fuel efficiency, lower operating costs, and improved compliance with federal air quality regulations. While our review is restricted to transit vehicle fuel and technology, we believe that our findings may be applicable to future markets in alternative automobile design as well. Although hybrid technology is on the market and in use, several of the largest transit agencies have been converting fleets to compressed natural gas in order to improve emissions of smog-related pollutants. Data on the emissions-reduction potential of compressed natural gas is mixed, some work suggesting that CNG does not reduce greenhouse gas emissions as aggressively as 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 greenhouse gas reduction is understandable, since CO_2 and other greenhouse gas emissions are not regulated and have only recently emerged as an area of concern to the public. Fortunately, hybrid-electric technology has the potential to reduce emissions of criteria pollutants and greenhouse gases, 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 that it promotes, will demonstrate realistic procurement options available to transit agencies working to reduce greenhouse gas 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 100% biodiesel can reduce carbon dioxide emissions over 80% compared to emissions from conventional diesel buses. Hybrid-electric engines fueled with 20% biodiesel -- that by itself, reduces emissions over 14% -- are probably the most cost-effective alternative currently available. In some cities, smaller battery-powered electric buses have also been used very effectively for certain specialized applications, such as Chattanooga's pedestrian-friendly downtown region. Structural changes to the 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 percent of a gallon of fuel per mile.

The hydrogen fuel cell, using steam-reformed hydrogen, is a very efficient propulsion technology, though 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 their adoption.

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 specifically addressed the potential for greater use of public transportation and reformed land-use practices to reduce CO_2 emissions. While 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 vehicle miles traveled (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 by only 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 us to view the overall emissions profiles of regions across the country, but we are able to conduct micro-level analyses for Chicago, San Francisco, and Los Angeles only. While the regional modeling done for these three urban regions could act as a template for formulating models in other regions, it should be possible to tabulate this data in any non-attainment region where there is a smog check type program that tracks VMT at the household level and links it to specific addresses.

A precursor to the national and regional maps, The Location Efficient 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 impact 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 walkable neighborhoods and conversely, how pedestrian-oriented built 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 – such as reducing congestion and improving air quality. Research should consider the factors that motivate people to walk instead of drive, and the social and environmental conditions contributing to these decisions.

The LEM model emphasizes the need for researching strategies that effectively reduce the demand for travel. In other words, the 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 could also 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, and 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 transit calculator. While 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 does not currently measure ridership changes directly impacted by land-use developments. We 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, including the effects of additional constructed sidewalks, increased population density, and retail development; the results, such as the socio-economic and environmental impacts of such research may first need to be measured.

Further, the quantification capacity of the calculator could be enhanced so that it provides additional emissions computations for transit vehicles and automobiles. Specifically, we would concentrate on calculating currently regulated criteria pollutants such as oxides of nitrogen and sulfur dioxide emissions. Since many regions are required to report on 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 this is done, 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 larger strategies like mode split which affect emissions from the industry. Freight transportation should not be ignored as a contributor to climate change and local air quality and health problems.

Emissions Trading and Tracking

As communities begin to strategize about how they can reduce greenhouse gas emissions in addition to regulated pollutants, they will consider the financial incentives for implementing programs. There is currently an emissions trading market emerging for carbon dioxide, though 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 country emissions estimates given in this report attempt to provide a baseline for transportation emissions. Governments involved in greenhouse gas programs through the International Council of Local Environmental Initiatives are conducting surveys of greenhouse gas 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 of them in terms of emissions tracking.

Transit agencies using electricity to power their vehicles (as in 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. Renewable energy represents a small share of electric power in most parts of the United States; the exception being the West Coast that derives a considerable portion of its power from hydroelectric dams. 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 for renewable power, and the socio-economic, political and environmental results of these programs.

CONCLUSION

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 (warming) climate change 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, leading 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. Enough is now known, despite the uncertainties of measurement and forecasting, to warrant prudent actions to moderate or reduce emissions of greenhouse gases. Much of what can be done in this regard will have the multiple effect of improving air quality, in addition to improving human physical health and increasing fuel efficiency. While improving personal and transit vehicle fuel efficiency is one tactic in any future greenhouse gas reduction strategy, another equally important tactic involves expanding the overall share of transit in U.S. transportation.

APPENDIX A

Methodology for Estimating Greenhouse Gas Reductions Resulting from Use of Public Transportation[1,2]

Actual calculations made according to the method outlined below are presented in Table A-1.

1. Gather data on the number of passenger miles and vehicle miles traveled 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 n 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 MKWH in Table 16b. Add the results to determine the total pollution produced by the locality's public transit.[2]
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/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).

APPENDIX A ENDNOTES

[1] Methodology extracted from R. Shapiro, K. Hassett and F. Arnold "Conserving Energy and Preserving the Environment: The Role of Public Transportation" (American Public Transportation Association, 2002).

[2] 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 MkWH** 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 **MkWH/Vehicle Mile instead of BTU/Vehicle Mile**, or Table 16b's "Emissions by Electricity-powered Rail Systems" would be converted to **Grams/BTU** <u>**instead of**</u> **Grams/MkWH** to make the multipliers in *Step 3* consistent.
4. Our assumption is that since Table 10 gives "Energy Efficiency" in terms of BTU/Vehicle mile, we can make a simple conversion of the figure given in Table 16b (618,499,055) from Grams/MkWh to Grams/BTU for CO2, giving us <u>**0.18 Grams of CO2/BTU**</u> as the multiplier in *Step 3* for electric-rail.
5. We made the following conversion:
6. 1BTU = 2.93 x 10 -4 kWH
7. 1 kWH = 1/2.93 x 10 -4 = 10000/2.93 = 3412 BTU/kWH

8. 1MkWH = 3.412 x 10 9 BTU

9. .618 x 10 9 grams of CO2 per mkwh [Table 16b]/3.412 x 10 9 grams per MkWH

= .618/3.41 = **0.18 Grams of CO2/BTU**

APPENDIX B

METHODOLOGY FOR TRANSIT EMISSIONS PROJECTION MODEL[1]

MODEL INPUTS

The model is based on vehicle miles traveled 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 American Public Transportation Association 2001 Fact Book, which reports data collected from transit agencies by the Federal Transit Administration of the Department of Transportation. Information about alternative fuel vehicles in use was only available for buses, and was not very in-depth. Data on the quantity of alternative fuel consumed was not accessible either, except in a general category of "Other." We also collected the number of unlinked passenger trips, and the number of active vehicles, although this data did not weigh in significantly in the actual projection. All of the above data was collected for years 1990-2000, 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 vehicle miles traveled was estimated based on the average rate of growth from 1990-2000. 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 other data that went into the model were the emissions produced per unit of fuel. 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 elsewhere in this report, we calculated that burning a gallon of diesel results in the emission of 27.824 pounds of carbon equivalents, and a gallon of gasoline results in the emission of 24.116 pounds of carbon equivalents. The Energy Information Administration estimates that the national average emissions of carbon equivalents from a kilo Watt hour (kWh) of electricity results in the emission of 1.384 pounds of carbon equivalents. 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 Typical VMT Growth and Technology, High VMT Growth with Typical Technology, Typical VMT Growth with Advanced Technology, and 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 we are projecting the amount of emissions reduced with the use of Advanced Technologies, we subtract the advanced technology total emissions for 2020 and 2040 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 five years of projections for bus emissions:

Typical VMT Growth and Technology, Buses

lbs CO2/gal or kWh		27.824	1.3484	3.39		
Percent of 2000 fleet VMT		93.0%	0.009%	6.991%		
	Annual Growth 1.5%	gal/mile 0.30	kWh/Mile 5.42	gal/mile 0.42		Tg/lb 4.54E-10
Year	VMT millions	Diesel Consumption gallons	Electricity Consumption kwh	CNG Consumption (Includes other fuels) gal	Carbon Equivalent Emissions lbs CE	Carbon Equivalent 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

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

2001 VMT = 2000 VMT * (1+1.5%growth)
2001 fuel consumption = 2001 VMT * 93% diesel fleet * 0.30 gallons per mile traveled
2001 electricity consumption = 2001 VMT * .009% electric fleet * 5.42 kWh per mile travelled
2001 pounds of carbon equilvalents = (gallons of diesel * 27.824 lbs CE/gal) + (kWh electricity * 1.384 lbs CE/kWh)
2001 Mt (Mega tons) or Tg (Tera gram) = 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 2000-2020 and 2000-2040.

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 greenhouse gas emissions. For this variable it is necessary to make assumptions about the potential use of fuels and technologies up to 40 years in the future. Because the task is to compare a best case scenario against a no change scenario, the assumptions we have made about the availability, and particularly the market penetration, of fuels and technologies are optimistic, assuming that transit agencies are quick to implement low-emissions vehicles.

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

Bus

Our 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 15-30%). In addition we project the increased adoption of electric buses to 1.5% of the national VMT in 2002-2004, 5% in 2005-2016, and 20% in 2017-2040. We project the adoption of biodiesel, in the form of B20, starting in 2003 and continuing on at 10% of the national VMT through 2040. We project the increased use of CNG buses to 7.5% of the national VMT in 2001-2003 and 10% in 2004-2016, at which time we project CNG will be completely replaced by other alternatives. Finally, we project a 5% adoption rate for hydrogen fuel cells--where the hydrogen is generated by electrolysis—in 2010-2016, increasing to 20% in 2017-2027 and increasing again to 40% in

2028-2040. The adoption of these alternative technologies displaces fossil fuel diesel as a percentage of VMT.

Rail

Emissions reducing technologies for rail are still in 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 and hydroelectric. For this model we assume 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 there not being 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 around 8 years or 2010. An additional five 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, we are assuming 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 up to a 25% decrease in net emissions beginning in 2015.

APPENDIX B ENDNOTES

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[1] Data for the projection model was drawn from the following sources: A.D. Vyas, 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, (1997): [http://www.transportation.anl.gov/ttrdc/publications/papers/evstudy.html];
Interlaboratory Working Group on Energy-Efficient and Clean-Energy Technologies, U.S. Department of Energy, "Scenarios for a Clean Energy Future," (2000): [http://www.ornl.gov/ORNL/Energy_Eff/CEF.htm];
U.S. Energy Information Administration, "Annual Energy Outlook 2002 with Projections to 2020," (2001): [http://www.eia.doe.gov/oiaf/aeo/], "The Transportation Sector Model of the National Energy Modeling System. Model Documentation Report," (2001) : [http://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 or others who are comparing fuels is the variety of sources of information and disparities among them. Most important to understanding the discussion below are two definitions, and a recognition of reality:

- 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 reality 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.)

Table C-1 contains information from the GREET Model that is necessary to compare emissions from eight fuels. Seven of the fuels are being used in buses and the eighth, gasoline, is familiar as a fuel for passenger cars. (The section below, "Results from GREET and other data sources," 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, 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.)

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 passenger car in the GREET Model. Assumptions are made in the model about the efficiencies of future technologies, in BTUs per mile, that will be achievable. These assumptions are shown in Table C-3. Energy Consumption – Automobile Operation in Table C-2 is also shown in Table C-1 as the Energy Consumption – Vehicle Operation as calculated by the GREET model. In order to obtain rough estimates of the energy consumption for buses from this data, the energy consumption for passenger car operation of each fuel are converted to Energy Consumption vs. Petroleum Diesel by dividing the BTU/mile for each fuel by the BTU/mile for petroleum diesel. Given that this ratio may vary under different driving cycles for the same bus, this assumption leads to only a first approximation. It is also assumed that the diesel bus used for the comparison has an average energy use of 60,000 BTU/mile, or approximately two miles per gallon.

The BTU/mile is then multiplied by the lb.CO_2/BTU for each fuel, to obtain the GHG emissions per mile for each fuel. The two bottom lines of Table C-1 provide the information needed to consider costs of emission reduction, which are shown in Table C-2.

COMPARISON OF EMISSION REDUCTION COSTS FOR BUSES

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 first section of Table C-2 shows the GHG emission reductions that can be achieved for each fuel as a substitute for conventional diesel fuel. The emissions are in pounds of CO_2 equivalent GHG emissions per mile so that the relative efficiencies of the fuels are accounted for. The second section uses current examples of fuel costs and vehicle costs to estimate the costs of substituting each fuel. The costs are given in dollars per mile. The third section yields costs per ton of GHG reduction for several scenarios. Table C-2, again, should not be used to make decisions in the absence of other considerations – the costs are too roughly estimated for that – but it can be the basis for ongoing refinement of cost estimations.

The following paragraphs explain the components of Table C-2. Sources of data are included in the notes at the bottom of the table. Petroleum diesel is the standard fuel in buses at this time, and is used as the standard for comparison in Table C-2. The Emission Coefficient for each fuel in Table C-2 is the same that was identified in Table C-1.

The following portion of Table C-2 presents 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.

The next portion of Table C-2 adds 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. The Cost of Bus less Cost of Diesel Bus – Capital amounts shown for hydrogen are one estimate of future costs at a point when fuel cell buses are under 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. The further assumptions of no penalty due to maintenance costs or fuel infrastructure costs would, again, only apply to a mature, full-scale system.

The Costs of Emission Reduction were calculated for each fuel, using the assumptions discussed above, and are shown as Scenario One. 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 with biodiesel, B20 and ethanol would be very expensive. The low cost of CNG make it a less costly option, but relatively low emission reductions would be achieved. However, for B20 and Hydrogen the initial assumptions yield significant savings as well as GHG reductions. This is not the case under current conditions, and it may be some time before fuel cells are cost-competitive, so another way of looking at substitution of alternate fuels is shown.

Scenario Two assumes the same costs of fuels as in Scenario One, 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. 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 compare with bus costs in the near future

Scenario Three also assumes the same costs of fuels as in Scenario One, and that the investments of Scenario Two are feasible. It also 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 Two.

These scenarios only begin to show how the information in the tables can be used to explore the costs and benefits of alternate 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.

RESULTS FROM GREET AND OTHER DATA SOURCES

GREET is used as the basis for Tables C-1 and C-3 because all of the fuels of interest are factored in the model. Other sources of data, none of which contain more than three of the eight fuels, are shown lower in the table and discussed below. The calculations can all be made using the GREET website. Long-term technologies must be used for each of the fuels since the long-term technologies assume engine efficiencies that are higher than those of near-term technologies.

Seven different sources of data were used to create Table C-1. 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-1 were assembled from these sources, each of which is referenced in the notes at the bottom of the table.

Properties

The Fuels selected for inclusion in Table C-3 are those that are, according to our research, now being considered by agencies for use in transit vehicles. Methanol and propane are not on the list because they are no longer being considered as practical fuels.

The Chemical Formulas and Molecular Weights are included in the table 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 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 from GREET

As mentioned above, GREET 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.

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)

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 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 Table C-1 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*.

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 log-term technologies. The dedicated spark-ignition engine and fuel cell are considered long-term technologies. The Calculated MPG in Table C-1 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 doesn't 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 of Table C-1 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-1 for which data is included are motor gasoline, distillate fuel (diesel), and natural gas.

Another EIA source consulted 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-1 shows the values in Moles/VMT for these fuels in the row labeled Weighted Quantity of GHG. The next row 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

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-1.

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-1 requires determining that one bhp-h equals 2,544 BTU. The resulting net CO_2 emissions 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/mmBTU
- 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 statements are 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:

• 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-1. The conversion requires a lower heating value for hydrogen, which in Table C-1 is shown as 51,532 BTU/pound. The conversion results in an Emission Coefficient of 230.7 lb CO_2/mmBTU for hydrogen.

The final row in Table C-1 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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Figure 2.1 Atmospheric Carbon Dioxide at Mauna Loa Observatory, Hawaii
[TCRP H-21 Center for Neighborhood Technology]
Source: Scripps Institution of Oceanography, UCSD

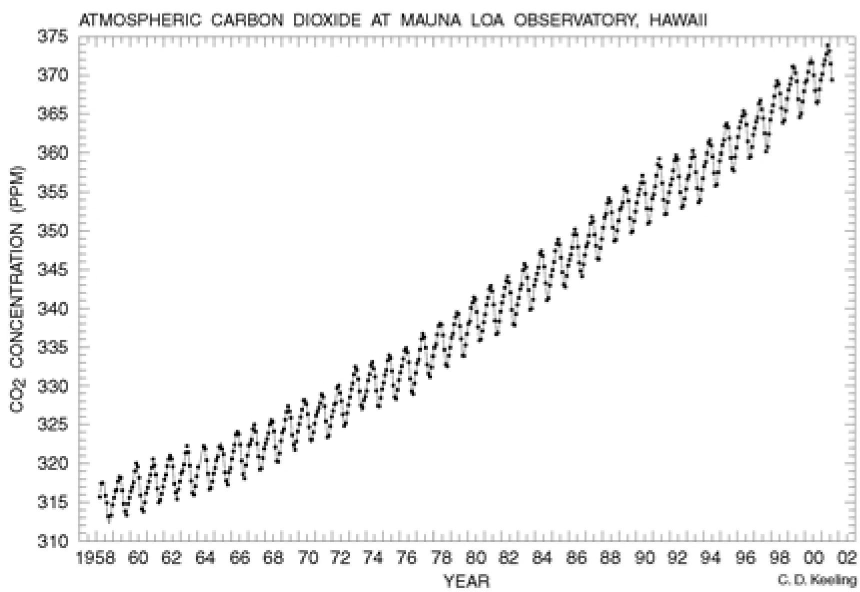


Figure 2.2 U.S. GHG Emissions by Economic Sector
[TCRP H-21 Center for Neighborhood Technology]
Source: U.S. Department of Energy, Emissions of Greenhouse Gases in the U.S. 2000, "Carbon Dioxide."

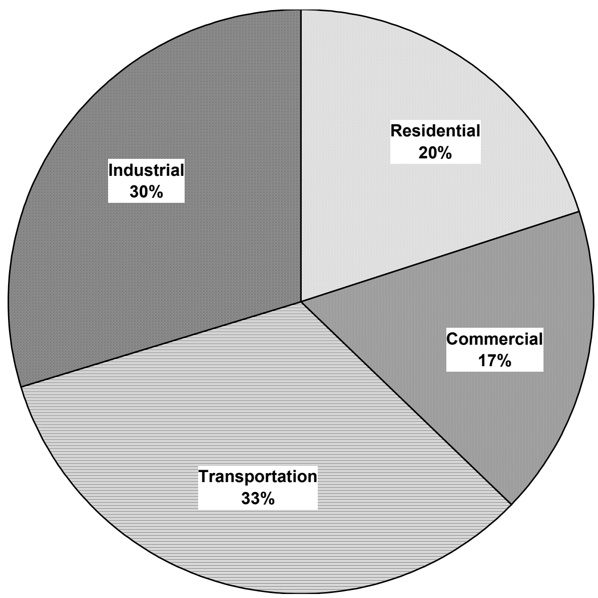


Table 3.1 Comparative Emissions from Public Transit and From Replacement Use of Private Vehicles
(Metric Tons of CO_2 1999)
[TCRP H-21 Center for Neighborhood Technology]

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]

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

Figure 3.2
CO_2 Emissions per Square Mile
Chicago
[TCRP H-21 Center for Neighborhood Technology]

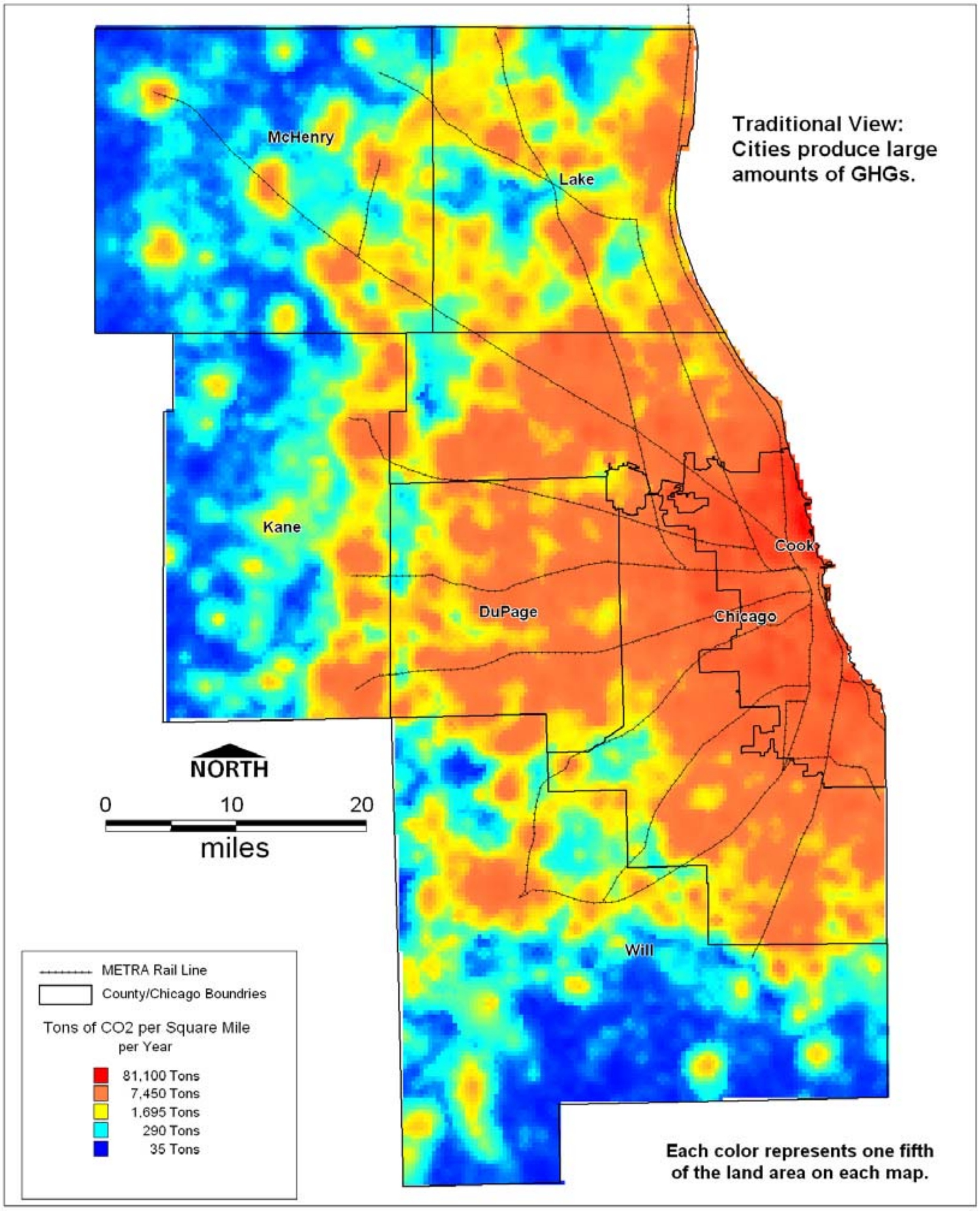


Figure 3.3
Household CO_2 Emissions
Chicago
[TCRP H-21 Center for Neighborhood Technology]

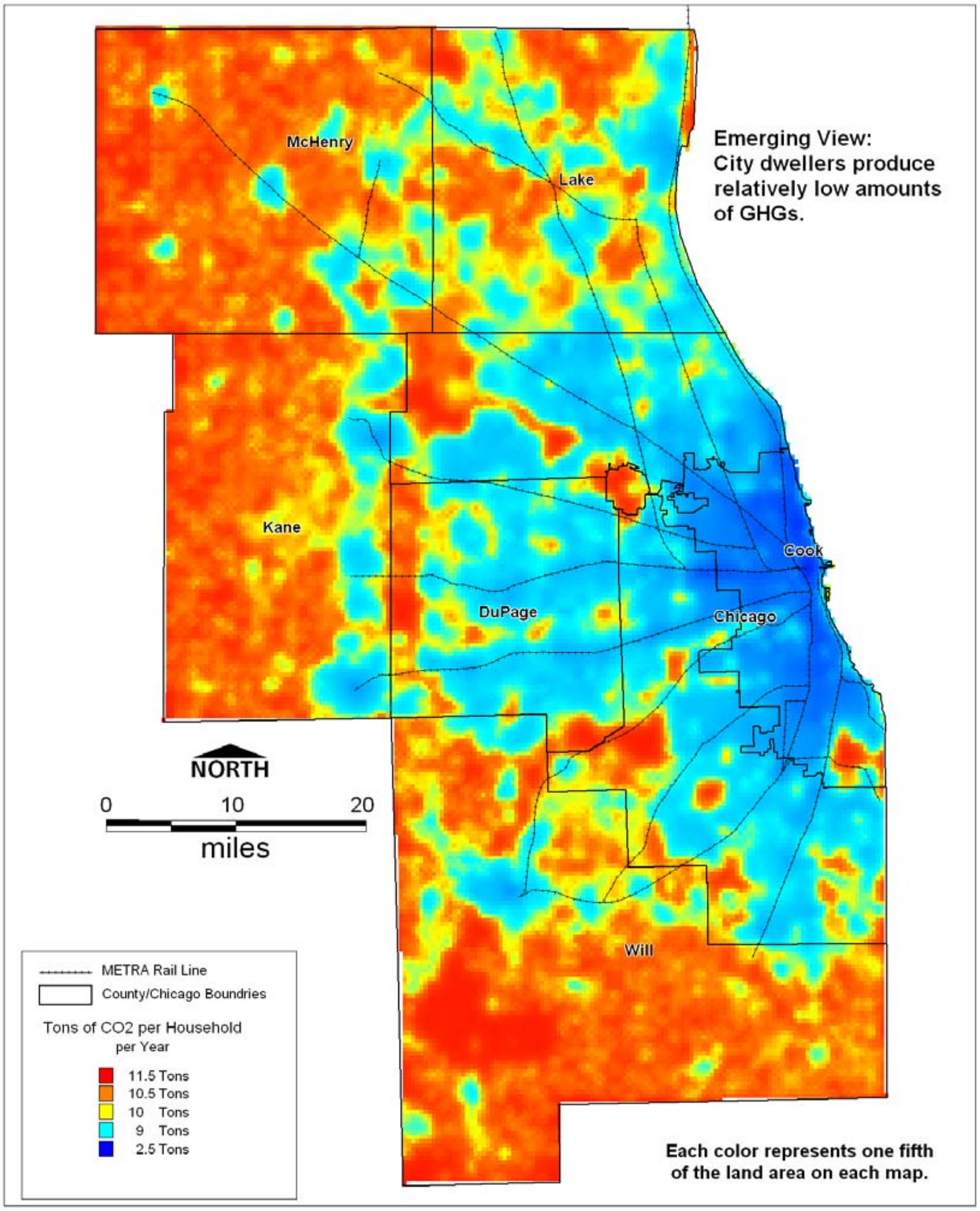


Figure 3.4
CO_2 Emissions Per Square Mile
Los Angeles
[TCRP H-21 Center for Neighborhood Technology]

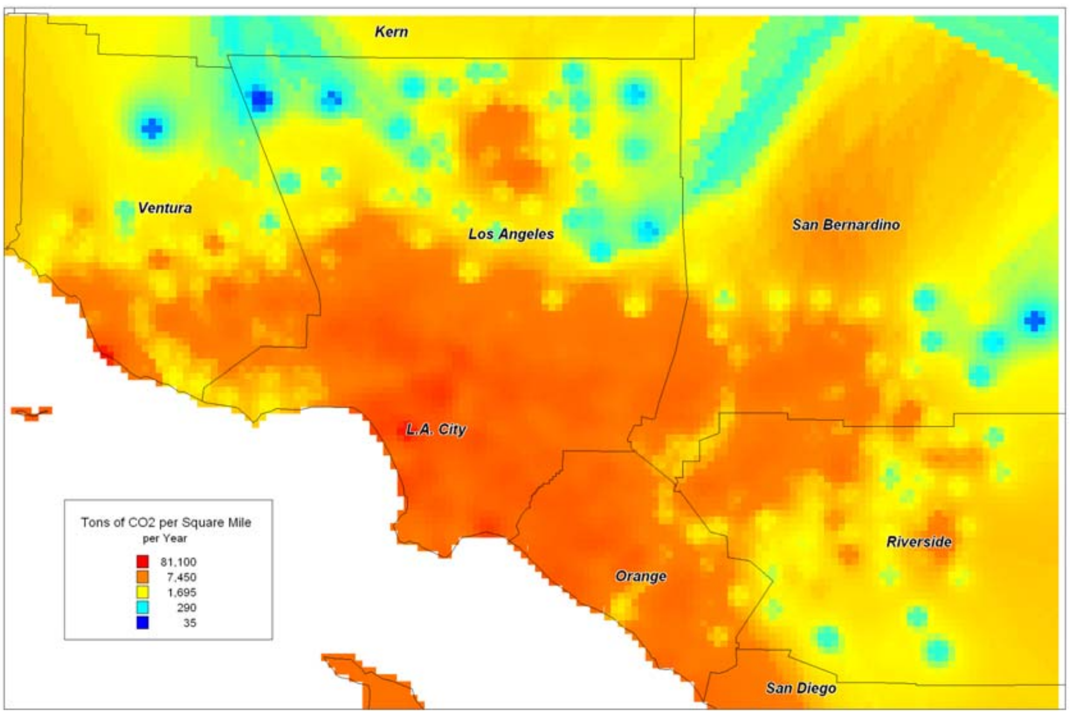


Figure 3.5
Household CO_2 Emissions
Los Angeles
[TCRP H-21 Center for Neighborhood Technology]

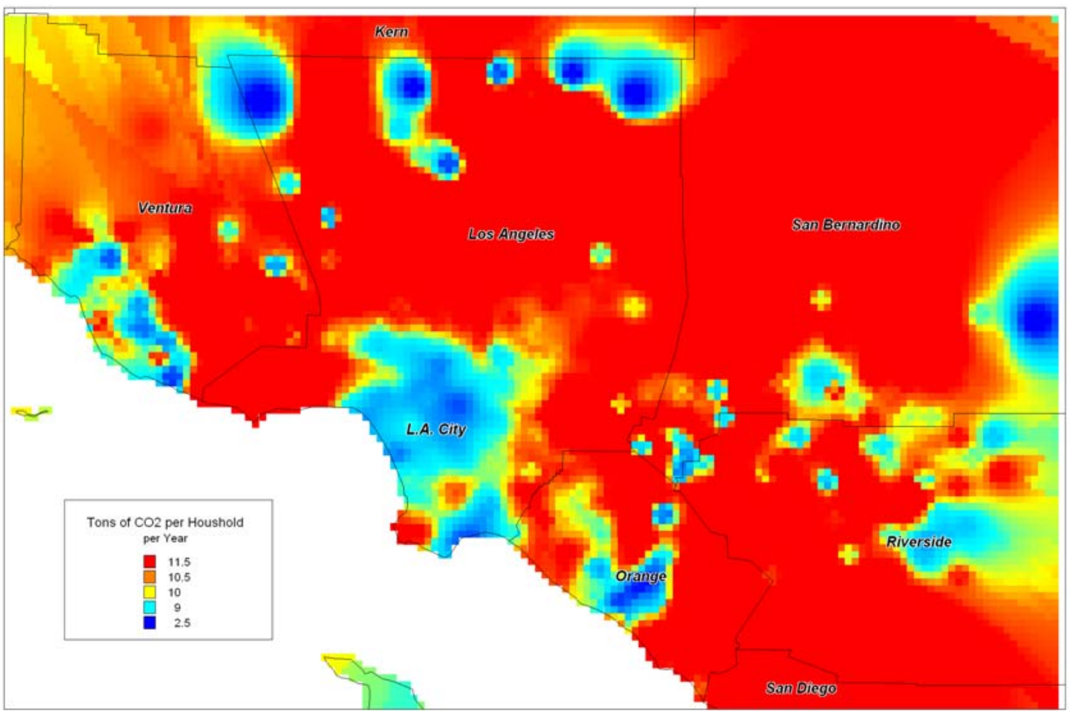
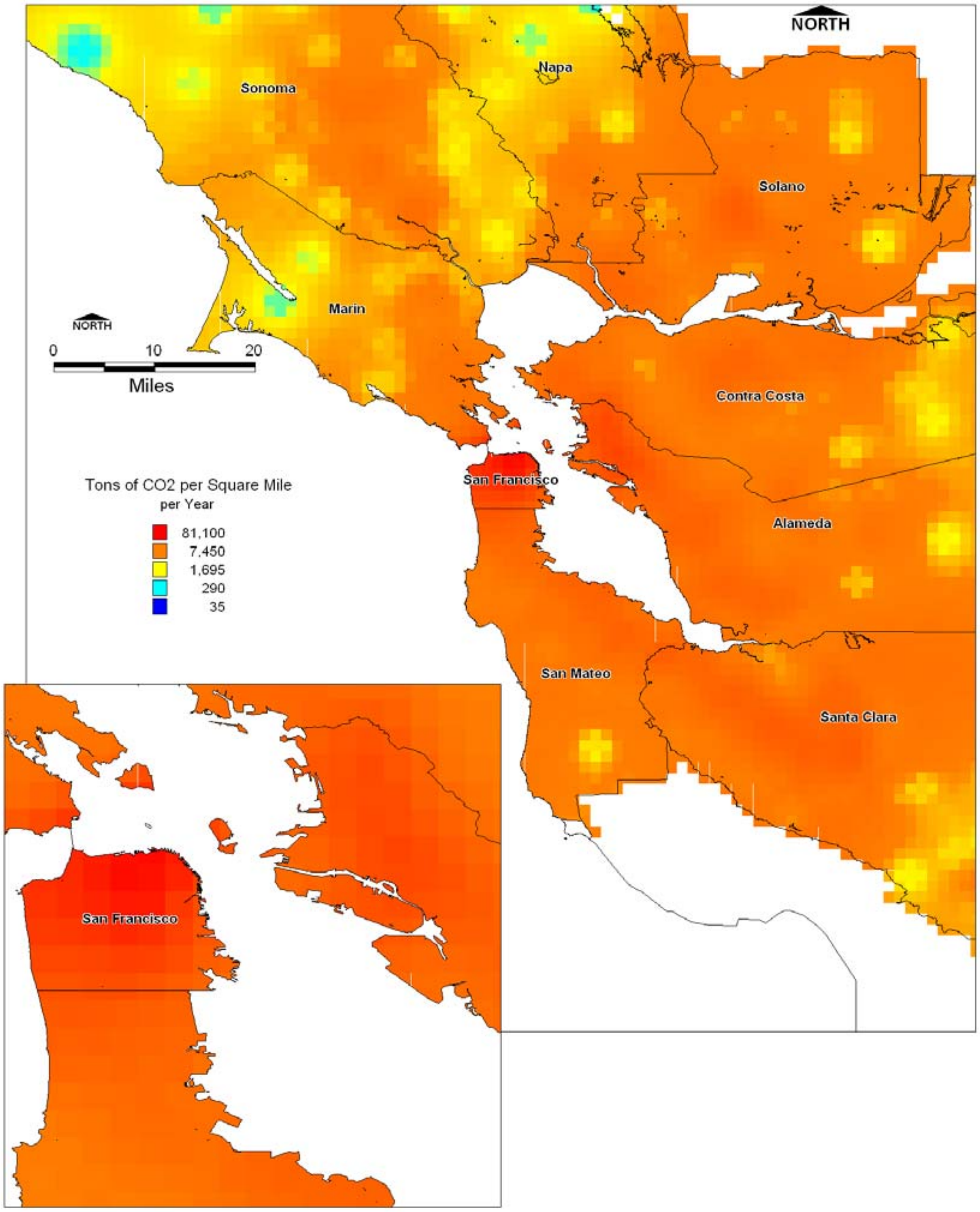
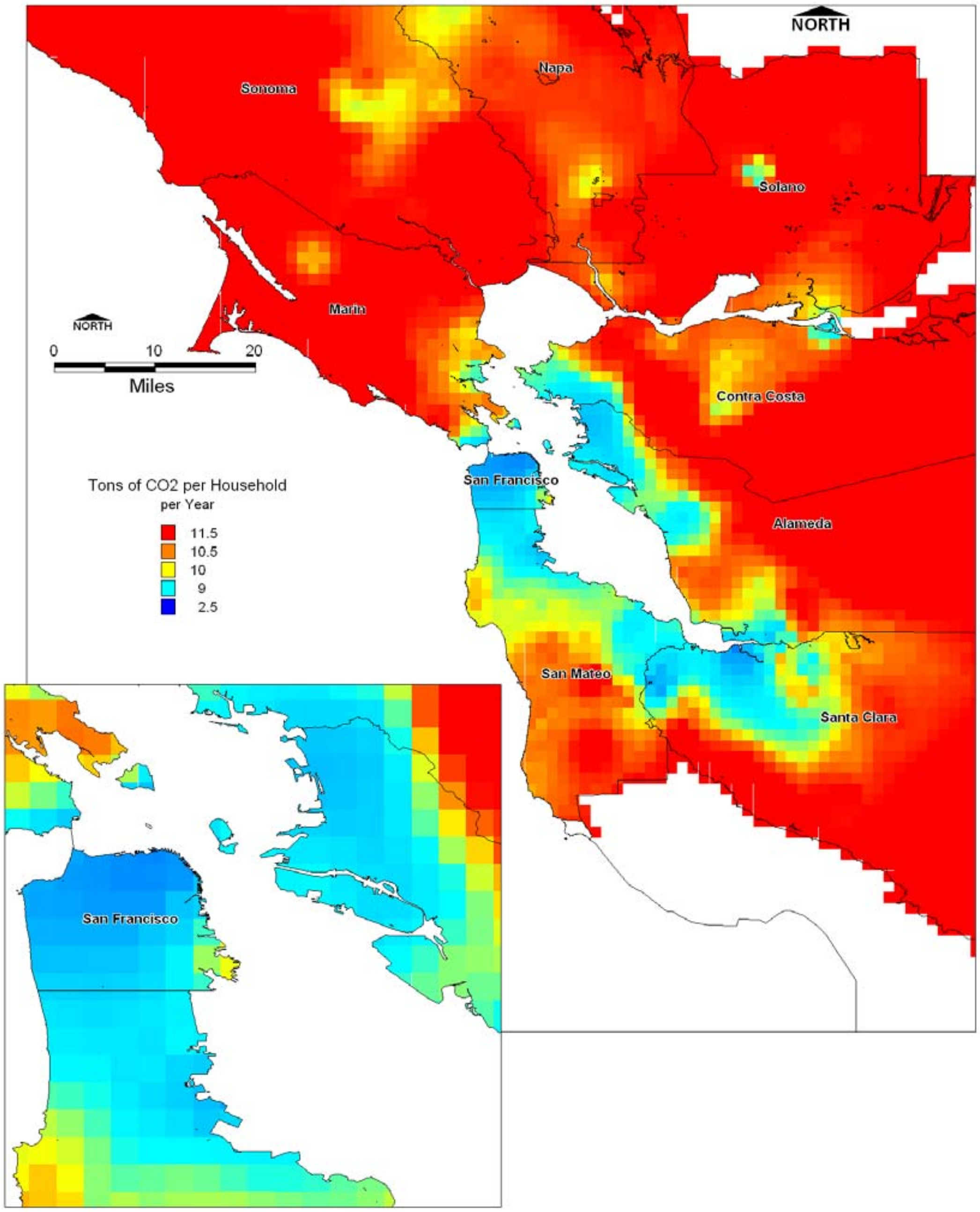


Figure 3.6
CO_2 Emissions Per Square Mile
San Francisco
[TCRP H-21 Center for Neighborhood Technology]



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

Figure 3.7
Household CO_2 Emissions
San Francisco
[TCRP H-21 Center for Neighborhood Technology]



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

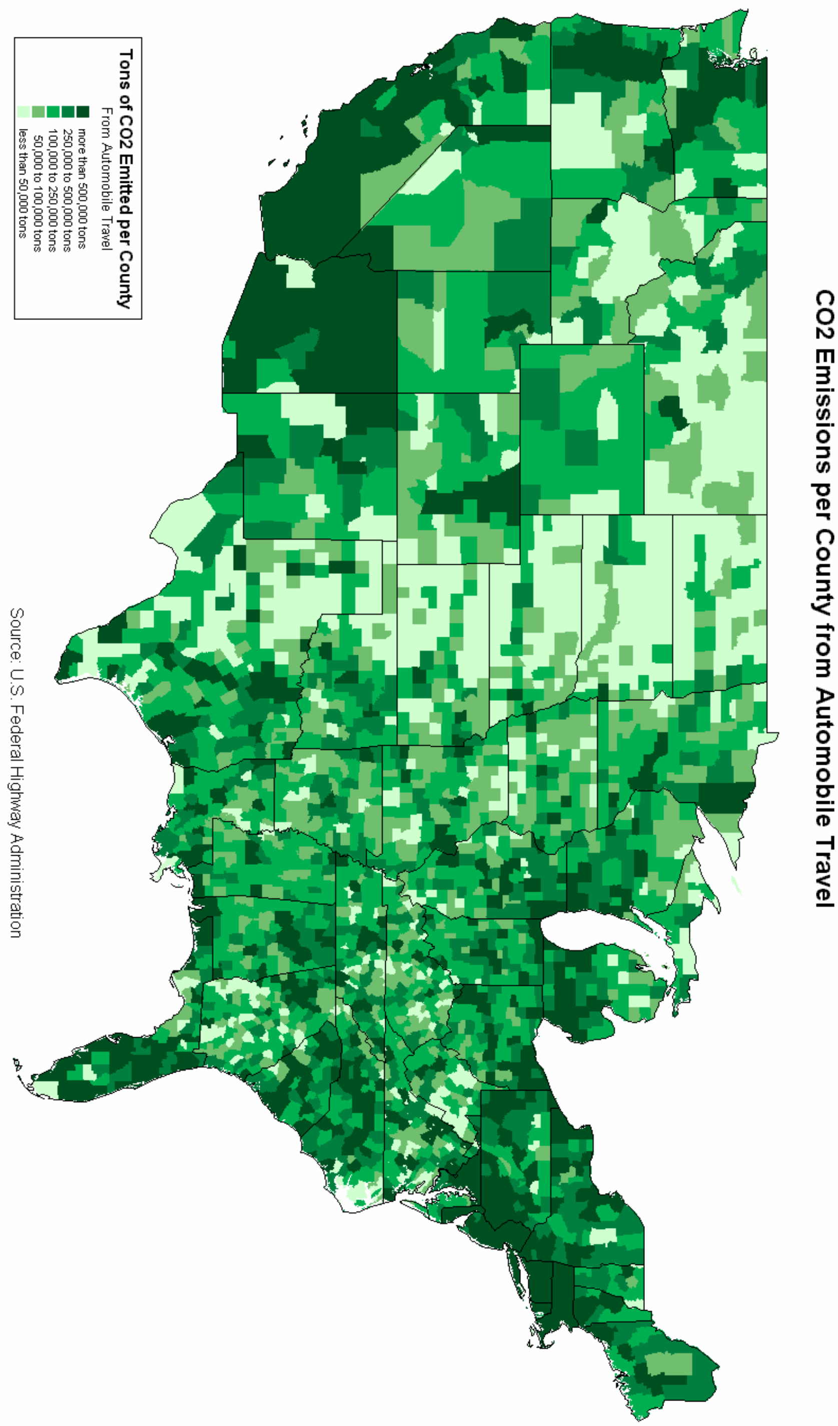


Figure 3.8 National CO_2 Emissions Per County
[TCRP H-21 Center for Neighborhood Technology]

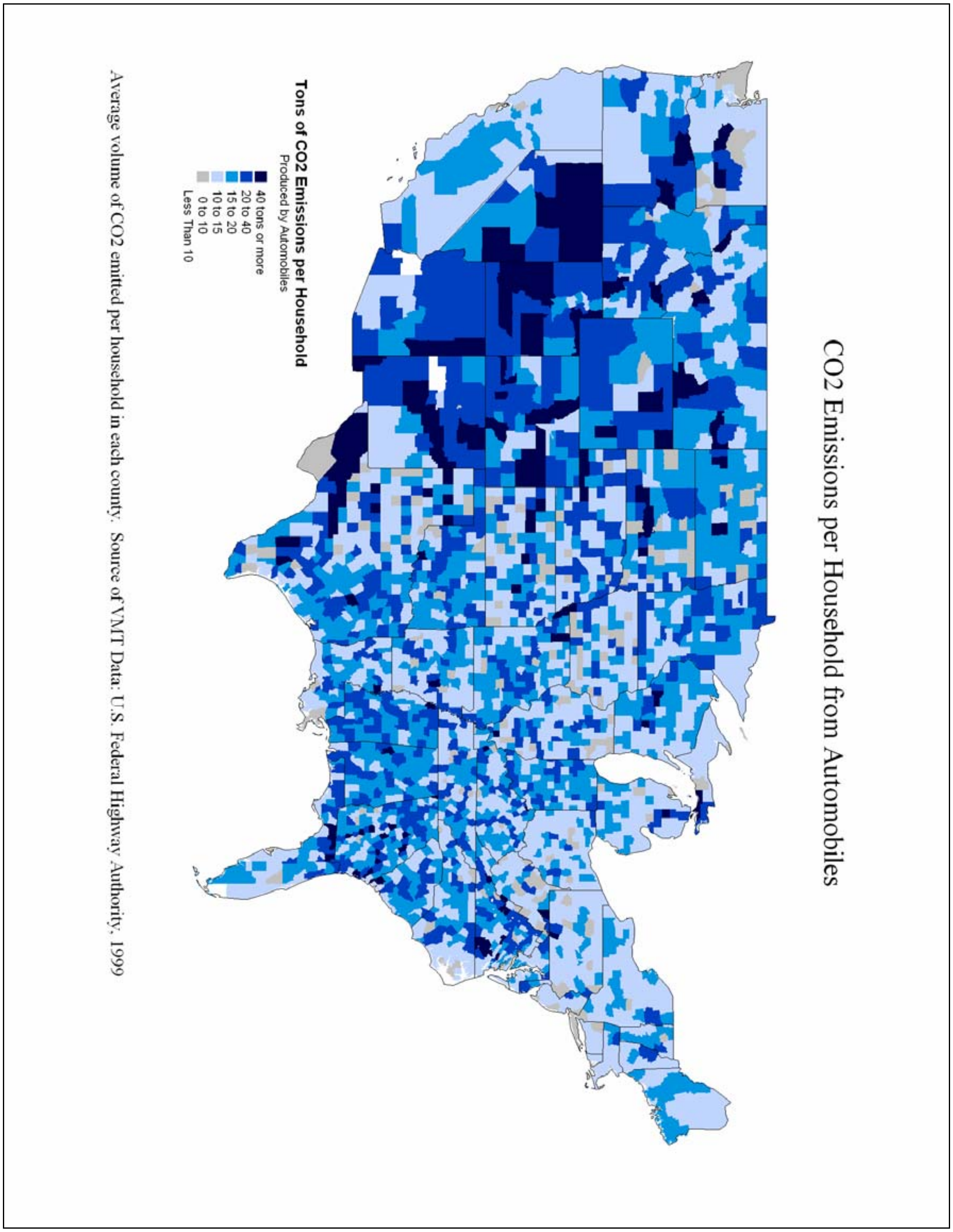


Figure 3.9 National CO_2 Emissions Per Household
[TCRP H-21 Center for Neighborhood Technology]

Figure 4.1 U.S. Transit Emissions Projections 1999-2040 (Carbon Equivalents)
[TCRP H-21 Center for Neighborhood Technology]

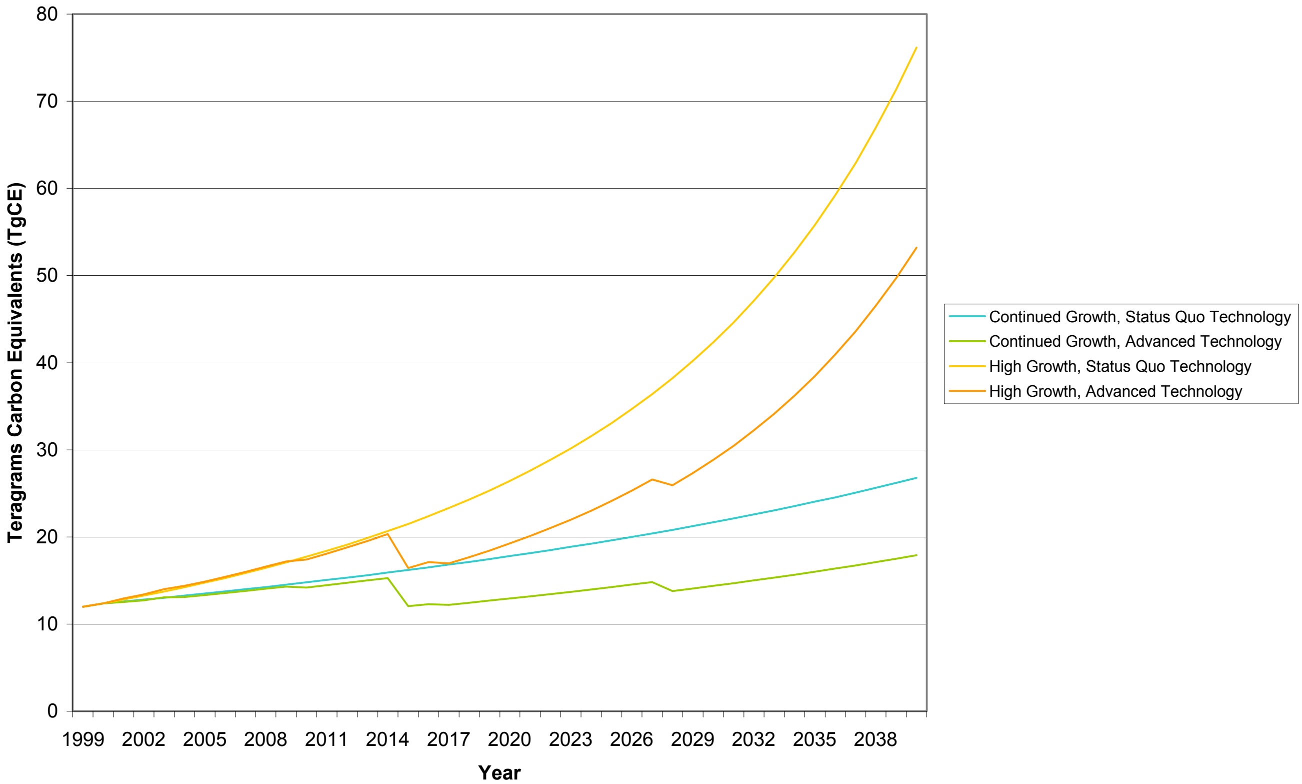


Figure 5.1 Individual Calculator, Personal Vehicles Form
[TCRP H-21 Center for Neighborhood Technology]
[http://www.travelmatters.org]

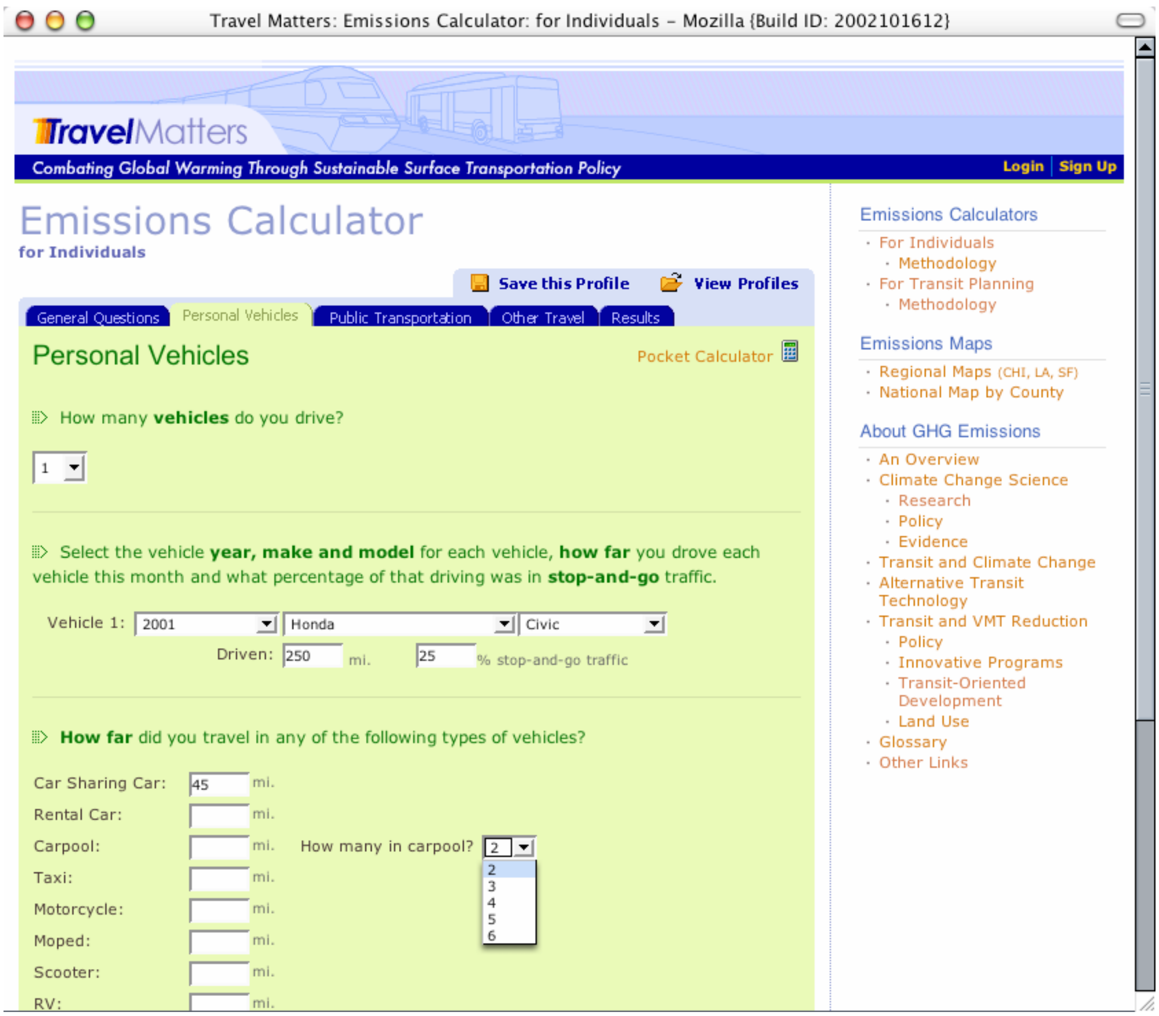


Figure 5.2 Individual Calculator, Results Page
[TCRP H-21 Center for Neighborhood Technology]
[http://www.travelmatters.org]

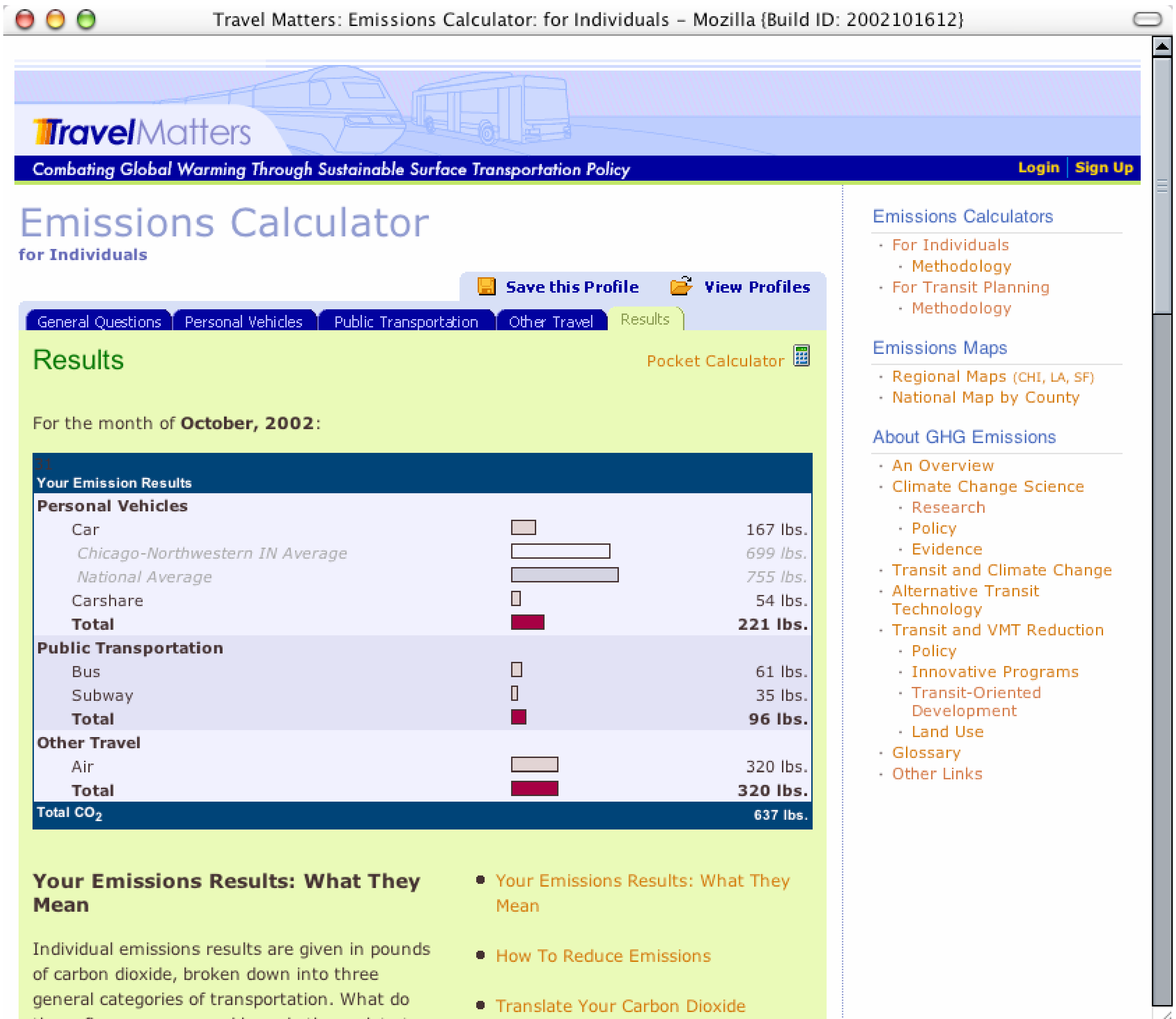
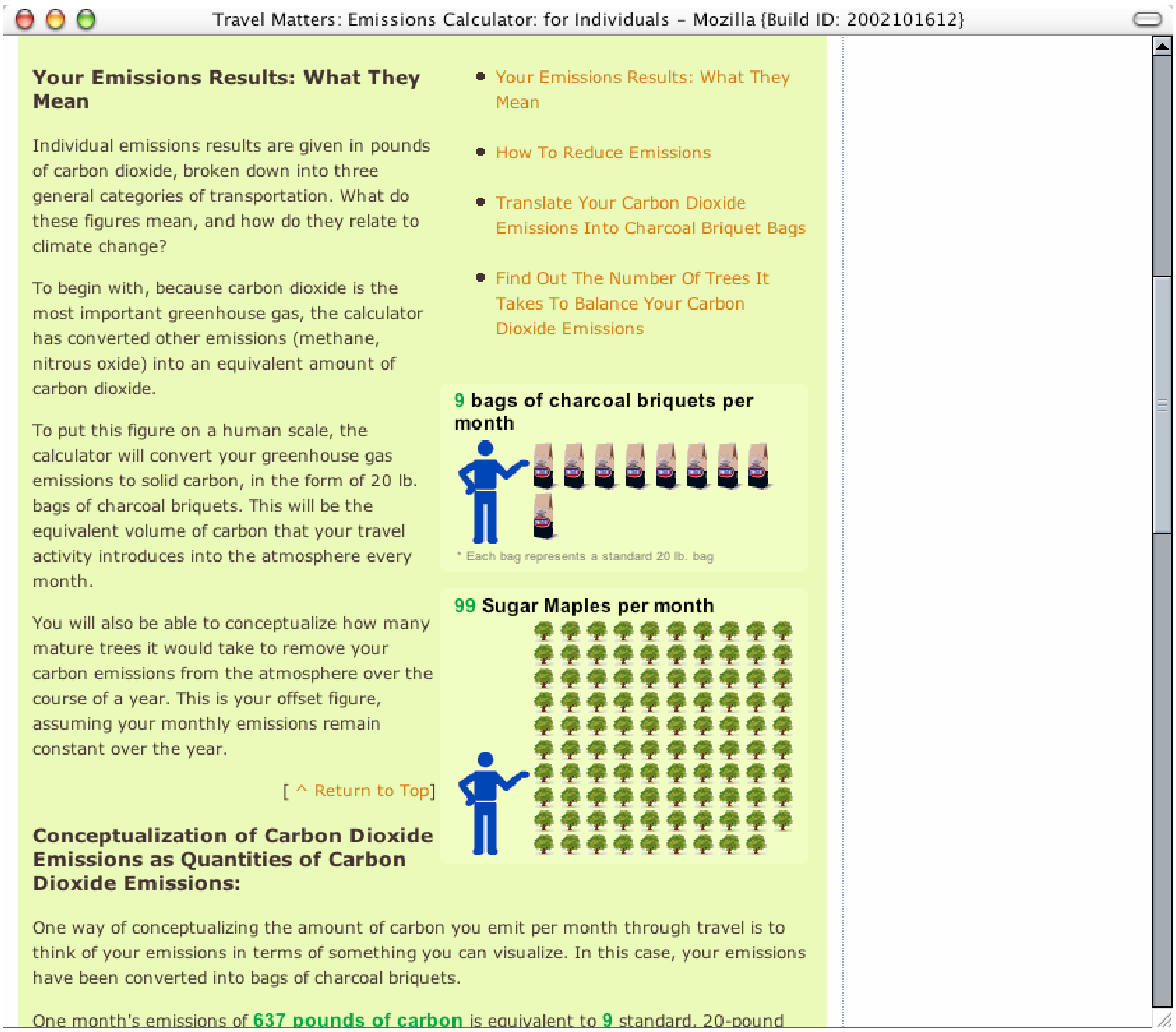


Figure 5.3 Individual Calculator, Results Page II
[TCRP H-21 Center for Neighborhood Technology]
[http://www.travelmatters.org]



Travel Matters: Emissions Calculator: for Individuals - Mozilla {Build ID: 2002101612}

Your Emissions Results: What They Mean

Individual emissions results are given in pounds of carbon dioxide, broken down into three general categories of transportation. What do these figures mean, and how do they relate to climate change?

To begin with, because carbon dioxide is the most important greenhouse gas, the calculator has converted other emissions (methane, nitrous oxide) into an equivalent amount of carbon dioxide.

To put this figure on a human scale, the calculator will convert your greenhouse gas emissions to solid carbon, in the form of 20 lb. bags of charcoal briquets. This will be the equivalent volume of carbon that your travel activity introduces into the atmosphere every month.

You will also be able to conceptualize how many mature trees it would take to remove your carbon emissions from the atmosphere over the course of a year. This is your offset figure, assuming your monthly emissions remain constant over the year.

[^ Return to Top]

Conceptualization of Carbon Dioxide Emissions as Quantities of Carbon Dioxide Emissions:

One way of conceptualizing the amount of carbon you emit per month through travel is to think of your emissions in terms of something you can visualize. In this case, your emissions have been converted into bags of charcoal briquets.

One month's emissions of **637 pounds of carbon** is equivalent to **9** standard, 20-pound

- Your Emissions Results: What They Mean
- How To Reduce Emissions
- Translate Your Carbon Dioxide Emissions Into Charcoal Briquet Bags
- Find Out The Number Of Trees It Takes To Balance Your Carbon Dioxide Emissions

9 bags of charcoal briquets per month

* Each bag represents a standard 20 lb. bag

99 Sugar Maples per month

Figure 5.4 Transit Planning Calculator, Introduction Form
[TCRP H-21 Center for Neighborhood Technology]
[http://www.travelmatters.org]

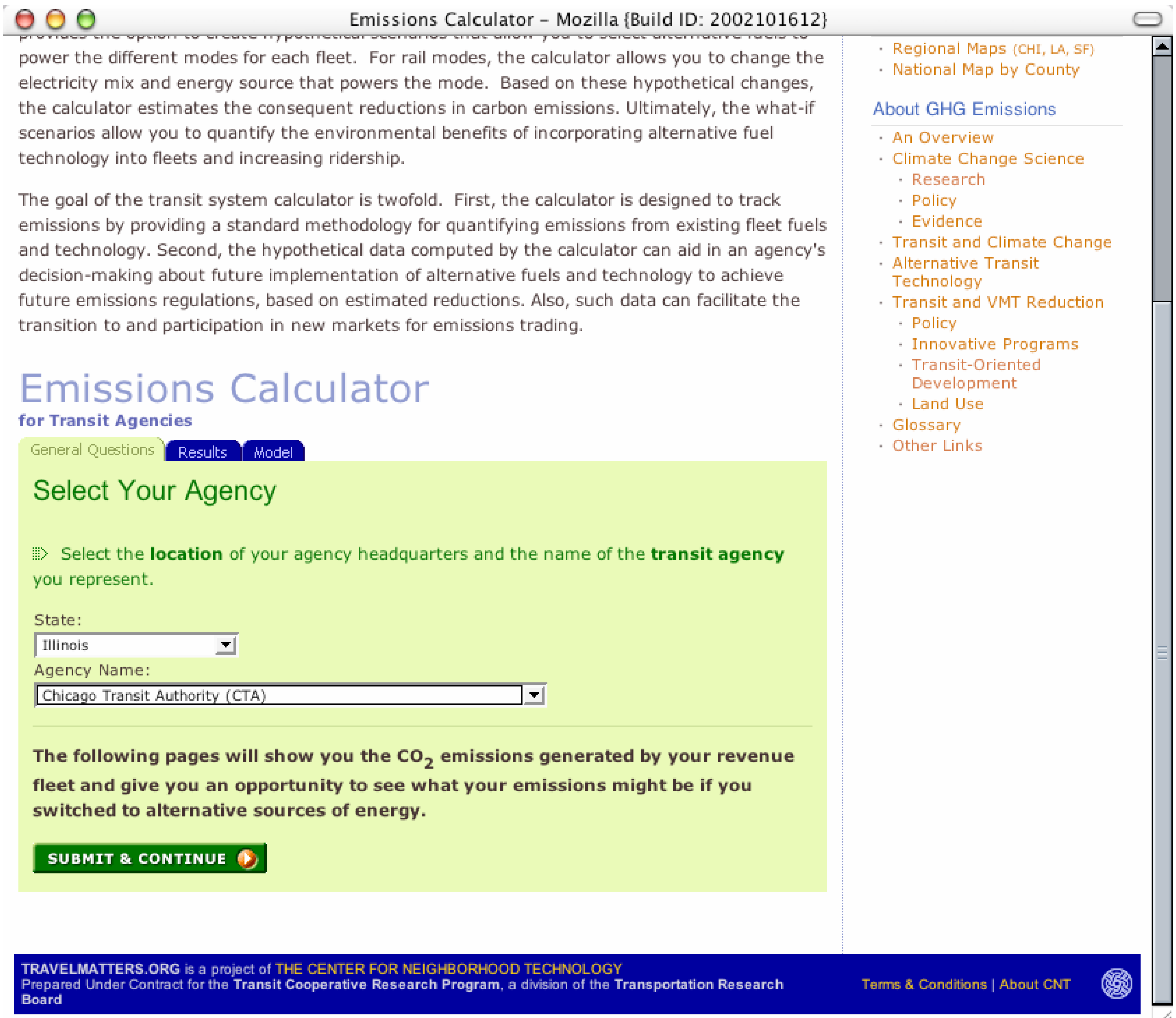
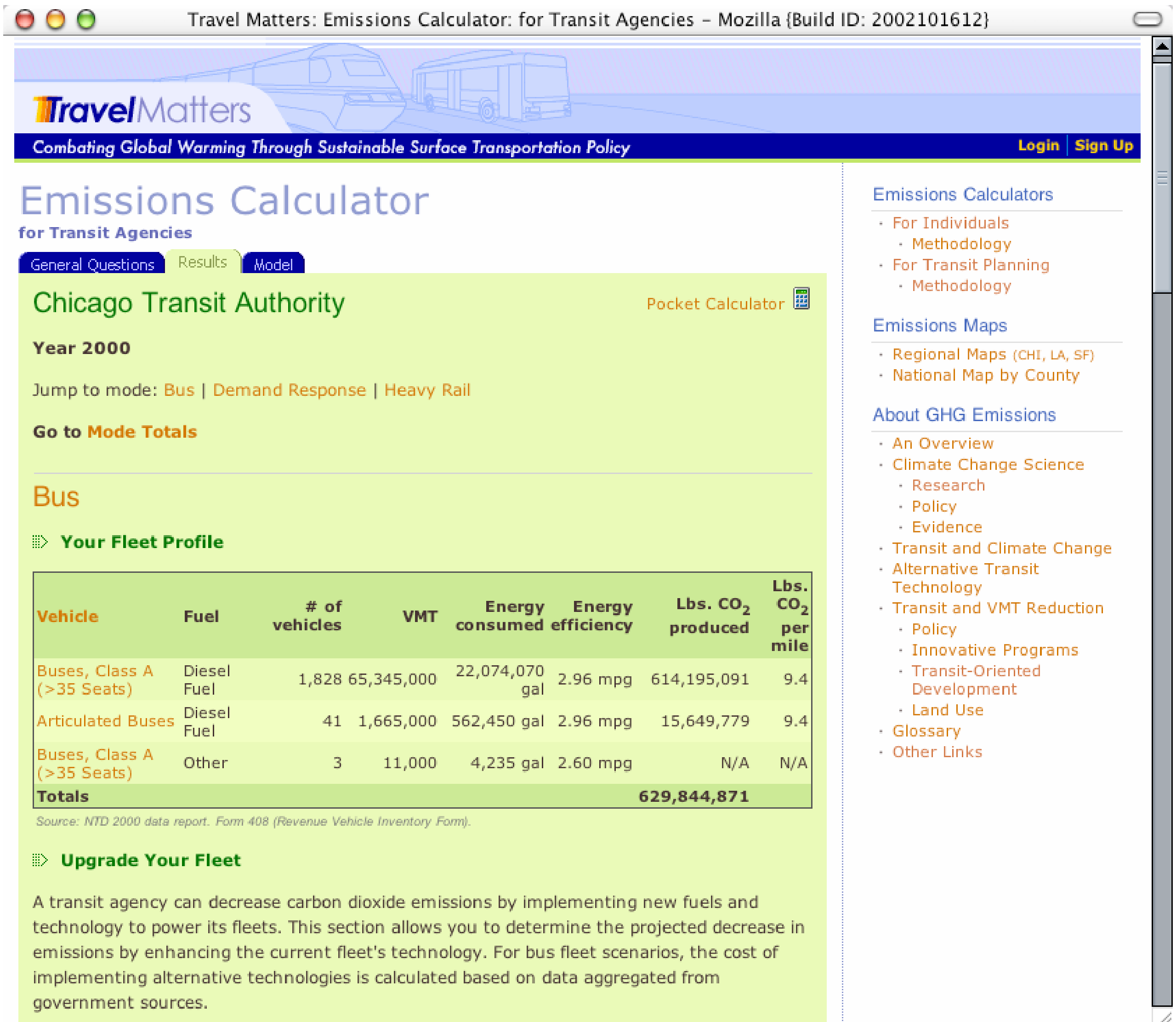


Figure 5.5 Transit Planning Calculator, Tabulation of Emissions
[TCRP H-21 Center for Neighborhood Technology]
[http://www.travelmatters.org]



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 5.6 Transit Planning Calculator, Hypothetical Scenarios
[TCRP H-21 Center for Neighborhood Technology]
[http://www.travelmatters.org]

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

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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	Costs to achieve this reduction
Buses, Class A (>35 Seats)	Diesel Fuel	1,578	56,408,500	19,056,926 gal	2.96 mpg	530,245,236	9.4	
	B20	*250*	*8,936,500*	*3,019,088 gal*	*2.96 mpg*	*70,102,918*	*7.8*	*You save $110,776*
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						**600,185,354**		
Total reduction from alternative fuels						***29,496,717***		***You save $110,776***
Effective reduction from increased ridership						***162,800***		

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

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
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  - Policy
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  - Transit-Oriented Development
  - Land Use
- Glossary
- Other Links

Table 3.1 Comparative Emissions from Public Transit and From Replacement Use of Private Vehicles (Metric Tons of CO_2 1999)
[TCRP H-21 Center for Neighborhood Technology]

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]

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

Table 3.2 Highest and Lowest Average Household Auto Costs by Suburban Chicago Municipality 1990

[TCRP H-21 Center for Neighborhood Technology]
Source: CNT Location Efficient Mortgage Database

Lowest Average Auto Cost 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

Table 3.3 CO_2 Savings From Transit Use
Washington, D.C. 2000
[TCRP H-21 Center for Neighborhood Technology]

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]

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

Table 3.4 CO_2 Savings From Transit Use
Los Angeles 2000
[TCRP H-21 Center for Neighborhood Technology]

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]

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

Table 3.5 CO_2 Savings From Transit Use
Santa Monica 2000
[TCRP H-21 Center for Neighborhood Technology]

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]

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

Table 4.1 Comparative CO_2 Emissions from Bus Fuels
[TCRP H-21 Center for Neighborhood Technology]

Source: Argonne National Laboratory's GREET Model. All lifecycle greenhouse gas emissions have been converted to CO_2 equivalents.

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

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 1-5, Federal Transit Administration's National Transit Database, 2000.
Source: Columns 6-11, Calculations based on American Public Transportation Authority'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.

Annual Vehicle (Revenue) Miles	[step 2] Energy Used by Public Transportation (BTU)	[step 3] CO_2 Produced by Public Transit (Grams)	[step 4] Fuel Used if Pvt. Vehicles Replaced Public Transit (BTU)
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 CO2/BTU = Conversion of grams of CO2/MKWH to grams of CO2/BTU	

[step 5] CO_2 Produced if Pvt. 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 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	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 CO2) for alternate fuels

	Units	Gasoline	Diesel	Biodiesel	B20	Ethanol	CNG	Hydrogen from NG	Hydrogen electrolysis
Emission Reduction									
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
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
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									
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
Cost of Fuel per mile	$/mile	$0.72	$0.55	$1.04	$0.65	$1.11	$0.54	$0.23	$0.48
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									
Cost of Bus less Cost of Diesel Bus - Capital (4)	$/bus		standard	$0	$0	$20,000	$50,000	$60,000	$60,000
Bus Life	miles		1 million	1 million	1 million	1 million	1 million	1 million	1 million
Cost of Bus less Cost of Diesel Bus - Capital	$/mile			$0.00	$0.00	$0.02	$0.05	$0.06	$0.06
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									
Cost of Fuel less Cost of Petroleum Diesel	$/mile		--	+$0.49	+$0.10	+$0.56	-$0.01	-$0.32	-$0.07
Cost of Bus less Cost of Diesel Bus - Total	$/mile		--	$0	$0	+$0.02	+$0.05	+$0.06	+$0.06
Cost less Cost of Diesel	$/mile		--	+$0.49	+$0.10	+$0.58	+$0.04	-$0.26	-$0.01
Bus Emissions less Petroleum Diesel Emissions	lb.CO_2/mile		--	-9.6	-1.8	-2.3	-1.6	-6.0	-12.0
TOTAL COST OF EMISSION REDUCTION	$/lb. CO_2			+$0.051	+$0.055	+$0.252	+$0.025	-$0.043	-$0.001
Scenario 1 - Cost of Emission Reduction	**$/ton CO_2**	**NA**	**Standard**	**+$102**	**+$110**	**+$504**	**+$50**	**-$86**	**-$2**
Cost of Fuel less Cost of Petroleum Diesel	$/mile						-$0.01	-$0.32	-$0.07
Scenario 2 - Avail. $ to Pay for Alternative Bus	**$**						**$10,000**	**$320,000**	**$70,000**
$ Gained by Trading CO^2 at $10/ton	$/mile						$0.008	$0.030	$0.060
$ Gained by Trading CO^2 at $10/ton	$						$8,000	$30,000	$60,000
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