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COMBATING GLOBAL WARMING THROUGH

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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.

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

CHAPTER 1

After reviewing the literature on climate change, travel demand, and land use, the 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.

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

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 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 im

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 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

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 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 0lc J17-17 -2.3 TD1 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:

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 vol 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]

20,000 years."[25] Similar evidence has been obtained 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

"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

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

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

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

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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.

[30] Sydney Levitus, John J. Anthony, Timothy P. Boyer, & Cathy Stephens, “Warming of the World Ocean,” *Science*, vol. 287, 5461 (March 24, 2000): 2225-2229.

[31] “Temperature Trends Over the Past Five Centuries Reconstructed from Borehole Temperatures,” Huang, S., Pollack, H.N. & Shen, Po-Yu., *Nature*, vol. 403, 6771 (February

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[40] Third Assessment Report. Climate Change 2001: The Scientific Basis, “Summary for Policymakers,” 38.

[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]

[44] U.S. Department of Transportation, Center for Climate Change and Environmental Forecasting. [http://climate.volpe.dot.gov/index.html]

[45] U.S. Department of Energy, Emissions of Greenhouse Gases in the U.S. 2000, “Carbon Dioxide.” [http://www.eia.doe.gov/oiaf/1605/ggrpt/index.html]

[46] 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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[47] US Department of Transportation, Transportation and Global Climate Change: A Review and Analysis of the Literature, (Washington, D.C.: 1998).

CHAPTER 3

LOCAL STRATEGIES FOR REDUCING CO_2

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 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 expansi 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.

> 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 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 te

The emissions maps in Figures 3.2-3.7 pr

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 vehicle miles traveled in each city, offer visu 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 incr 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 21 municipalities to decide how transportation spending will affect their co 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

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 station area developments that took the subway to work. Taken togeth

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 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

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.

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 neent in Unirien in 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.

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.

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 within two blocks of a bus stop."[64] In fiscal year 1998-1999, the Blue Bus moved over 20

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, Public Transportation and Land Use Policy, (Bloomington, Indiana: Bloomington University Press, 1977), 5.

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

[5] Ibid., 37.

[6] Ibid., 172-173.

[7] Ibid., 173.

[8] Ibid., 174.

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[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/]

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[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*

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[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,

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(CARTA) "The Chattanooga Stor

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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, "Large

CHAPTER FOUR

TRANSIT TECHNOLOGIES FOR REDUCING GREENHOUSE GASES

OPTIMAL TRANSIT TECHNOLOGIES FOR GREENHOUSE GAS REDUCTION

life *fuel-cycle*

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ALTERNATIVE TRANSIT FUELS AND TECHNOLOGIES FOR WHICH MARKETS HAVE EMERGED

Compressed Natural Gas

Alcohol-Based Fuels

Lightweight Materials

monocoque

ALTERNATIVE TRANSIT FUELS AND TECH

Hydrogen Fuel Cells

COSTS OF EMISSIONS REDUCTION FROM BUSES

EMISSIONS REDUCING POTENTIAL OF ALTERNATIVE FUELS AND TECHNOLOGIES

CHAPTER 4 ENDNOTES

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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.

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

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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.

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 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.

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 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.

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

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 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 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 COh vehic08 Tw

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

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 B

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

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

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

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)
-

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.

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

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

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 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

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}

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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Kirk Shore, Advanced Vehicle Systems, personal communication, October 22, 2001.

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

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

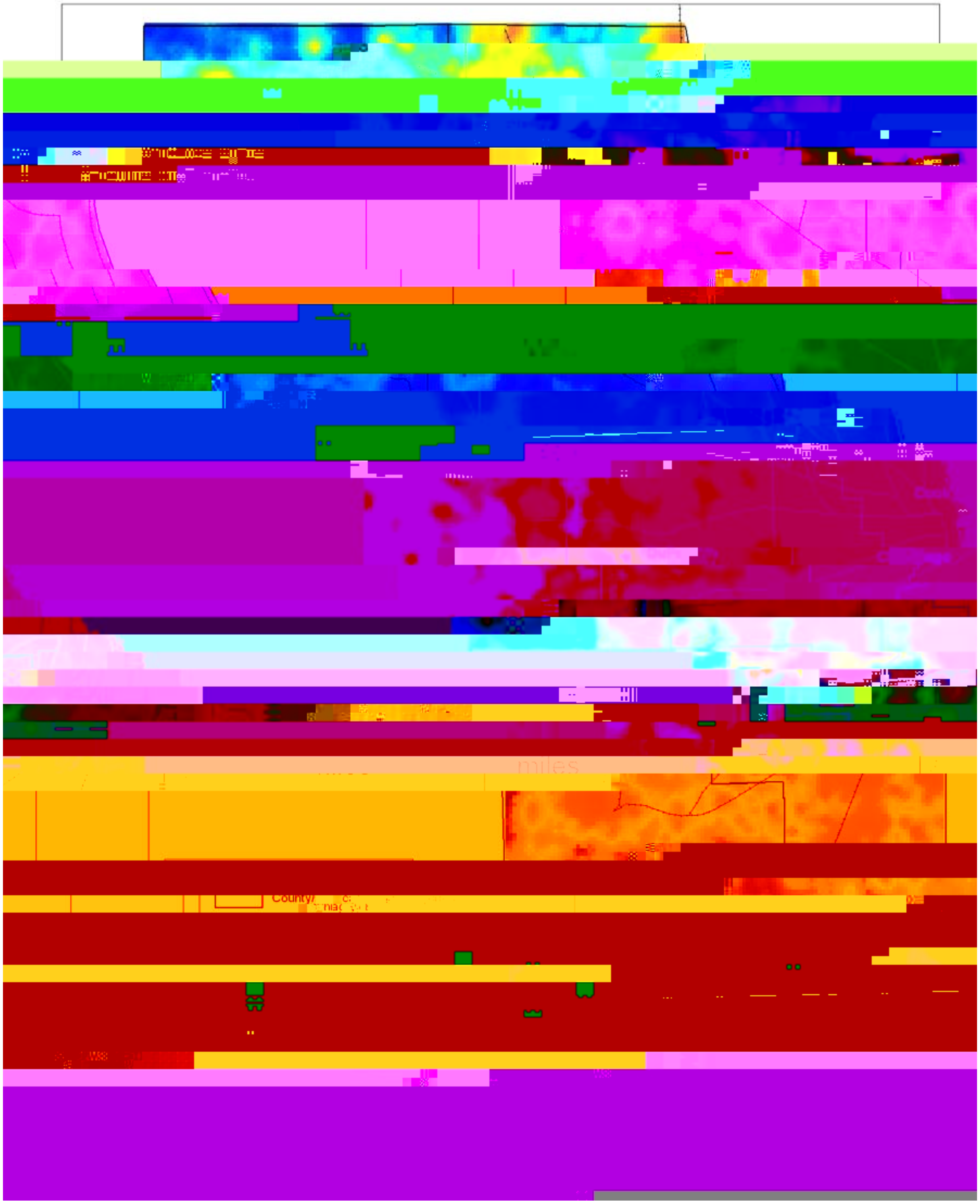


Figure 3.3
Household CO_2 Emissions
Chicago
[TCRP H-21 Center for Neighborhood Technology]

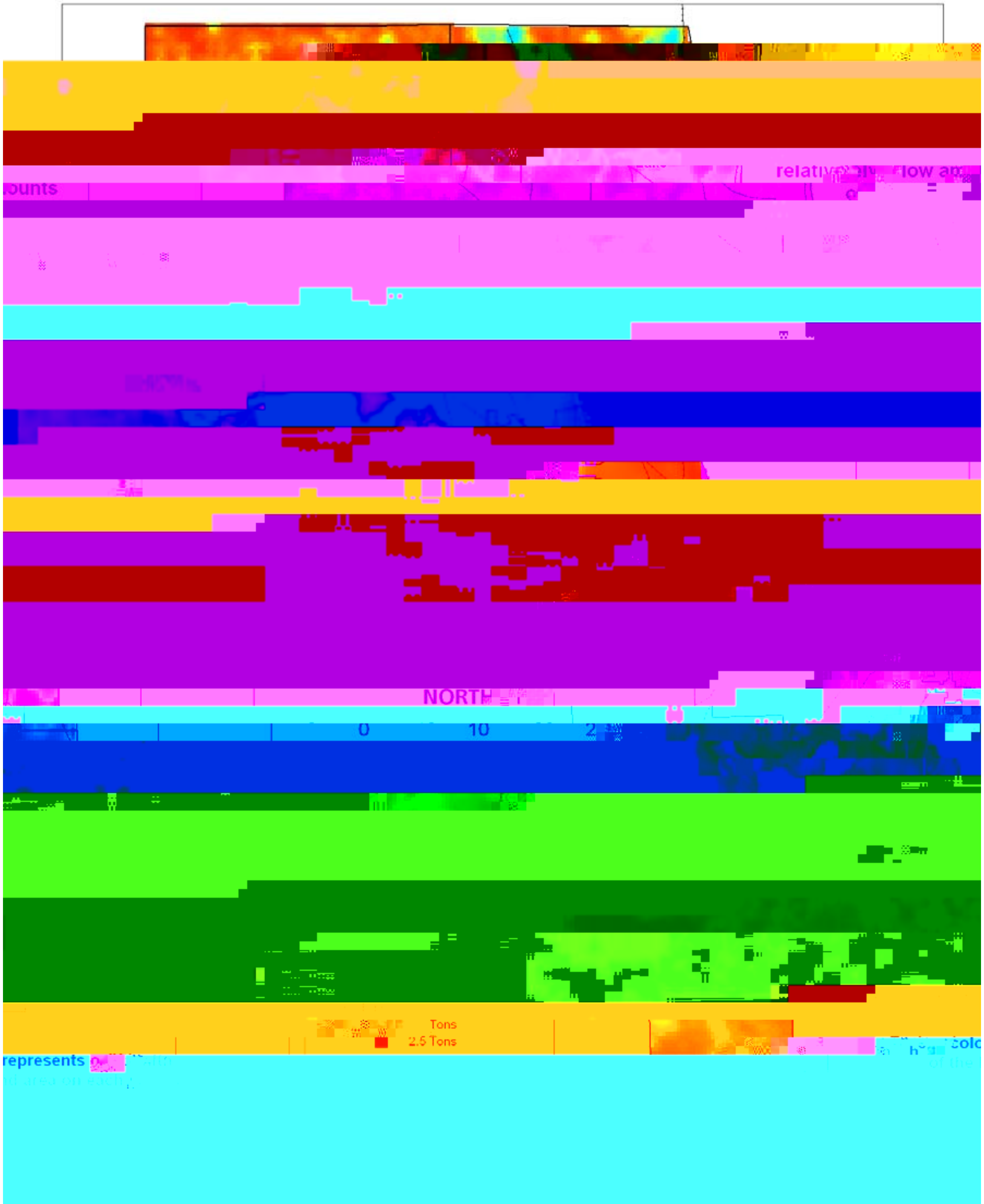


Figure 3.4
CO_2 Emissions Per Square Mile
Los Angeles
[TCRP H-21 Center for Neighborhood Technology]

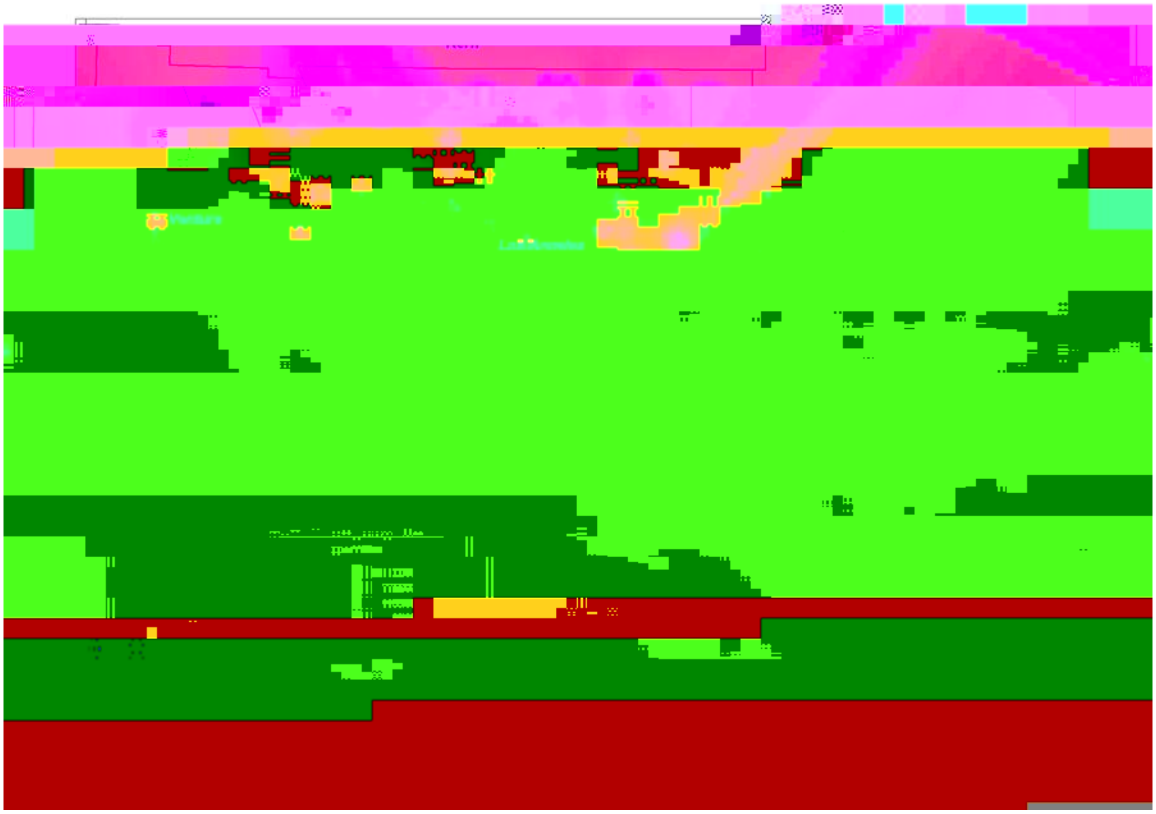
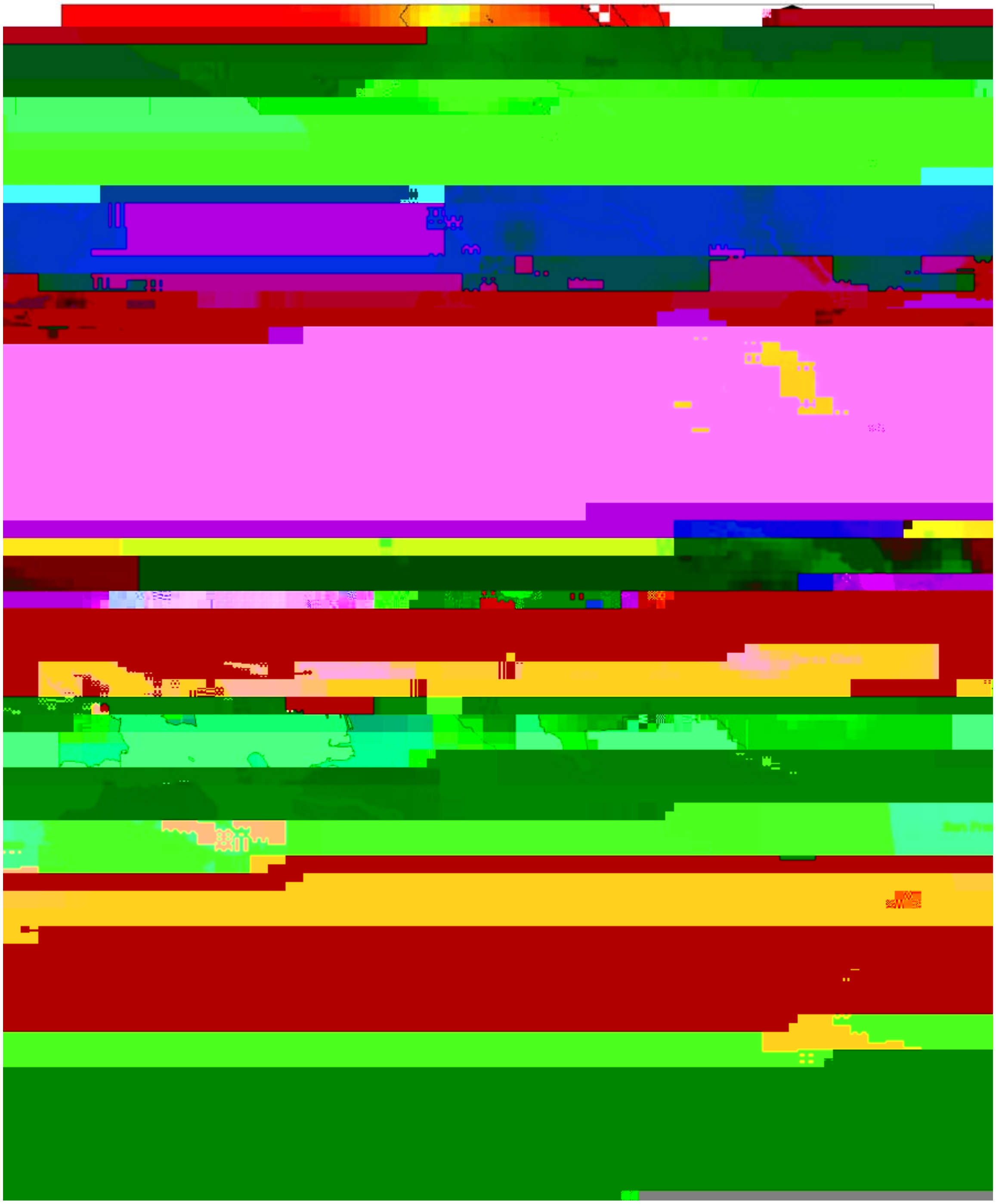


Figure 3.5
Household CO_2 Emissions
Los Angeles
[TCRP H-21 Center for Neighborhood Technology]

Figure 3.6
CO$_2$ Emissions Per Square Mile
San Francisco
[TCRP H-21 Center for Neighborhood Technology]

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



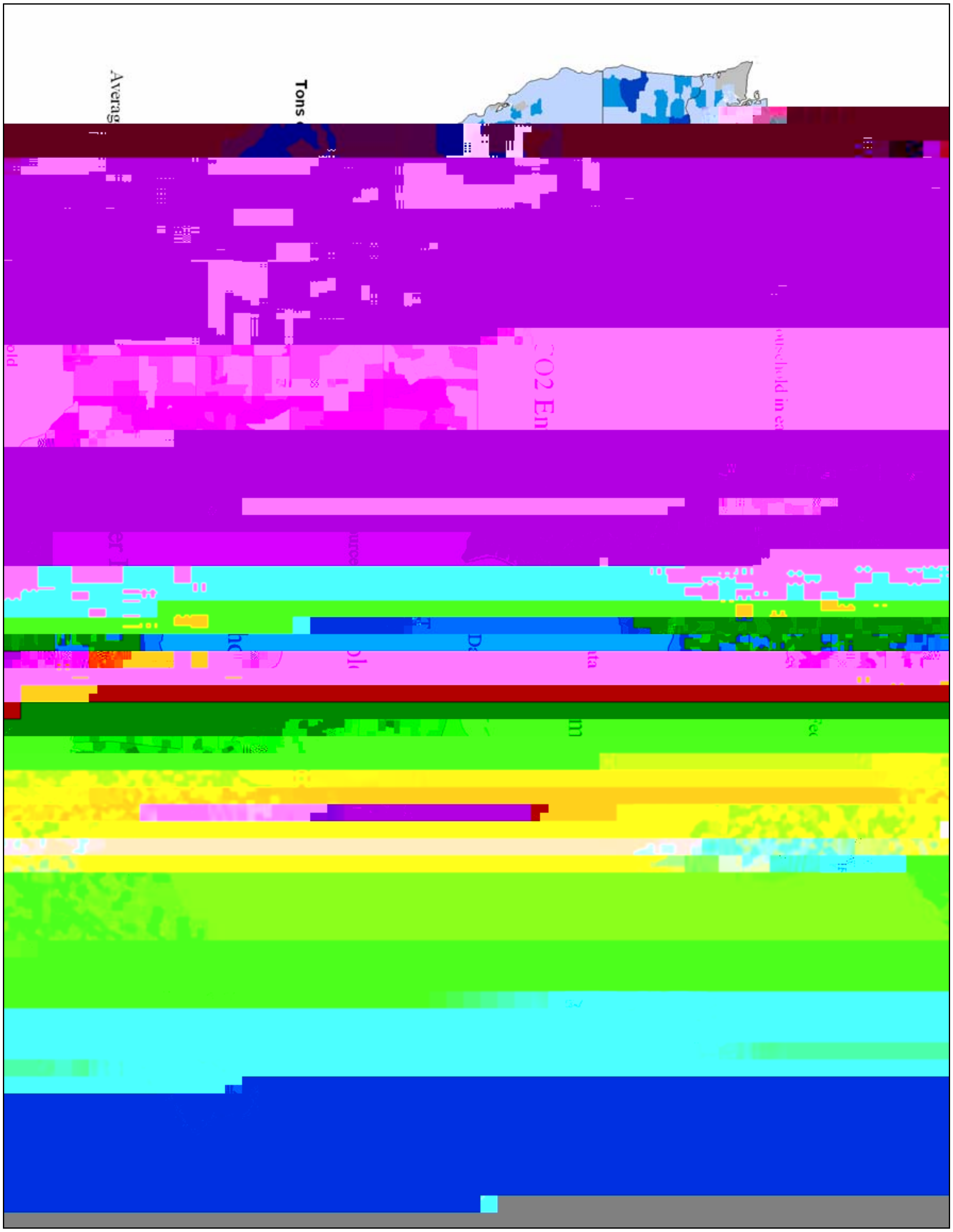


Figure 3.9 National CO_2 Emissions Per Household
[TCRP H-21 Center for Neighborhood Technology]

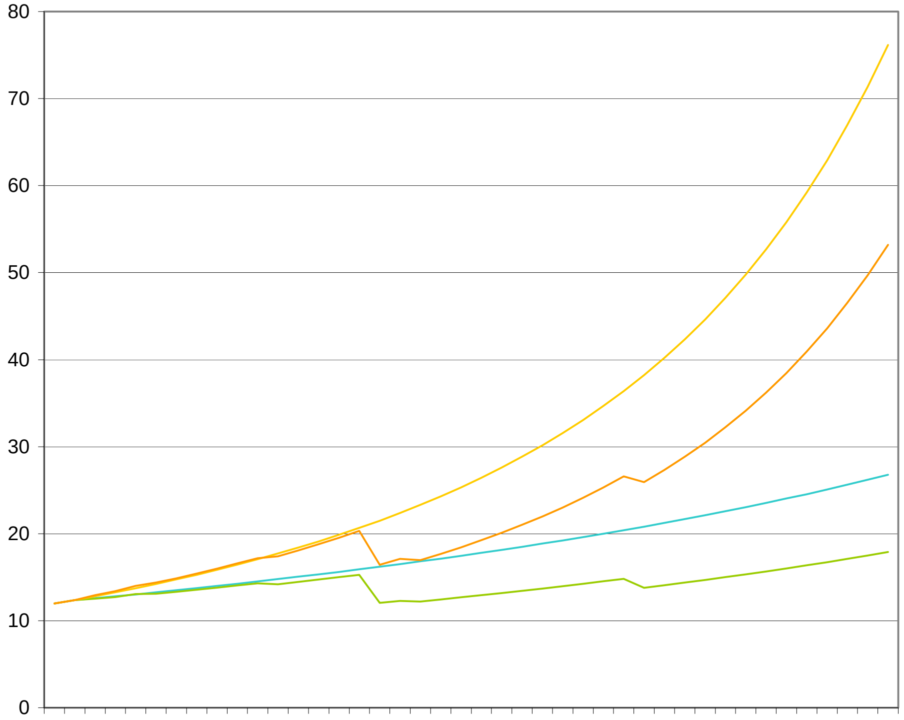

80
70
60
50
40
30
20
10
0

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

How many vehicles do you drive? 1

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

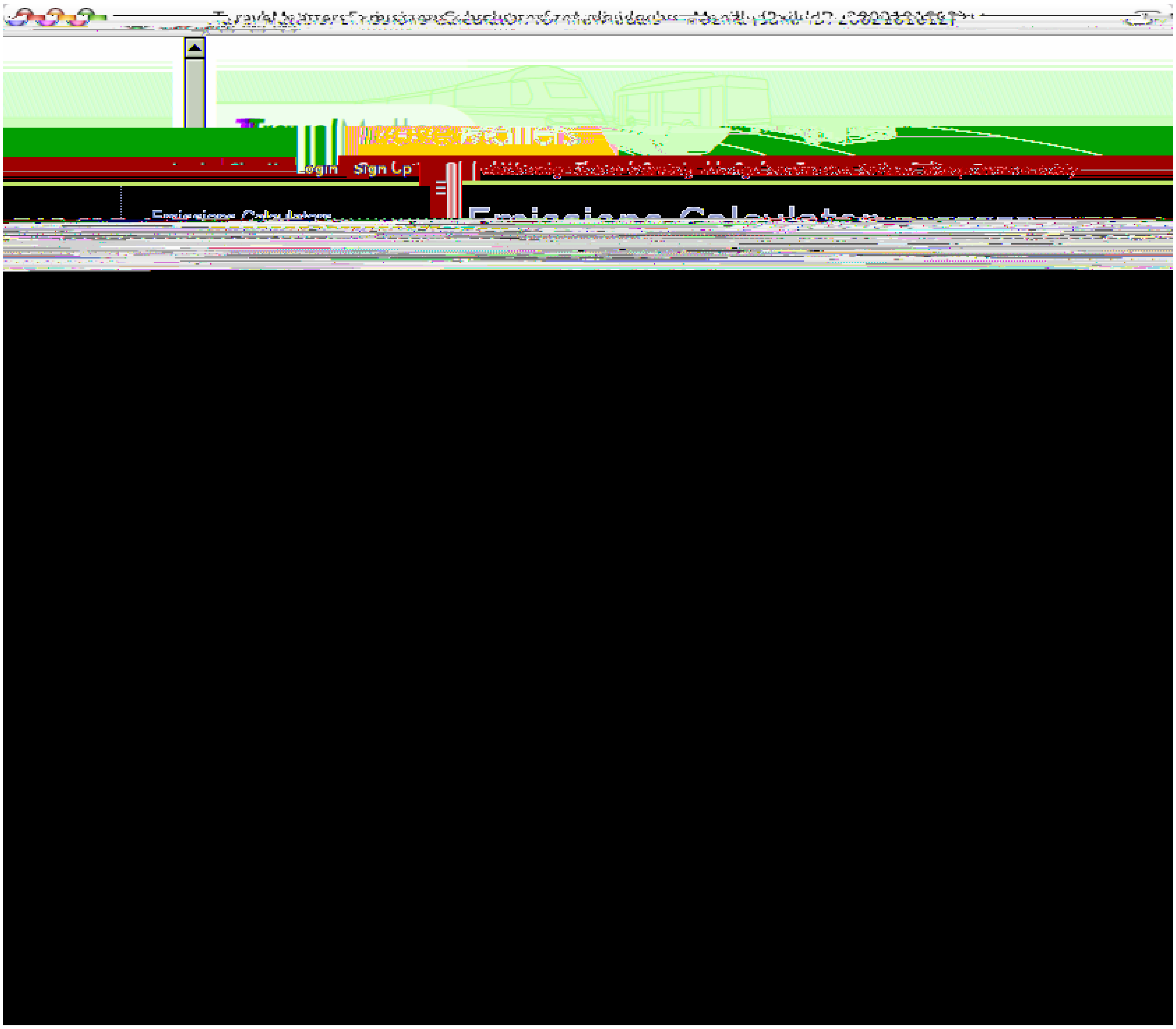


Table 3.2 Highest and Lowest Average Household Auto Costs by Suburban Chicago Municipality 1990

[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

Passenger Miles	1,554,723,063
CO	

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

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

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		

[step 5] CO$_2$ Produced if Pvt. Vehicles Replaced Public Transit (Grams)	[step 6] Environmental

Table C-1: Emissions from Alternative Fuels
All emissions are total CO_2 equivalents.

	Source	Units	Gasoline	Petroleum Diesel	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	179	433	265	97	0
Fuel	(1)	BTU/mile	893	582	667	1,834	300	1,142	1,101
Vehicle Operation	(1)	BTU/mile	4,115	3,397	3,407	3,828	3,886	1,741	1,741
Total Energy Consumption	(1)	BTU/mile	5,179	4,122	4,253	6,095	4,451	2,980	2,842

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**

Table C-3: Emission Coefficients for Alternative Fuels
All emission coefficients are total CO_2 equivalents.