Transportation Research Board | SPECIAL REPORT 298

Driving and the Built Environment

The Effects of Compact Development on Motorized Travel, Energy Use, and CO_2 Emissions

NATIONAL RESEARCH COUNCIL
OF THE NATIONAL ACADEMIES

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Committee for the Study on the Relationships
Among Development Patterns,
Vehicle Miles Traveled, and Energy Consumption

Transportation Research Board

Board on Energy and Environmental Systems

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This report has been reviewed by a group other than the authors according to the procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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* Dr. Geller was a member of the Transportation Research Board staff when she performed the work on this study.

Preface

In September 2008, the California state legislature passed the first state law (Senate Bill 375) to include land use policies directed at curbing urban sprawl and reducing automobile travel as part of the state's ambitious strategy to reduce greenhouse gas (GHG) emissions. The legislature recognized that cleaner fuels and more fuel-efficient vehicles would not be sufficient to achieve the state's goal of reducing GHG emissions to 1990 levels by 2020. The bill requires the state's 18 metropolitan planning organizations to include the GHG emissions targets established by the state Air Resources Board (ARB) in regional transportation plans, and to offer incentives for local governments and developers to create more compact developments and provide transit and other opportunities for alternatives to automobile travel to help meet these targets. ARB currently estimates that reductions in vehicle miles traveled (VMT) resulting from these actions will contribute only about 3 percent of the 2020 targets—an estimate that reflects uncertainties in the state of knowledge about the impacts of more compact development patterns on travel and the short time horizon involved.

The present study, which was requested in the Energy Policy Act of 2005 (Section 1827) and funded by the U.S. Department of Energy, is aimed at establishing the scientific basis for and making appropriate

judgments about the relationships among development patterns, VMT, and energy consumption (see Chapter 1 and Appendix A for a full discussion of the study charge). The statement of task was expanded to include the impacts of development patterns on GHG emissions. To carry out the study charge, the Transportation Research Board (TRB) and the Board on Energy and Environmental Systems (BEES) of the Division on Engineering and Physical Sciences, both of the National Research Council (NRC), formed a committee of 12 experts. The panel was chaired by José A. Gómez-Ibáñez, Derek C. Bok Professor of Urban Planning and Public Policy at Harvard University. The study committee included members with expertise in transportation planning, metropolitan area planning, and land use; transportation behavior; transportation and land use modeling; geography; energy conservation; and economics.

The committee approached its task by commissioning five papers to explore various aspects of the study charge; conducting its own review of the literature; receiving informational briefings at its early meetings; and holding a meeting in Portland, Oregon, to examine firsthand the impacts of that area's well-known growth management policies on development patterns and travel.

The five commissioned papers enhanced the committee's own expertise in several areas. The first, by David Brownstone of the University of California, Irvine, provides a critical review of the literature on the relationship between compact development patterns and household VMT. The next two papers provide background information on historical and future trends, respectively, as they affect the potential for more compact development: Genevieve Giuliano, Ajay Agarwal, and Christian Redfearn of the University of Southern California examine recent spatial trends in U.S. metropolitan areas, with a focus on employment and housing; John Pitkin of Analysis and Forecasting, Inc., and Dowell Myers of the University of Southern California examine U.S. housing trends to 2050, with a focus on

demographic changes and immigration patterns that could affect future markets for more compact development. The fourth paper, by Michael S. Bronzini of George Mason University, explores what is currently known about the relationship among land use, urban form, and freight and commercial VMT in metropolitan areas. The final paper, by committee member Kara Kockelman and student researchers Matthew Bomberg, Melissa Thompson, and Charlotte Whitehead from the University of Texas at Austin, analyzes the potential reductions in energy use and GHG emissions from a wide range of policies and design strategies—such as vehicle technologies, fuel types, appliances, and home and building design—to provide a basis for comparison with potential reductions from changes in development patterns. Special thanks are due to Ms. Whitehead, student researcher in the Department of Civil, Architectural and Environmental Engineering, who conducted numerous analyses for the committee on projected savings in residential building energy use and carbon dioxide emissions from more compact development strategies. The papers, listed in Appendix B, were reviewed by the committee and revised by the authors. Because of their length and printing costs, they are available only in electronic form. The reader is cautioned that the interpretations and conclusions drawn in the papers are those of the authors. The key findings endorsed by the committee appear in the body of the report.

The briefings received at the committee's initial meetings served as an invaluable supplement to its own expertise. In particular, the committee would like to thank Stephanie Potts, program associate of Smart Growth America, who provided her perspective on the committee's charge; Reid Ewing, professor in the College of Architecture and Planning, University of Utah, who provided an overview of the land use–transportation literature; John Holtzclaw, consultant to the Natural Resources Defense Council, who spoke about location efficiency models; and John Landis, Chair of the

Department of City and Regional Planning at the University of Pennsylvania, who presented his analysis of spatial changes in population and employment for a sample of metropolitan areas over time. Thanks are extended as well to committee member Andrew Cotugno, Director of Metro's Planning Department at the time, and his staff for hosting the committee's third meeting in Portland, where the committee visited several neighborhood compact development projects and was briefed on the impacts of Portland's urban growth boundary on regional land use patterns and travel. Finally, the committee thanks the following federal agency staff for their help in launching the study and their continuing assistance throughout: Philip D. Patterson, Jr., of the U.S. Department of Energy; Megan Susman and John V. Thomas of the U.S. Environmental Protection Agency; Frederick Ducca of the U.S. Department of Transportation (USDOT); and Ed Weiner, formerly of USDOT.

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by NRC's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that assist the authors and NRC in making the published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The contents of the review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. The committee thanks the following individuals for their participation in the review of this report: A. Ray Chamberlain, Parsons Brinckerhoff, Fort Collins, Colorado; Randall Crane, School of Public Policy and Social Science Research, University of California, Los Angeles; Paul A. DeCotis, Office of the Governor, State of New York, Albany; Robert T. Dunphy, Urban Land Institute (retired), Washington, D.C.; Gordon Garry, Sacramento Area

Council of Governments, California; Susan L. Handy, Department of Environmental Science and Policy, University of California, Davis; and Kevin J. Krizek, Department of Planning and Design, University of Colorado, Denver.

Although the reviewers listed above provided many constructive comments and suggestions, they were not asked to endorse the committee's conclusions or recommendations, nor did they see the final draft of the report before its release. The review of this report was overseen by Maxine L. Savitz, Honeywell Inc. (retired), Los Angeles, California, and C. Michael Walton, University of Texas at Austin. Appointed by NRC, they were responsible for making certain that an independent examination of the report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

Stephen R. Godwin, Director of Studies and Special Programs at TRB, and Nancy P. Humphrey, TRB, managed the study. Ms. Humphrey, with assistance from Laurie Geller, drafted the final report under the guidance of the committee and the supervision of Stephen Godwin. James Zucchetto, Director of BEES, served as liaison to the committee. Suzanne Schneider, Associate Executive Director of TRB, managed the report review process. Special appreciation is expressed to Rona Briere, who edited the report; and to Norman Solomon, for editorial production; Juanita Green, for managing the design, typesetting, and printing of the book; and Jennifer Weeks, who formatted the manuscript for prepublication web posting, under the supervision of Javy Awan, Director of Publications. Amelia Mathis assisted with meeting arrangements, contracts with paper authors, and communications with committee members. Alisa Decatur provided word processing support for preparation of the final manuscript.

Contents

Summary

The vast majority of the U.S. population—some 80 percent—now lives in metropolitan areas, but population and employment continue to decentralize within regions, and density levels continue to decline at the urban fringe. Suburbanization is a long-standing trend that reflects the preference of many Americans for living in detached single-family homes, made possible largely through the mobility provided by the automobile and an extensive highway network. Yet these dispersed, automobile-dependent development patterns have come at a cost, consuming vast quantities of undeveloped land; increasing the nation's dependence on petroleum, particularly foreign imports; and increasing greenhouse gas (GHG) emissions that contribute to global warming. The primary purpose of this study is to examine the relationship between land development patterns, often referred to as the built environment, and motor vehicle travel in the United States and to assess whether petroleum use, and by extension GHG emissions, could be reduced through changes in the design of development patterns (see Appendix A for the full statement of task). A key question of interest is the extent to which developing more compactly would reduce vehicle miles traveled (VMT) and make alternative modes of travel (e.g., transit, walking) more feasible. The study is focused on metropolitan areas and on personal travel, the primary vectors through which policy changes designed to encourage more compact development should have the greatest effect.

The adverse effects of suburbanization and automobile dependence have long been evident but are currently of particular concern for several reasons. First, after decades of low energy prices, the cost of oil rose to record highs in 2008, reflecting the growth of China and India and the instability of many key suppliers in the Middle East and other oil-producing areas and underscoring U.S. dependence on imported fuels. The transportation sector as a whole accounts for more than 28 percent of annual U.S. energy consumption. Cars and light trucks, most of which are used for personal transportation, represent about 17 percent of that total, and this share has been rising. Second, concern about climate change continues to rise both domestically and internationally, and transportation is a major and increasing contributor to that growing problem. Gasoline consumption, largely by personal vehicles, accounts for about 20 percent of annual carbon dioxide (CO_2) emissions, the largest single source of U.S. GHG emissions and the focus of the analyses conducted for this study. An additional factor, although less newsworthy, is the health risks resulting from transportation emissions and the difficulty being experienced by many regions in meeting federal clean air standards. At the same time, changing demographics—an aging population, continued immigration—and the possibility of sustained higher energy prices should lead to more opportunities for the kinds of development patterns that could reduce vehicular travel, thereby saving energy and reducing CO_2 emissions.

To examine the potential for reducing VMT, energy use, and CO_2 emissions through more compact development, the committee formed to conduct this study commissioned five papers to augment its members' expertise, received informational briefings at its early meetings, and performed a review of the literature. The committee's findings and resulting recommendations are presented below. The committee reached consensus on all but one issue—the extent to which development is likely to become more compact by 2050 (see the text following Finding 4 for a detailed discussion).

FINDINGS

Link Between Development Patterns and VMT

Finding 1: *Developing more compactly, that is, at higher residential and employment densities, is likely to reduce VMT.*

Both logic and empirical evidence suggest that developing at higher population and employment densities results in closer trip origins and destinations, on average, and thus in shorter trip lengths, on average. Theory suggests that reduced trip lengths can increase trip frequencies, but empirical evidence suggests that the increase is not enough to offset the reduction in VMT that comes from reduced trip length alone. Shorter trips also may reduce VMT by making walking and bicycling more competitive alternatives to the automobile, while higher densities make it easier to support public transit. Mixing land uses to bring housing closer to jobs and shopping can reduce trip lengths as well. The committee refers to these development patterns as compact, mixed-use development.

Compact, mixed-use development can reduce VMT by differing means and amounts depending on where the development in a region occurs. Empirical data are lacking that demonstrate how specific design features applied in different contexts affect VMT. Nevertheless, at the low-density urban fringe, for example, simply reducing single-family lot sizes—say, from 1 acre to a quarter acre—should reduce vehicle trip distances by bringing origins and destinations closer together. In established moderate-density suburbs and along transportation corridors, smaller lots and multiunit housing can support public transit and encourage walking and bicycling, further reducing VMT. And in established urban cores, redevelopment of strategically located but underused parcels can support investment in rail transit.

The effects of compact, mixed-use development on VMT are likely to be enhanced when this strategy is combined with other policy measures

that make alternatives to driving relatively more convenient and affordable. Examples of such measures include a street network that provides good connectivity between locations and accommodates nonvehicular travel, well-located transit stops, and good neighborhood design. Likewise, demand management measures, such as reducing the supply and increasing the cost of parking, can complement efforts to reduce VMT.

Evidence from the Literature

> ***Finding 2:*** *The literature suggests that doubling residential density across a metropolitan area might lower household VMT by about 5 to 12 percent, and perhaps by as much as 25 percent, if coupled with higher employment concentrations, significant public transit improvements, mixed uses, and other supportive demand management measures.*

Studies aimed at isolating the effect of residential density while controlling for sociodemographic and other land use variables consistently find that doubling density is associated with about 5 percent less VMT on average; one rigorous California study finds that VMT is lower by 12 percent. The same body of literature, mainly U.S.-based studies, reports that VMT is lower by an average of 3 to 20 percent when other land use factors that often accompany density, such as mixed uses, good design, and improved accessibility, are accounted for, and suggests further that in some cases these reductions are additive. These studies include changes in density for a range of geographic areas, from census block groups, to census tracts, to neighborhoods.

A higher VMT reduction that the committee uses as an upper bound in its own scenario analyses comes from a single but carefully done statistical analysis of metropolitan development patterns, transit service, and travel behavior. The authors of this analysis interpret its findings by using the following thought experiment. If households in Atlanta, one of the least dense metropolitan areas, were located in an area with the

residential population density, concentrated employment, extensive public transit system, and other land use characteristics of the Boston metropolitan area, VMT per household could be lowered by as much as 25 percent. Of course, the urban structure of Atlanta could not literally be converted to that of Boston because of vast differences in topography and historical development patterns. Combining density increases with transit investment, mixed uses, higher parking fees, and other measures, however, could provide the synergies necessary to yield significant reductions in VMT, even in low-density metropolitan areas like Atlanta.

Most of the above studies are subject to a number of shortcomings. For example, many fail to distinguish among different types of density changes (e.g., decreasing lot size versus increasing multifamily housing) or the location of these changes in a region. Relatively few (but including the California study mentioned) attempt to account for self-selection—the tendency of people to locate in areas consistent with their housing and travel preferences. Without doing so, one could not assume, for example, that the typical Atlanta resident who moved to an area with the characteristics of Boston would travel like the typical Boston resident, although both attitudes and behavior are likely to be influenced by the built environment over time. Finally, most studies are cross-sectional, that is, they find an association between higher density and lower VMT at a single point in time but cannot be used to infer cause and effect.

Effects on Energy and CO_2 Emissions

Finding 3: *More compact, mixed-use development can produce reductions in energy consumption and CO_2 emissions both directly and indirectly.*

To the extent that more compact development reduces VMT, it will directly reduce fuel use and CO_2 emissions. The VMT savings will be slow to develop, however, if only because the existing building stock is

highly durable; therefore, opportunities to build more compactly are limited largely to new housing as it is built to accommodate a growing population and to replace the small percentage of existing units that are scrapped each year. Over time, moreover, if the fuel efficiency of the passenger vehicle fleet improves through either regulation (such as the new Corporate Average Fuel Economy standards) or sustained higher fuel prices that encourage consumers to purchase more energy-efficient vehicles, the savings in fuel use and CO_2 emissions from developing more compactly will be reduced, all else being equal.

Additional, indirect savings in energy consumption and CO_2 emissions from more compact, mixed-use development can accrue from higher ownership of smaller, more fuel-efficient vehicles; longer vehicle lifetimes due to driving less; smaller homes and more multifamily units, which are more energy efficient than the average single-family home; and more efficient urban truck travel and delivery patterns. Savings from reduced heating and cooling needs per dwelling unit due to a higher share of multifamily units and, to a lesser extent, smaller single-family units could add significantly to the savings from VMT reductions. Over time, however, if the energy efficiency of residential heating and cooling improves, the savings in energy and CO_2 emissions from shifting to multifamily or smaller single-family units will decline proportionately.

Quantification of the Effects

> ***Finding 4:*** *Illustrative scenarios developed by the committee suggest that significant increases in more compact, mixed-use development will result in modest short-term reductions in energy consumption and CO_2 emissions, but these reductions will grow over time.*

The committee's scenarios assume that compact development is focused on new and replacement housing because of the difficulty of converting any significant fraction of existing housing to higher densities. As many as 57 million new housing units are projected to accommodate

population growth and replacement housing needs by 2030, growing to between 62 million and 105 million units by 2050—a substantial net addition to the housing stock of 105.2 million in 2000. Developing more compactly is defined as doubling the current density of new residential development, mainly at the urban fringe where most new development is taking place, but also through some strategic infill. The scenario results depend importantly on assumptions about what percentage of new housing developments will be built compactly and how much less residents of these new, more compact developments will drive. The scenarios do not account for any behavioral feedbacks, but the sensitivity of key assumptions is tested.

In an upper-bound scenario that represents a significant departure from current conditions, the committee estimates that steering 75 percent of new and replacement housing units into more compact development and assuming that residents of compact communities will drive 25 percent less would reduce VMT and associated fuel use and CO_2 emissions of new and existing households by about 7 to 8 percent relative to base case conditions by 2030, with the gap widening to between 8 and 11 percent less by 2050. A more moderate scenario, which assumes that 25 percent of new and replacement housing units will be built in more compact developments and that residents of those developments will drive 12 percent less, would result in reductions in fuel use and CO_2 emissions of about 1 percent relative to base case conditions in 2030, growing to between 1.3 and 1.7 percent less than the base case in 2050. If the residents of compact developments drive only 5 percent less—the lower bound of available estimates—the savings in fuel use and CO_2 emissions would be less than 1 percent compared with the base case, even in 2050. Thus, the committee believes that reductions in VMT, energy use, and CO_2 emissions resulting from compact, mixed-use development would be in the range of less than 1 percent to 11 percent by 2050, although the committee disagreed about whether the changes in development patterns and public policies necessary to achieve the high end of these findings are plausible.

All scenarios increase the density of development and thus represent a departure from current trends. New development in metropolitan areas has occurred at lower than average densities for decades. Nevertheless, doubling the density of 25 percent of new development is possible, particularly by 2050. Average densities for new development would not be higher than the average density of development that existed in 2000, and precedents for higher densities through smaller lot sizes and infill development near major transportation corridors can be found in growing areas such as Phoenix and Portland. Doubling the density of 75 percent of new development by 2050 would be much more challenging. It would require, for example, curtailing most large-lot development or adding a significant proportion of new development as infill to achieve densities above current levels and substantially above a 2050 baseline of continuing low-density development.

The committee disagreed about the feasibility of doubling the density of 75 percent of new development, even by 2050. Those members who believe it possible question whether densities will keep declining. Macroeconomic trends—likely higher energy prices and carbon taxes—in combination with growing public support for strategic infill, investments in transit, and higher densities along rail corridors could result in considerably higher densities by 2050. Other members believe that the curbing of large-lot development at the urban fringe or substantial infill entailed in the upper-bound scenario requires such a significant departure from current housing trends, land use policies of jurisdictions on the urban fringe, and public preferences that those measures are unrealistic absent a strong state or regional role in growth management.

Obstacles and Opportunities

Finding 5: *Promoting more compact, mixed-use development on a large scale will require overcoming numerous obstacles. These obstacles include the traditional reluctance of many local governments to zone for such*

development and the lack of either regional governments with effective powers to regulate land use in most metropolitan areas or a strong state role in land use planning.

Local zoning regulations—particularly suburban zoning that restricts density levels and the mixing of land uses—represent one of the most significant barriers to more compact development. Highly regulated land use markets also limit the supply of compact developments, despite evidence of increased interest in such communities. Land use control is, and has remained, largely a local government function and thus sensitive to local concerns. These local concerns—about congestion, for example, or local taxes or home values—are understandable and legitimate even though they sometimes conflict with other understandable and legitimate regional or national concerns, such as housing affordability or global warming. Land use policies aimed at achieving sweeping changes in current development patterns are thus likely to be impeded by political resistance from existing homeowners and local governments that reflect their interests. This political resistance may help explain why metropolitanwide or state policies aimed at controlling land use and steering development and infrastructure investments are not widespread. It is also the reason why the committee characterized as an upper bound the scenario in which 75 percent of new development is compact.

In the near term, the biggest opportunities for more compact, mixed-use development are likely to lie in new housing construction and replacement units in areas already experiencing density increases, such as the inner suburbs and developments near transit stops and along major highway corridors or interchanges. Coordinated public infrastructure investments and development incentives can be used to encourage more compact development in these locations, and zoning regulations can be relaxed to steer this development to areas that can support transit and nonmotorized travel modes. Market-based strategies, such as congestion pricing and market-based parking fees,

along with zoning requirements for maximum rather than minimum parking, can complement higher-density development patterns that encourage transit use and pedestrian travel. The Portland, Oregon, and Arlington, Virginia, case studies described in this report demonstrate how the application of these policies has led the real estate market to respond with more compact, mixed-use development. In the longer term, if housing preferences and travel patterns change and compact, mixed-use developments become more commonplace, a greater political consensus may emerge in support of stronger state and regional measures to control land use. Policy instruments might include setting urban growth or greenbelt boundaries to steer growth to areas already developed.

Other Benefits and Costs

> ***Finding 6:*** *Changes in development patterns significant enough to substantially alter travel behavior and residential building efficiency entail other benefits and costs that have not been quantified in this study.*

On the benefit side, more compact, mixed-use development should reduce some infrastructure costs, increase the feasibility and cost-effectiveness of public transit, and expand housing choices where compact developments are undersupplied. Other benefits include less conversion of agricultural and other environmentally fragile areas and greater opportunities for physical activity by facilitating the use of nonmotorized modes of travel, such as walking and bicycling.

On the cost side, the savings in highway infrastructure will be offset, at least in part, by increased expenditures for public transit, particularly rail transit, to support high-density development. As noted earlier, moreover, many Americans appear to prefer detached single-family homes in low-density suburbs that are often associated with more privacy, greater access to open space and recreation, and less noise than characterize many urban neighborhoods. Of course, housing

preferences may change in the future with changes in the demographic and socioeconomic characteristics of the population. Moreover, as suggested above, well-designed compact, mixed-use developments may currently be undersupplied because of exclusionary suburban zoning.

RECOMMENDATIONS FOR TAKING ACTION

Recommendation 1: Policies that support more compact, mixed-use development and reinforce its ability to reduce VMT, energy use, and CO_2 emissions should be encouraged.

The committee recognizes that it does not have as much verifiable scientific evidence to support this recommendation as it would like. The committee's own scenarios suggest that compact development will generate only modest reductions in energy use and carbon emissions in the near term, although these savings will grow over time. Moreover, the committee has not examined the other benefits and costs of compact, mixed-use development or how the trade-offs among these benefits and costs might vary by the specific types of compact development policies and the contexts in which they are applied. Nevertheless, climate change is a problem that is likely to be more easily dealt with sooner rather than later, and more energy-efficient development patterns may have to be part of the strategy if the nation sets ambitious goals to move toward greater energy efficiency and reduced production of GHGs. Compact development also promises benefits in the form of reduced pressure for highway construction due to lower growth in VMT. Moreover, compact development does not entail the demise of single-family housing and may, if implemented carefully, reduce housing costs while increasing housing choices.

Given the uncertainties, it would be wise to proceed carefully, monitoring the results and taking into account new research as it adds to the understanding of the benefits and costs that various compact, mixed-use development policies generate at different places and times.

But given that the full energy and emissions benefits of land use changes will take decades to realize and current development patterns will take years to reverse, it is important to start implementing these policies soon.

Recommendation 2: More carefully designed studies of the effects of land use patterns and the form and location of more compact, mixed-use development on VMT, energy use, and CO_2 emissions should be conducted so that compact development can be implemented more effectively.

In particular, the committee identified five areas in which more research would be productive:

• **Longitudinal studies:** Federally funded empirical studies based on panel data would allow better control for socioeconomic characteristics and self-selection, thus helping to isolate the effects of different types of development patterns on travel behavior. Use of longitudinal panel data is the only way to determine how a change in the built environment can lead to a change in preferences and travel behavior in the long run.

• **Studies of spatial trends within metropolitan areas:** Studies that track changes in metropolitan areas at finer levels of spatial detail over time (e.g., the evolution of employment subcenters and changing patterns of freight distribution) would help determine the needs and opportunities for policy intervention.

• **Before-and-after studies of policy interventions to promote more compact, mixed-use development:** Careful evaluations of pioneering efforts to promote more compact, mixed-used development would help determine what works and what does not. The landmark California legislation to reduce urban sprawl and automobile travel offers an obvious example; baseline data should be collected soon so before-and-after evaluations can be conducted.

• **Studies of threshold population and employment densities to support alternatives to automobile travel:** Studies of the threshold densities required to support rail and bus transit would help guide infrastructure investments as well as zoning and land use plans around stations. Current rules of thumb are based on outdated references. Similar threshold information is needed to determine what development densities and land use patterns are optimal to support walking and bicycling.

• **Studies of changing housing and travel preferences:** Studies of the housing preferences and travel patterns of an aging population, new immigrant groups, and young adults are needed to help determine whether future trends will differ from those of the past.

1 | Introduction

The United States after the turn of the century remains a nation with an expanding population and spreading cities. The suburbanization of America is a long-standing trend, made possible largely by the automobile and encouraged by rising incomes and public policies, including public investment in an extensive highway network. For all the mobility it has provided, automobile transportation has also helped make the nation dependent upon petroleum, with associated adverse health effects of vehicular emissions, dependence on imports, and increasing greenhouse gas (GHG) emissions.

The scale of automotive travel and energy consumption is enormous. Transportation on U.S. roads and highways totaled about 3 trillion vehicle miles traveled (VMT) in 2007 and consumed about 176,100 million gallons of gasoline, virtually all from petroleum (FHWA 2009, Table VM-1). (The transportation sector alone consumes more petroleum than is produced domestically.) Cars and light trucks (most of which are used for personal transportation) account for about 17 percent of total annual U.S. energy consumption (Davis et al. 2008, Table 2.1), and this share has been growing. In addition, gasoline consumption, largely by personal vehicles, accounts for about 20 percent of carbon dioxide (CO_2) emissions—the largest source of U.S. GHG emissions, which contribute to global warming (Davis et al. 2008, Tables 11.4 and 11.5).[1]

[1] CO_2 emissions account for 94 percent of all transportation-related GHG emissions (Davis et al. 2008, Table 11.4). Methane, nitrous oxide, and hydrofluorocarbons account for the other 6 percent.

The United States has been increasingly reliant on imported petroleum for decades, so why has the energy consumption associated with low-density development patterns become such a prominent concern, motivating this study? Despite the energy shocks of the 1970s and 1980s and many plans to reduce reliance on imported fuels, demand has only grown, stimulated by declining gasoline prices and consumer preferences for larger, less energy-efficient vehicles during the 1990s. But the terrorist attacks of September 11, 2001, followed by instability in various parts of the Middle East and other oil-producing countries (e.g., Venezuela, Nigeria) and the growth of China and India, began a period of rising oil prices. By July 2008, the price of a barrel of crude oil had reached a historic high in real terms, increasing awareness of U.S. vulnerability to imported fuels.[2] In addition, concern about climate change continues to rise both domestically and internationally, and transportation is a major and increasing contributor to that growing problem. The United States currently accounts for about 33 percent of world CO_2 emissions from road transport (IEA 2006), although emissions have been growing more rapidly in some developing countries, such as China. An additional factor, although less newsworthy, is the health risks resulting from transportation emissions and the difficulty being experienced by many regions in meeting federal clean air standards. At the same time, changing demographics—an aging population, continued immigration—and the possibility of sustained higher energy prices should lead to more opportunities for the kinds of development patterns that could reduce vehicular travel, thereby saving energy and reducing CO_2 emissions.

STUDY CHARGE AND SCOPE

The purpose of this study is to examine the relationship between land development patterns and motor vehicle travel in the United States to support an assessment of the scientific basis for and make appropriate

[2] Since then, however, oil prices have fallen, reflecting the reduction in economic activity due to the current global recession.

judgments about the energy conservation benefits of more compact development patterns. More specifically, the study request, contained in Section 1827 of the Energy Policy Act of 2005 (see Appendix A), calls for consideration of four topics:

- The correlation, if any, between land development patterns and increases in VMT.
- An assessment of whether petroleum use in the transportation sector can be reduced through changes in the design of development patterns.
- The potential benefits of
  - Information and education programs for state and local officials (including planning officials) on the potential for energy savings through planning, design, development, and infrastructure decisions;
  - Incorporation of location efficiency models in transportation infrastructure planning and investments; and
  - Transportation policies and strategies to help transportation planners manage the demand for and the number and length of vehicle trips, including trips that increase the viability of other means of travel.
- Any other relevant topics deemed appropriate for consideration.

The study committee interpreted its charge by both expanding and consolidating the scope. The most important addition was an assessment of the potential benefits of more compact development in reducing CO_2 emissions, which can readily be derived from estimates of reduced petroleum use.[3] On the other hand, the committee determined that evaluating the potential benefits of information and education programs was not feasible through a scientific assessment because the

[3] This addition was approved by staff of the U.S. Department of Energy, which funded the study.

link between such programs and policy outcomes in this arena is too tenuous to be established reliably from the literature. Nevertheless, the committee considered the more general political and institutional context of land development policies both in illustrative case studies and as an important factor in policy implementation. In sum, the committee reorganized its charge into two main components: (*a*) an assessment of the impact of land development patterns, specifically more compact development, on VMT,[4] and (*b*) an estimate of the potential energy savings and reductions in CO_2 emissions resulting from land use policies that reduce VMT.

The study is focused on land development patterns and motor vehicle travel in metropolitan areas of the United States, where more compact development would have the greatest effect. International studies and experience with compact development are considered to the extent that the comparisons are relevant. Decentralized responsibility for land use planning and many other institutional and political differences between the United States and other countries, however, limit the applicability of international experience. The study is also focused primarily on personal travel. Policies that encourage more compact development could affect metropolitan freight distribution and delivery patterns—a topic examined in this study—but those policies target mainly residential and employment location decisions and personal travel.[5]

The remainder of this chapter provides an overview of trends in VMT growth and the primary determinants of that growth. Then, development strategies for curbing VMT are introduced, and the broader context for their merits and limitations is briefly examined. The chapter ends with a summary of the organization of the report.

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[4] VMT is a composite measure—the product of trip length, trip frequency, and mode choice (Ewing and Cervero 2001).

[5] The report addresses commercial and industrial location decisions only to the extent that they affect where people live, work, and shop and their travel to and from these destinations.

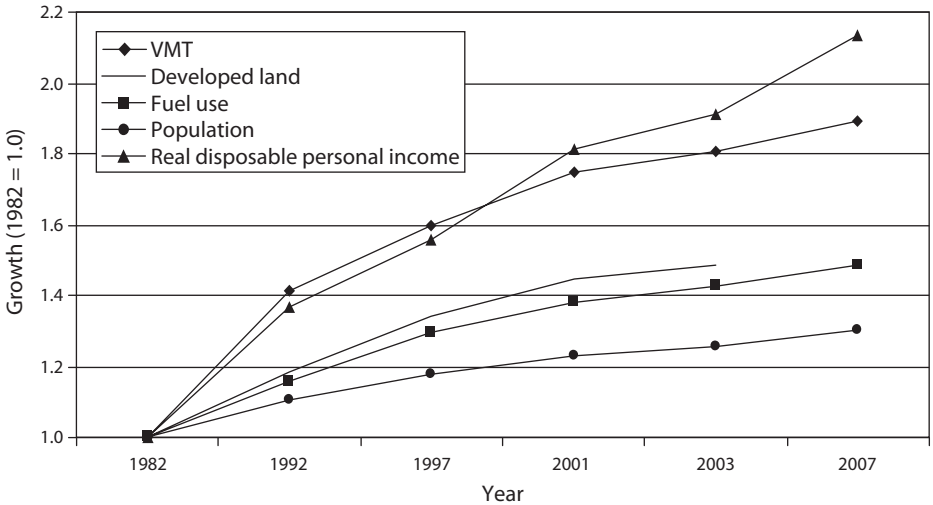

FIGURE 1-1 **Growth in U.S. highway passenger VMT, population, developed land, real disposable personal income, and energy consumption, indexed to 1982.**

Sources: FHWA 2008, Table VM1, for VMT and fuel use; U.S. Bureau of the Census 2008, Table 2, for population; NRCS, various years, for developed land; BEA 2009, Table 2-1, for real disposable personal income.

TRENDS IN VMT GROWTH

For several decades, passenger vehicle travel on U.S. highways has been increasing at a much faster rate than either population or developed land (see Figure 1-1).[6] Low-density development, which has been the dominant U.S. development pattern for generations, spreads destinations farther apart and therefore necessitates longer distances to complete trips. Attributing increased travel to such development patterns has intuitive appeal. However, the factors

[6] VMT statistics are for passenger cars; motorcycles; and other two-axle, four-wheeled vehicles, which include vans, pickup trucks, and sport utility vehicles. The data on developed land are from the *National Resources Inventory* (NRI), described in Chapter 2; these data are not available before 1982, hence the starting date for the graph. The most recent NRI data on developed land are from 2003. The distortion in the *x*-axis is due to the irregular years for which developed land data are available.

affecting VMT growth are far more complex. Like passenger vehicle travel, for example, real disposable personal income has risen more rapidly than either population or developed land. The effects of higher income on highway passenger vehicle travel are manifested in higher levels of automobile ownership and growth in the proportion of households owning multiple vehicles; these trends in turn not only increase trips and travel but also reduce the number of trips made by transit or walking and increase the number of discretionary trips (Memmott 2007).[7] Another plausible explanation for the high rate of growth of VMT during this period is the higher proportion of the driving-age population that became licensed as women completed their entry into the labor force. By 2001, as a result of the confluence of these various factors, 93 percent of all U.S. households owned at least one vehicle (Memmott 2007, 2).

Since about 1997, however, incomes have apparently been rising somewhat more rapidly than VMT, perhaps because of saturation of automobile ownership and the increasing time cost of travel due to congestion. Recent rising gasoline prices (not shown on Figure 1-1), followed by the current recession, have also reduced the growth of VMT, but it remains to be seen whether the reduction will continue.[8]

Of interest, growth in highway passenger vehicle VMT does not track especially well with fuel consumption (see Figure 1-1). Between 1982 and 2007, VMT rose by 189 percent, while passenger vehicle fuel consumption increased by 148 percent, leveling out after 2001.[9] Presumably, improved fuel economy reduced some of the energy use from VMT growth over this period.

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[7] From his analysis of the 2001 National Household Travel Survey, for example, Memmott (2007, 3) found that households in the highest income class (>$100,000) make about 30 percent more trips, and the average length of those trips is more than 40 percent greater than that of trips made by those in the lowest income class ($0–$24,999).

[8] The Federal Highway Administration's monthly traffic volume trends report for January 2009 (FHWA 2009) actually reported a downward trend in VMT that began in November 2007.

[9] The fuel consumption figures are for passenger cars; motorcycles; and other two-axle, four-wheeled vehicles.

The broad trends shown on Figure 1-1 tend to mask the diversity of development patterns and travel within metropolitan areas, a topic addressed more fully in the next chapter. Developed land, for example, can range from 2-acre lots with single-family homes in suburban areas; to ¼- to ⅛-acre lots with single-family homes in the inner suburbs; to much more densely developed multifamily housing, often near office and retail complexes, at densities high enough to support transit. Each of these different development patterns and their locations in a region help determine the length and frequency of trips and the mode of travel employed.

DEVELOPMENT STRATEGIES TO CURB VMT GROWTH

History and Measurement of Land Development Patterns

Current land development patterns, frequently referred to as the built environment, have evolved over many decades, if not generations.[10] The growth of U.S. metropolitan areas and the decentralization of population to lower-density residential areas within central cities and to outlying suburbs can be traced back to at least the 1880s (NRC 1999) and in some cities to the 1810s (Jackson 1985).

During the industrial age, cities grew intensely crowded in the United States and Europe. Most urban dwellers lived in poor housing where they faced high levels of pollution and natural hazards and low levels of public services and open space. The laying of streetcar lines by wealthy U.S. landowners in the latter third of the 19th century enabled the middle class to escape the ills of overcrowded cities, giving rise to the first wave of suburbanization (Warner 1978). Only a small fraction of affluent families, however, could afford to move to the suburbs. In the early 1900s, city planners advocated measures to reduce density

[10] The built environment is broadly defined to include land use patterns, the transportation system, and design features that together generate the need and provide the opportunity for travel (TRB 2005).

and separate land uses. In tune with their recommendations, state governments began to adopt zoning and subdivision reform in the 1920s, and in the 1930s the New Deal brought federal involvement with mortgage insurance, highway planning, and public housing legislation. These reforms set the stage for mass middle-class suburbanization in the postwar period, which was complemented by massive public transportation infrastructure investment in the Interstate Highway System.[11]

As early as the mid-1960s, however, many observers began to see that low-density and separated uses, which encouraged automobile dependence, would cause as many problems as they solved. As the environmental movement was born, critics of mass suburbanization began using the phrase *urban sprawl* to describe the low-density, dispersed, single-use, automobile-dependent built environment that—in their view—wasted energy, land, and other resources and exacerbated racial divisions (Burchell et al. 2002).[12]

Since the 1960s, at least two waves of planning reform have elevated land development patterns to national prominence. In the 1980s, suburb-to-suburb commuting led to a significant increase in traffic, prompting the creation of new growth management initiatives, some of which sought to contain spreading cities through such measures as urban growth boundaries. In the 1990s, fueled by large-lot development at the urban fringes, the *smart growth* movement discussed later in this chapter changed the development debate from the traditional emphasis on growth/no growth to a focus on how and where new development could best be accommodated (Knaap 2006).

Until recently, land use reformers had not defined sprawl very precisely; advocates liked the word partly because of its conceptual fuzziness

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[11] Suburban population growth increased following World War I and more rapidly following World War II (NRC 1999).

[12] The first use of the term *urban sprawl* is attributed to an essay with this title, written by William H. Whyte for *Fortune* magazine and reprinted in *The Exploding Metropolis,* a collection of six *Fortune* articles about the American city edited by Whyte and published in 1958 (Whyte 1958). Shortly thereafter, in 1961, Jane Jacobs published her seminal work *The Death and Life of Great American Cities* (Jacobs 1961).

(Markusen 1999). Better practice and replicable modeling, however, demanded more rigor. Responding to the need for clarity, academic observers began to sharpen measures to distinguish the real effects (and causes) of a variety of land development patterns. Consensus has now emerged on some of the important dimensions on which land development patterns should be measured, although work on quantifying the consequences of these patterns is still in its infancy.

Most observers agree that *density* is an essential dimension of land development patterns and seek to test whether (as suspected) low-density development has a variety of harmful consequences. Recent literature stresses the importance of measuring density on the basis of people (residents, households, or businesses) or buildings (houses, business spaces) per acre of developed land, as opposed to using overall land area within a city or county as the denominator (see, for example, Fulton et al. 2001; Galster et al. 2001; Carruthers and Úlfarsson 2008).[13] A second critical measure is the *mix* of land uses within neighborhoods and districts; a land use pattern in which highly complementary activities are separated in space is considered more sprawling (Cervero and Kockelman 1997; Galster et al. 2001; Ewing et al. 2002). Third, the concentration of development in one or more high-density *centers* of employment (or mixed-use centers) outside the central business district is hypothesized to have potentially important effects on travel, facilitating transit use and walking and shortening automobile commute trips by bringing jobs closer to housing. Researchers, however, are in less agreement about either the measurement or the potential impact of centering. Fourth, a range of measurements describe the *spatial arrangement* or *contiguity* of land uses with respect to each other.

[13] When the entire land area of a county is used in the denominator, vast areas of undeveloped and undevelopable land will often be included. Some cities are also very expansive because they contain large areas of parkland and even vacant farmlands. If density is measured according to the surface area of a whole jurisdiction or county, then two areas with different boundaries may have very different density measurements even with identical built environments.

Key concerns include, for example, the relationship between developed and undeveloped land and the average proximity of business and residential uses. Development that is discontinuous—that leapfrogs beyond undeveloped land—is considered more sprawling (Galster et al. 2001). A fifth area under consideration and measurement is the *design* of street fronts and neighborhoods in ways that encourage walking and bicycling (e.g., presence of attractive houses and stores, shade, planting) (Cervero and Kockelman 1997).

As measurement of land uses has progressed, so, too, has that of transportation systems and their relationship to land use. Transportation networks complement and interact with land development patterns, necessitating independent measurement of transportation networks and their relationship to development (Ewing and Cervero 2001). One key set of transportation infrastructure measures concerns the spatial pattern of *transportation networks:* whether they are sparse or dense; whether they are arranged in grids that improve connectivity versus a hierarchy of streets resembling the branching of rivers, trees, or blood vessels that may lead to circuitous routes or end in cul-de-sacs; whether they feature a strong fixed-rail transit network; and so on. Two other characteristics measure how transportation networks interact with development patterns to affect accessibility. *Destination accessibility* measures the ease or convenience of trip destinations relative to point of origin and is often measured at the regional level in terms of distance relative to the central business district or other major centers (Ewing and Cervero 2001). *Distance between development and transit,* either rail stations or bus stops, has been thought to have a separate and significant effect on the likelihood that people will use transit.

Strategies

Various strategies are being tried to counter sprawl, including increasing the density, mix, contiguity, connectedness, and pedestrian orientation of development and implementing steps to encourage nonautomotive

travel. These strategies are referred to by such terms as *transit-oriented development, neotraditional design,* and *smart growth.* The smart growth movement, for example, is a broad coalition of interests representing land and historic building trusts, environmental groups, planning organizations, and public interest groups and is often associated with advocacy positions. For purposes of this report, the committee sought a more neutral term; hence, strategies to reduce sprawl are all referred to as *more compact, mixed-use development*.

The Broader Context

The topics of sprawl and compact, mixed-use development are often contentious.[14] Proponents of more compact development see various possible benefits from future land use patterns that concentrate more housing and employment on less acreage. More compact development reduces distances between origins and destinations, thereby reducing trip lengths and VMT.[15] To the extent that more compact development encourages transit and nonmotorized travel, it may also reduce congestion and air pollution. Debate on the merits of antisprawl, compact development, however, turns on more than density and reduction of automobile dependence and VMT. More compact development also reduces the cost of providing infrastructure, increases the feasibility and cost-effectiveness of transit, increases the feasibility of providing moderately priced housing and provides more housing choices, and may foster a greater sense of community. Other benefits include less demand for undeveloped land and for conversion of agricultural and other lands, including environmentally fragile areas, such as wetlands and sensitive watersheds (Burchell et al. 2005). Finally, less development of land reduces runoff into streams and receiving waters and preserves open space.

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[14] For two views, see the point (Bruegmann 2008) and counterpoint (Crane 2008) articles in the first issue of the *Journal of Transport and Land Use*.

[15] The examples of benefits are drawn from Downs (2004, Chapter 12).

Critics of compact development claim that proponents ignore its costs. Although a good argument can be made that compact, mixed-use development is undersupplied to meet existing demand (Levine 2005), the higher densities of most compact developments involve trade-offs.[16] They allow, for example, less personal space for individuals and families than has been the norm for many new residential developments, often entailing more housing units on an acre of land than has been typical in recent decades. Whether this would be perceived as an undesirable cost for many—and in particular the extent to which higher residential density would require a shift from detached single-family to attached housing styles—is explored later in this report. Neither proponents nor critics of compact development are well informed about how people's housing preferences are formed or how they might change in the future, the topic of Chapter 4. As also discussed later, it is possible for increased densities to increase congestion, or at least the time required to complete trips, and lead to higher levels of noise and air pollution. More concentrated development may also contribute to the urban "heat island" effect resulting from the greater heat retention of urban surfaces, creating higher temperatures and electricity use (particularly for cooling) than characterize surrounding areas of more dispersed development; very compact development, however, may also limit the heat island effect if associated with a reduction in surface area covered with parking lots. This report focuses mainly on the effects of compact development on VMT, energy use, and CO_2 emissions, although the wider benefits and costs are also noted.

Those seeking to address energy and climate change issues through land development strategies aimed at reducing VMT must also confront certain realities about the length of time necessary to affect VMT through changes in the built environment and the difficulties of making a substantial dent in petroleum imports in the near term. The

[16] Levine argues that current land use regulations and the local governments that promulgate them are biased toward single-family residential zoning and automobile-dependent development that effectively zones out compact development alternatives.

desirability of energy self-sufficiency in general is debatable; trade is beneficial for each partner because of the exploitation of comparative advantage.[17] Moreover, the nation and the world are far from achieving consensus on how to share the burden of reducing GHG emissions. Nevertheless, as discussed later in the report, turnover of the housing stock over the next several decades provides opportunities for change that, along with the above-noted aging of the population and the arrival of new immigrants, may result in location and housing preferences for a greater number of compact developments than are in evidence today.

ORGANIZATION OF THE REPORT

The next two chapters are focused on the potential effects of land development policies on VMT—the first part of the committee's charge. Chapter 2 describes trends in land development at the national and metropolitan area scales and also within metropolitan areas, particularly changes in population and employment densities and their implications for travel. Chapter 3 examines the empirical evidence on the relationship between the built environment and VMT by reviewing the enormous literature that has developed on the topic over the past two decades. Quantitative estimates of VMT reductions from more compact development are provided from the most reliable studies, but methodological and data problems hinder making more definitive statements about the magnitude of expected impacts.

The next two chapters are focused on the second part of the committee's charge—estimating the potential future energy savings and reductions in CO_2 emissions from more compact development. Chapter 4 helps set the stage by projecting how much new construction might be

[17] The term *comparative advantage* refers to the ability of a country to produce a product at a lower marginal cost and opportunity cost than another country, that is, where the country has a relative cost advantage. In a simplified two-country, two-product world, each country gains by specializing in the good in which it has the comparative advantage and in trading that good for the other.

expected in the coming decades to provide perspective on the numbers of residences and workplaces that could be influenced by more compact development strategies. Chapter 5 applies the results from the earlier chapters to develop scenarios for estimating the extent to which these strategies might reduce VMT and related energy consumption and CO_2 emissions by 2030 and 2050. It examines the plausibility of reaching the development densities implicit in these scenarios, an area of disagreement among committee members. The chapter also considers other closely related benefits of more compact development, such as improved residential energy efficiency from increasing multifamily housing units or developing housing on smaller lots, as well as the costs of compact development. A final chapter presents the committee's recommendations for policy and research.

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Abbreviations

BEA	Bureau of Economic Analysis
FHWA	Federal Highway Administration
IEA	International Energy Agency
NRC	National Research Council
NRCS	National Resources Conservation Service
TRB	Transportation Research Board

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2 | Trends in Development Patterns

As a prelude to examining the relationship between land development patterns and vehicle miles traveled (VMT), this chapter provides background information on development patterns in the United States. It begins with a review of national and metropolitan area trends with respect to population and land development. The chapter then turns to an examination of spatial trends within metropolitan areas, the primary geographic focus of this study, including changes in population density and employment concentration over time, topics on which the most data are available. The chapter ends with findings concerning metropolitan development trends and their implications for travel.

NATIONAL AND METROPOLITAN AREA TRENDS IN POPULATION AND DEVELOPMENT

The U.S. census is the traditional source of long-term data on population trends by geographic area. Census data from 1970 to 2000 show that the U.S. population has continued to urbanize and suburbanize. As a share of total population, metropolitan population increased from 69 percent in 1970 to 80 percent in 2000 (Hobbs and Stoops 2002 in Giuliano et al. 2008, 11). Within metropolitan areas, however, the population has continued to suburbanize. From 1970 to 2000, the suburban population slightly more than doubled, from 52.7 million

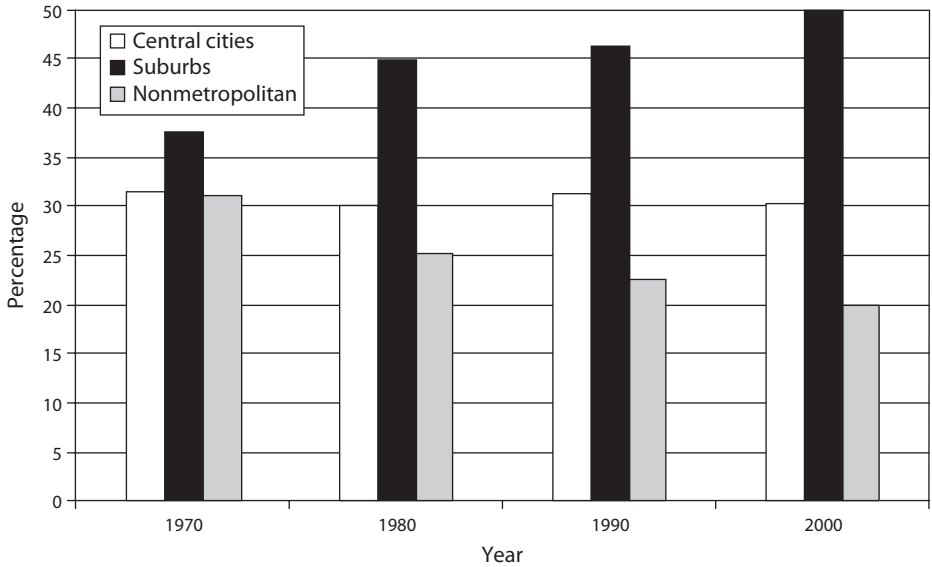

FIGURE 2-1 **Percentage of total population living in central cities, suburbs, and nonmetropolitan areas, 1970–2000.**

Source: Hobbs and Stoops 2002, 33, in Giuliano et al. 2008, 12.

to 113 million.[1] This growth occurred mainly at the expense of nonmetropolitan areas. Population in central cities grew, but only by about 55 percent, from 44 million to 68.5 million, while nonmetropolitan population declined from 63 million to 55.4 million (Giuliano et al. 2008, 11) (see Figure 2-1 for percentage changes). In terms of relative share, the suburban population increased from 54.5 percent of the total metropolitan area population in 1970 to more than 62 percent in 2000.

Jobs have followed population to the suburbs, although with a lag. In 1970, for example, 55 percent of jobs were still located in central cities (Mieszkowski and Mills 1993, 135). By 1990, that share had fallen to 45 percent.

[1] The U.S. Bureau of the Census does not identify a location as "suburban." Metropolitan areas are divided into two classifications: (*a*) inside central city and (*b*) outside central city. Many researchers treat the latter areas as suburban, and they are so treated in this report (see Giuliano et al. 2008, Appendix B).

Another way to look at population and development trends is to focus on land development patterns and how they have changed over time, the principal concern of this study. According to the U.S. Department of Agriculture's *National Resources Inventory* (NRI),[2] between 1982 and 2003, an estimated 35 million acres of land (55,000 square miles) was developed in the United States—approximately one-third of all the land that had been developed by 2003.[3] In all, 108.1 million acres was classified as developed in 2003—approximately 5.6 percent of the national total. Developed land grew at almost twice the rate of population over this 21-year period, clearly indicating that population densities were declining.[4]

Population and land development patterns, however, exhibit considerable variation across the United States. For example, some rapidly growing western states, such as California, Nevada, and Arizona, added population to their metropolitan statistical areas (MSAs) at a faster rate than they were spreading out (Fulton et al. 2001).[5] At the same time, slowly growing MSAs of the northeast and midwest expanded in land area even as their population growth slowed or reversed. Overall, the northeast and midwest regions each gained about 7 percent in population, but their urbanized land increased by 39 and 32 percent,

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[2] The NRI is a national longitudinal panel survey based on a sample of nonfederal land in all 50 states and Puerto Rico. Periodic inventories are conducted to estimate changes in the amount of developed land, among other objectives. Consistent data for this purpose are available going back to 1982.

[3] According to the NRI, developed land covers a combination of land use categories, including urban and built-up areas and rural transportation land (NRCS 2002).

[4] Developed land grew from 72.9 million acres in 1982 to 108.1 million acres in 2003, a 48 percent increase (NRCS 2007, 5), while the U.S. resident population increased from 232.2 million in 1982 to 290.9 million in 2003, nearly a 25 percent increase (U.S. Bureau of the Census 2008, 7).

[5] Land use trends examined by Fulton et al. are focused on the "urban and built-up" category of developed land as defined by the NRI, which the authors define as urbanized land. Population data are focused on MSAs, a U.S. census designation. An MSA is defined as a core-based statistical area associated with at least one urbanized area that has a population of at least 50,000. The MSA comprises the central county or counties containing the core, plus adjacent outlying counties having a high degree of social and economic integration with the central county as measured through commuting (OMB 2000).

respectively, between 1982 and 1997, the most recent year for which urbanized land data are available. In comparison, while the west and south gained 32 and 22 percent, respectively, in population, their land area grew by 49 and 60 percent, respectively (Fulton et al. 2001, 19). These data are too broad to ascertain whether MSA development is occurring in ways that could shorten automobile trips and support alternative modes of transportation. In the following section, spatial patterns of residential and employment development are examined at a finer geographic scale within metropolitan areas.

SPATIAL TRENDS WITHIN METROPOLITAN AREAS

Spatial trends within metropolitan areas encompass both the density and the location of development.

Density of Development

As noted in Chapter 1, density is one of the most commonly used measures to characterize development patterns. The level of density also has implications for travel. The length of trips taken in metropolitan areas with higher densities should be shorter than the length of those in areas with low densities, assuming that other built environment dimensions are the same. As density rises, trip origins become closer to trip destinations, on average. In addition, metropolitan areas with comparatively high average density tend to have centers where population and employment are dense enough to support transit service at levels that make it competitive with the automobile.

Density is often measured in terms of persons per square mile of total area within a city or county, as in the U.S. census. As noted in Chapter 1, however, this measure does not adequately capture development patterns, as some cities and counties contain large amounts of undeveloped land, while others are completely developed. Researchers employ several approaches to improve on this measure by using devel-

oped land on which people or jobs are located as the denominator. Fulton et al. (2001) use land-cover data from the NRI, for example, while Cutsinger and Galster (2006) set "extended urban area" (EUA) boundaries on the basis of census definitions and thresholds and identify developed and developable land within the EUAs to establish their denominator. Ewing et al. (2002) combine a series of density measures using both NRI and census results to create a standardized density index that forms one of four factors within their overall "sprawl" index.

On the basis of Fulton's measure, of the 281 MSAs studied, density levels ranged from more than 20 persons per urbanized acre in New York and Jersey City to fewer than 2.5 persons per urbanized acre in Scranton, Charlotte, Knoxville, and Greenville–Spartanburg.[6] The list of dense metropolitan areas—those over the 75th percentile density of 5.55 persons per urbanized acre—features a significant number of older metropolitan areas established before the advent of the automobile: the primary MSAs within metropolitan New York, San Francisco, Chicago, Buffalo, Providence, Washington, Boston, and New Orleans.[7] But many areas that have experienced most of their growth since World War II also appear in this group, including Los Angeles–Long Beach (10.0 persons per urbanized acre), Anaheim–Santa Ana (9.2), San Jose (8.5), Las Vegas (6.7), and Phoenix (7.2). Perhaps more surprising, when considered over time, the fastest decline in density has not been occurring in areas often considered to be epicenters of sprawl. Las Vegas, Denver, Phoenix, and Riverside–San Bernardino, for example, all had population growth that exceeded growth in urbanized land according to the NRI data. Using other methods, Galster et al. (2001) and Ewing et al. (2002) confirm the relatively high density of California

[6] Fulton's measures are based on 1997 data and census definitions of MSAs and consolidated MSAs (CMSAs) that were replaced by the Office of Management and Budget's new standards for defining metropolitan and micropolitan statistical areas in 2000.

[7] A primary MSA is a major urban area within a CMSA, an urbanized county or set of counties with strong social and economic ties to neighboring communities.

metropolitan areas, Las Vegas, and Phoenix and the low density of metropolitan areas in the southeast.

Larger residential lot sizes are at least partly responsible for the rapid decline in density in some metropolitan areas. From 1987 to 1997, the density of the average urban acre declined from 1.86 dwelling units (DUs) per acre to 1.66 DUs per acre, largely because the new development over this period was built to a density of only 0.99 DUs per urban acre, bringing down the overall average.[8] Recent results of the American Housing Survey, however, suggest a wide variation in lot sizes across metropolitan areas. For example, between 1998 and 2002, the median lot size for new one-family houses in the Anaheim–Santa Ana area (Orange County, California) was only 0.17 acre; in Portland (Oregon), 0.19 acre; and in Denver, 0.21 acre—all metropolitan areas defined as higher density. In Atlanta, a metropolitan area noted for its more dispersed land development patterns, the median lot size was 0.58 acre; in Hartford, at the extreme, it was more than 1.5 acres.

It is worth noting that a traditional rule of thumb for the density needed to support transit is 7 to 15 DUs per residential acre, or a gross density of more than 4,200 to 5,600 persons per square mile (Pushkarev and Zupan 1977, 177, in Downs 2004). No MSA in the country is that dense across its entire region, although for the 40 or so largest MSAs, areas within their boundaries exceed this minimum density. According to the 2000 U.S. census and the national database of the Center for Transit-Oriented Development, a total of about 14 million people, representing 6.2 million households, live within a half-mile radius

[8] The density calculations are based on the NRI's land-cover data, which were aggregated to correspond with U.S. census designations for metropolitan areas as defined in 1999. The NRI's urban and built-up land category is used as the denominator, and intercensal estimates of housing units at the metropolitan level as the numerator. Changes in density are discussed in more detail in Chapter 5 and Appendix C. The reader should note that 0.99 DU per urban acre does not directly translate into residential lot sizes of 1 acre, nor is it equivalent to the lot sizes used in the American Housing Survey. NRI-defined urban acres include not only residential land but many other uses. See Appendix C, Box C-1, for more details.

of existing fixed-route transit stations in the 27 metropolitan areas studied (Center for Transit-Oriented Development 2004, 18).[9] The half-mile radius is considered to be a reasonable catchment area for having an impact on the travel behavior of area residents (i.e., encouraging a mode shift to transit).

Location of Development

The distribution of population and employment in a metropolitan area is determined by the relative strength of economies and diseconomies of agglomeration—the clustering of economic activities because of economies of scale, reduced transportation costs, and many other benefits.[10] The standard monocentric urban model assumes the existence of an employment center, such as the central business district (CBD), and distributes households in relation to that center on the basis of trade-offs between the costs of housing and the costs of commuting (Anas et al. 1998 and Fujita 1989 in Giuliano et al. 2008). The model predicts declining and constantly decreasing population density the farther an area is from the CBD or city center as households face the trade-off between lower housing costs (land costs are lower farther from the city center) and higher commuting costs. Decentralization is accelerated by growth in real per capita income and declining unit (e.g., per mile) transportation costs as households seek to consume more housing and locate farther away from the city center (Mieszkowski and Mills 1993).

Researchers have employed many different measures to analyze the concentration (and dispersion) of both population and employment and clustering in centers, such as the CBD or newer suburban employment

[9] The Center for Transit-Oriented Development has created the first national database with information on 27 metropolitan areas that have some form of fixed-route transit, including heavy and light rail, commuter rail, streetcars and trolley buses, bus rapid transit, and cable cars.

[10] This section draws heavily on the literature review commissioned by the committee on metropolitan spatial trends in employment and housing (see Giuliano et al. 2008).

centers.[11] *Centrality* is a measure of the extent to which the development within a metropolitan area spreads out from a point of highest density. Closely related to centrality is the *density gradient,* a measure representing average density at increasing distances from the center.

Residential Location

As population density within some metropolitan areas has declined, so have density gradients. Kim (2007) analyzed population data for a consistent group of 87 cities with populations of at least 25,000 and their metropolitan areas from 1940 to 2000 to examine changes in population density and density gradients.[12] He assumed a monocentric metropolitan area to estimate density gradients. He found that average population density levels have declined since 1950, and the estimated density gradient has declined consistently over the entire period studied (see Table 2-1). Kim suggests that the accelerated flattening of the density gradient since 1950 is likely due not only to the suburbanization of the population but also to the expansion of suburban land area, as found by Fulton et al. (2001). The rate of change in both average density levels and the density gradient appears to have begun slowing in the 1990s, but this trend cannot be definitively established because Kim's city sample excludes cities that failed to meet the metropolitan area definitions of 1950.

Monocentric models and average measured density gradients, while reasonable for capturing broad trends in urban form, mask internal dynamics that may be more useful in ascertaining the evolution of

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[11] Various terms have been used to denote employment centers outside the CBD—*activity centers, subcenters, subcity employment centers, edge cities, job concentrations, employment poles,* and *employment centers* (see Guiliano et al. 2008 and Lee 2007 for discussion of each). The term *employment center* is used in this report.

[12] Kim (2007) notes that population density is typically measured as persons per square mile. The density gradient is usually estimated by using a negative exponential function: $D(x) = D_o e^{-yx}$, where $D(x)$ is population density at distance x from the center; D_o is the density at the center; and y, the density gradient, is the proportional rate at which population density falls with distance from the center.

TABLE 2-1 **Spatial Trends, Urban Population, 1940–2000**

	Central City–Metro Population Ratio		Average Metro Density (persons per square mile)		Density Gradient	
Year	**Ratio**	**Change**	**Density**	**Change**	**Gradient**	**Change**
1940	0.61	—	8,654	—	–0.72	—
1950	0.57	–0.04	8,794	140	–0.64	–0.08
1960	0.50	–0.07	7,567	–1,227	–0.50	–0.14
1970	0.46	–0.04	6,661	–906	–0.42	–0.08
1980	0.42	–0.04	6,111	–550	–0.37	–0.05
1990	0.40	–0.02	5,572	–539	–0.34	–0.03
2000	0.38	–0.02	5,581	9	–0.32	–0.02

Source: Giuliano et al. 2008. Adapted from Kim 2007, 283.

population and employment distributions within metropolitan areas (Giuliano et al. 2008). Nor do they provide a sufficiently detailed picture of the rich urban landscape. Outside the central city, density levels can vary greatly, from the generally more dense inner suburbs, to the very low densities of many outer suburbs, to housing complexes and communities of varying densities in between—all with different implications for travel and trip making.

Employment Location

In the field of economic geography, special attention has been paid to the location of employment, leading to the characterization of employment in metropolitan areas as monocentric, polycentric, or noncentered or dispersed (Lee 2007). The monocentric model has increasingly lost its explanatory power as employment has decentralized and the reasons for clustering in a single CBD have diminished (see Clark 2000 in Lee 2007). Two competing views have emerged with regard to the implications

of this decentralization for urban form. The first and dominant view, according to Lee (2007), holds that metropolitan areas are polycentric, increasingly characterized by the presence of multiple activity nodes or employment centers. The second view (Glaeser and Kahn 2001; Lang and LeFurgy 2003) holds that suburban employment should be conceived of as being dispersed, not polycentered (Glaeser and Kahn 2001). Lang and LeFurgy (2003) provide data that support the second view, at least as it relates to the dispersion of office space. In 13 of the nation's largest office markets, for example, most metropolitan rental office space exists either in high-density downtowns or in low-density edgeless cities, not in employment centers outside the CBD.[13]

Understanding employment patterns, particularly the factors that lead to the formation of employment centers outside the CBD, has particular relevance for the present study. Travel patterns are influenced by the density of commercial as well as residential development, particularly the density of development at the job end of the daily commute (Cervero and Duncan 2006). Of particular interest is whether jobs are clustering outside of the center city in aggregations large enough to support transit; encourage mixed-use development near job sites within walking distance; or facilitate shorter automobile trips because jobs are located closer to residents, thereby improving the jobs–housing balance.

A review of the literature in a paper commissioned for this study (Giuliano et al. 2008) finds support for the view that decentralization of employment in metropolitan areas has resulted in new agglomerations outside the CBD. The presence of employment centers is demonstrated across metropolitan areas of varying size, age, location, and growth rates (see Table 8 and discussion in Giuliano et al. 2008). Nevertheless, the authors note that, despite the presence of these centers, most metropolitan employment is dispersed; the share of employment outside centers is on the order of two-thirds to three-fourths (Giuliano

[13] Medium-density office environments of edge cities and secondary downtowns constitute just one-quarter of metropolitan office space (Lang and Le Furgy 2003).

et al. 2008, 32). The authors conclude, however, that this finding fails to support the view that today's metropolitan areas are better described as dispersed; rather, they exhibit both employment concentrations and dispersion.[14]

Only a handful of studies could be found that examine trends in employment patterns over time. The first, by Lee (2007), uses a series of centralization and concentration indices to examine patterns of employment change in six large metropolitan areas, from 1980 to 2000 for San Francisco and Philadelphia and from 1990 to 2000 for New York, Los Angeles, Boston, and Portland. Lee reports that development trends reinforced the polycentricity of Los Angeles and San Francisco, as a significant proportion of decentralizing jobs reconcentrated in suburban centers, but concludes that California metropolitan areas are not typical. Philadelphia, Portland, New York, and Boston are more monocentric, with the CBD housing a larger proportion of all center employment. Nevertheless, the CBDs of Philadelphia and Portland lost share; jobs dispersed without significant suburban clustering. In comparison, the well-established CBDs of Boston and New York were better able to retain their strength as city centers even as growth occurred on their peripheries.

Lee concludes that job dispersion is occurring as jobs continue to decentralize to the suburbs. However, he notes remarkable variation in spatial trends and evidence of suburban agglomerations just among the six metropolitan areas studied. He attributes the differences to history, topography, and the requirements of different economic sectors. Cities like New York, Boston, and Philadelphia, whose core areas were developed before the 20th century, have retained more of their monocentric character and radial development patterns, the result of path-dependent growth and the durability of the built environment.

[14] Giuliano et al. further explain that some proportion of employment (e.g., retail, many services) has always been dispersed, locating near the population it serves. Without historical data to determine what proportion of employment was similarly disbursed in earlier decades, it is impossible to make definitive generalizations about changes in employment dispersion.

Portland's monocentricity can best be explained by its relatively small size. And the polycentric character of San Francisco and Los Angeles is reinforced by their history and topography.

The second study is a case study of the Los Angeles metropolitan area, focused on the urbanized area portion of the five-county Los Angeles consolidated MSA (CMSA), comprising Los Angeles, Orange, Riverside, San Bernardino, and Ventura Counties (Giuliano et al. 2008). The researchers found evidence of both decentralization and deconcentration of employment.[15] The share of jobs in the densest 10 percent of land area declined from about 84 percent in 1980 to 71 percent in 2000 (Giuliano et al. 2008, 21). Employment concentrations also decentralized; the average (employment-weighted) distance of all census tracts to tracts with at least 20 jobs per acre increased from 8.3 miles in 1980 to 11 miles. Nevertheless, overall the region's employment remained highly concentrated. While Los Angeles County lost jobs between 1990 and 2000, it still housed the largest number of jobs in 2000 by nearly a factor of three compared with Orange County, which had the next highest employment level. Furthermore, employment centers grew over the period, from 36 centers identified in the 1980 data to 46 and 48 centers in 1990 and 2000, respectively (Giuliano et al. 2008, 21).[16] The share of county employment in centers remained steady in Los Angeles County but increased in Orange County, particularly in suburban areas northwest and southeast of the Los Angeles CBD that had become more urban over this period. In contrast, the outer suburbs are in a different stage of development and exhibited rapidly growing but dispersed employment.

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[15] The researchers used census tract–level employment data by place of work and population data from the U.S. census to analyze changes in employment and population from 1980 to 2000. Employment data were obtained from the Southern California Association of Governments and are based on employment records from the California State Economic Development Department. They were verified by using other data sources, such as Dunn and Bradstreet.

[16] Employment centers are defined on the basis of criteria outlined by Giuliano and Small (1991).

The authors also examined the impact of employment distribution on travel patterns, of particular interest to the present study. They found considerable variation in the economic characteristics and design of employment centers that affect commuting, particularly by transit. For example, the Los Angeles CBD is a mixed-use area with high average employment density and a transit system focused on the downtown, accounting for its high transit share (see Table 18 in Giuliano et al. 2008). In contrast, the Santa Ana–Irvine center, which is located around the Orange County airport, stands out for its high drive-alone share, reflecting its emergence around several major freeways and its automobile-oriented design. These examples illustrate the importance of employment center characteristics for travel behavior.

A third study (Lee et al. 2006) examines the employment trends and commuting patterns of 12 CMSAs from 1980 to 1990. The highest-growth CMSAs had the highest employment growth, but in all cases the total share of jobs in the central city declined (see Table 2-2).[17] Some cities fared better than others. New York and Chicago, for example, had minor share losses. In Denver, the central city share of employment dropped by 10 percentage points between 1980 and 1990. Cleveland and Detroit also registered substantial employment losses in the central city in what has come to be called a "hollowing out" phenomenon.

Changes in commuting patterns generally reflect differences in high-growth versus slow-growth cities. In all the CMSAs, the share of suburb-to-suburb commuting increased, while all other shares decreased (Lee et al. 2006 in Giuliano et al. 2008). CMSAs in the south and west had the greatest increase in commute flows, reflecting their more rapid growth and higher share of suburb-to-suburb commutes, and many showed resulting increases in average travel times. In contrast, longer travel times for suburb-to-suburb commutes in CMSAs in the northeast and midwest were partially offset by shorter

[17] The central city share depends on how large the central city is in relation to the total CMSA (Giuliano et al. 2008).

TABLE 2-2 **Employment Trends Inside and Outside the Central City, 1980–1990**

	Northeast			Midwest			South	West				
	Buff	NYC	Phil	Chic	Clev	Detr	Hous	Denv	LA	Port	SF	Sea
Percent change												
Total employment	13.2	26.7	28.6	20.3	9.1	19.1	34.9	30.9	48.8	34.8	42.1	48.8
Central city	1.2	22.2	7.7	13.3	–4.0	–6.9	22.4	4.0	32.7	23.8	23.3	21.8
Not central city	21.0	30.5	37.2	25.3	14.7	29.2	61.3	56.2	58.4	43.4	46.8	66.5
Central city share (%)												
1980	39	46	29	41	30	28	68	49	37	44	20	39
1990	35	45	25	39	26	22	62	39	33	41	17	32

Note: Buff = Buffalo; NYC = New York City; Phil = Philadelphia; Chic = Chicago; Clev = Cleveland; Detr = Detroit; Hous = Houston; Denv = Denver; LA = Los Angeles; Port = Portland; SF = San Francisco; Sea = Seattle.

Source: Guiliano et al. 2008, 17. Adapted from Lee et al. 2006, 2528, 2532–2534.

travel times in other categories, reducing the increase in metropolitan area averages.

Two other studies explore changes in the jobs–housing balance in metropolitan areas and how these changes have affected commuting travel. Horner (2007) examines changes in the relative distribution of workers and jobs in the Tallahassee metropolitan area between 1990 and 2000. He reports that the proximity of workers and jobs declined over the period with the decentralization of jobs. The actual average commute distance, however, increased by only 0.3 mile. Horner attributes this result in part to job adjustments by workers and to efforts of land regulators and developers to maintain a good jobs–housing balance (Horner 2007 in Giuliano et al. 2008). Data are not available with which to determine the number of workers living in a zone who actually work in that zone, which could partially explain the lack of change in commute distance.

Yang (2008) conducted a similar study of Boston, a relatively compact metropolitan area, and Atlanta, a lower-density metropolitan area without strong transit and with few mixed-use areas, to examine changes in the distribution of workers and jobs from 1980 to 2000. The average commute time and distance were shorter in Boston than in Atlanta, reflecting the greater proximity of jobs and housing in the former. Both areas showed an increase in the distance between the average resident and the average job over the period, but this increase did not translate into significantly longer commute distances. During the period, estimated actual average commute distances increased by about 3 miles in Boston and about 2.25 miles in Atlanta (Giuliano et al. 2008, 19).[18]

A final study—an analysis of metropolitan employment trends from 1998 to 2006 that builds on the work of Glaeser and Kahn (2001)—found that employment has continued to decentralize (Kneebone 2009).

[18] In percentage terms, the estimated actual average commute distance in Boston increased by 43 percent, from 7.1 miles in 1980 to 10.2 miles in 2000. In Atlanta, the percentage increase was only 19 percent, from a higher base of 11.6 miles in 1980 to 13.8 miles in 2000.

Private-sector jobs in 95 of the 98 largest metropolitan areas studied saw a decrease in the share of jobs located within 3 miles of a downtown.[19] Although the 98 metropolitan areas experienced a 10 percent overall increase in the number of jobs within 35 miles of downtown, the urban core saw an increase of less than 1 percent; the middle (3 to 10 miles) and outer (more than 10 to 35 miles) rings saw increases of 9 percent and 17 percent, respectively (Kneebone 2009).[20] As of 2006, approximately one-fifth (21 percent) of employees in the top 98 metropolitan areas worked within 3 miles of a downtown; more than twice that share (45 percent) worked more than 10 miles from the city center. The larger the metropolitan area, the more likely people were to work more than 10 miles away from the downtown. Type of industry also mattered. More than 30 percent of jobs in utilities and in financial and insurance and educational services were located within the urban core, while about half the jobs in manufacturing, construction, and retail were located more than 10 miles away (Kneebone 2009). The author concludes that the dominant trend during the study period was further dispersion of jobs toward the metropolitan fringe. The study, however, was not designed to examine the extent to which suburban employment centers were forming outside the CBD during the period.

FINDINGS AND IMPLICATIONS FOR TRAVEL

The data presented in this chapter support the finding that while the majority of the U.S. population (80 percent in 2000) lives in metropolitan areas, population and employment have continued to suburbanize.

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[19] Downtowns are defined to include not only CBDs but also other primary cities in the metropolitan areas meeting certain size requirements. The employment data exclude government employees, whose jobs tend to be more centralized (Kneebone 2009).

[20] To identify the geographic distribution of jobs in each metropolitan area, three rings were drawn around each CBD: one at a distance of 3 miles, the second at 10 miles, and the third at 35 miles. The 3-mile ring typically represents the central city core; the 10-mile ring typically captures activity out to the beltway of larger metropolitan areas; and the 35-mile ring bounds very large, dispersed metropolitan areas.

This trend threatens to reduce densities below levels that may be needed to support alternatives to the automobile, such as transit, and result in longer automobile trips.

To a large extent, these concerns are borne out by the data. In many MSAs, developed land is increasing more rapidly than population, population density gradients are continuing to decline, and the share of employment in the central city is falling. However, the data also show some encouraging trends with respect to both population and employment. With regard to the former, an increasing share of the U.S. population lives in metropolitan rather than in nonmetropolitan areas. In addition, there is some evidence that the decline in population density is attenuating. Some metropolitan areas in California, Nevada, and Arizona, for example, are surprisingly dense and becoming more so.

With regard to employment, the suburbanization of employment as well as residences may help reduce trip lengths by improving the jobs–housing balance, although the evidence is difficult to identify directly with current data sources. In some metropolitan areas, central cities appear to be retaining their share of total employment; this is particularly true for older metropolitan areas, such as New York and Boston, with relatively large central cities. Although metropolitan employment is dispersed, the presence of new agglomerations or suburban employment centers outside the CBD is evident in metropolitan areas of varying size, age, location, and growth rates. In some metropolitan areas, the share of suburban employment in centers appears to be increasing.

The implications of these development trends for travel are difficult to determine. The lack of fine-grained geographic data and longitudinal studies of population and employment changes within metropolitan areas limits our ability to understand spatial development patterns at the level necessary to determine effects on trip making, mode choice, and VMT. The key is to know how densely developed neighborhoods and job centers need to become and how they should be designed or redesigned to reduce VMT and encourage nonautomotive trips. The next chapter examines what is known from the literature about the relationship

between development patterns—in particular more compact, mixed-use development; better jobs–housing balance; and good transit service—and VMT and mode choice.

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Abbreviations

NRCS National Resources Conservation Service

OMB Office of Management and Budget

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3 | Impacts of Land Use Patterns on Vehicle Miles Traveled

Evidence from the Literature

The congressional request for this study asks for consideration of "the correlation, if any, between land development patterns and increases in vehicle miles traveled (VMT)," implying that sprawl induces more travel. This chapter summarizes what is known from the literature about the effect of changes in the built environment—in particular, more compact, mixed-use development—on VMT. It starts with a brief discussion of the built environment–VMT connection. It then examines issues related to research design and data that help explain the variability in study results. Drawing on a paper commissioned by the committee (Brownstone 2008) and earlier reviews of the literature, the main section of the chapter summarizes the results of the most methodologically sound studies that examine the relationship between household travel and the built environment while controlling for socioeconomic variables and other factors (e.g., attitudes, preferences) that influence travel behavior. Few of these studies, however, consider the potential effects on VMT of a package of policies that combine increased density with higher employment concentrations, improved access to a mix of diverse destinations, a good transit network, and parking charges. The potential synergies of these policies for VMT reduction are discussed next through two case studies that demonstrate what can be accomplished but also underscore the associated challenges and costs. The final section presents a series of findings. Additional detail on the two case studies is provided in Annex 3-1.

THE BUILT ENVIRONMENT–VMT CONNECTION

Chapters 1 and 2 describe the dimensions of the built environment (land use) and transportation networks that are believed to affect VMT. The built environment dimensions include density, mix or diversity of land uses, concentration of development into centers, spatial arrangement of land uses, and design. The transportation network dimensions include the spatial patterns of the transportation system (whether the networks are sparse or dense, gridlike or hierarchical). Together, the land use and transportation network measures interact to affect destination accessibility (ease of travel between trip origins and desired destinations) and distance between development and transit. These dimensions are referred to in the literature as "the D's" (see Box 3-1). A final set of characteristics—travel demand—can complement the first two, particularly through pricing.

Density is probably the most studied land use dimension, in part because it is readily measured. However, the effect of higher densities on VMT is not entirely straightforward, making it difficult to determine the net reduction in automobile use from increased densities. For example, trip frequencies may increase if desired destinations are closer and easier to access. Shifts to other modes, such as transit, require that transit services be available and that density thresholds be sufficient to support adequate and reliable service. VMT itself is a composite measure—the product of trip length, trip frequency, and mode choice (Ewing and Cervero 2001).

Moreover, increasing density alone may not be sufficient to lower VMT by a significant amount. A diversity of land uses that results in locating desired destinations, such as jobs and shopping, near housing (preferably in centers) and improved accessibility to these destinations from either home or work are also necessary. Development designs and street networks that provide good connectivity between locations and accommodate nonvehicular travel are important. Finally, demand management policies that complement efforts to lower VMT,

Box 3-1

THE FIVE D's

Land development patterns that describe the built environment, particularly in the context of those features that encourage more compact development, have come to be characterized in the literature by the shorthand of "the D's." The initial three D's, first used by Cervero and Kockelman (1997), have now been expanded to five:

- *Density:* Population and employment by geographic unit (e.g., per square mile, per developed acre).
- *Diversity:* Mix of land uses, typically residential and commercial development, and the degree to which they are balanced in an area (e.g., jobs–housing balance).
- *Design:* Neighborhood layout and street characteristics, particularly connectivity, presence of sidewalks, and other design features (e.g., shade, scenery, presence of attractive homes and stores) that enhance the pedestrian- and bicycle-friendliness of an area.
- *Destination accessibility:* Ease or convenience of trip destinations from point of origin, often measured at the zonal level in terms of distance from the central business district or other major centers.
- *Distance to transit:* Ease of access to transit from home or work (e.g., bus or rail stop within ¼ to ½ mile of trip origin)

such as establishing maximum rather than minimum parking requirements and introducing market-based parking fees, are also needed. As will be shown, however, few studies include many or all of these dimensions.

Even if it can be demonstrated that more compact, mixed-use development is associated with lower VMT, encourages mode shifts, and

lessens trip making by automobile, it is important to know the magnitude of these effects and whether they are of sufficient size to be relevant to policy. Researchers often use elasticities as a way of reporting the size of effects.[1] Thus, for a percentage increase in density—say, for example, a 100 percent increase in or a doubling of density (the independent variable)—they estimate the corresponding percentage reduction in VMT (the dependent variable). Relatively few of the studies reviewed in this chapter estimate elasticities, but they are reported when available.

It should also be noted that changes in the built environment, such as increased density, do not directly "cause" reductions in VMT. Rather, the built environment, as represented by residential and employment density and neighborhood or employment center design, provides the context for behavioral decisions regarding location choice (e.g., residence and jobs), automobile ownership, and travel modes that are also strongly affected by income, age, household size, and other socioeconomic variables (Badoe and Miller 2000). Measuring and controlling for these effects empirically raises significant issues with respect to research methods and data, which are addressed in the following section.

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[1] A *point* elasticity is the ratio of a percentage change in the dependent variable to a 1 percent change in the independent variable. The elasticities reported in the literature are generally point elasticities. Strictly speaking, the percentage impact on the dependent variable of a very large percentage change in the independent variable, such as doubling (a 100 percent increase), constitutes an *arc* elasticity. Consistent with common practice, the present discussion assumes a proportional change in the point elasticity to represent the arc elasticity (for example, if the point elasticity is –0.05, meaning that a 1 percent increase in the independent variable leads to a 0.05 percent decrease in the dependent variable, it is assumed that a 100 percent increase in the independent variable leads to a 5 percent decrease in the dependent variable), but the reader should be cautioned that the larger the increase assumed, the less accurate the proportionality assumption can be. Point elasticities can range in magnitude from zero to infinity. Elasticities of less than 1.0 (in magnitude) are called *ineslastic* and reflect changes in the dependent variable that are, proportionately, smaller than the change in the independent variable. Elasticities greater than 1.0 (in magnitude) are called *elastic,* and reflect changes in the dependent variable that are, proportionately, larger than the change in the independent variable.

ISSUES RELATED TO RESEARCH DESIGN AND DATA

This section reviews issues of aggregate versus disaggregate analyses, cross-sectional versus longitudinal studies, self-section and causality, measurement and scale, and generalizability that are important in understanding the variable results of studies of the relationship between more compact, mixed-use development and VMT.

Aggregate Versus Disaggregate Analyses

Worldwide attention was drawn to the relationship between urban form and automobile dependence through a series of books and articles by Newman and Kenworthy (1989, 1999, 2006). In their 1989 cross-national comparison of 32 cities,[2] these authors showed that per capita gasoline consumption—a proxy for automobile use—is far higher in U.S. cities than abroad, a fact the authors attribute to lower metropolitan densities in the United States. A follow-on study of 37 cities in 1999 directly linked low-density cities, particularly in the United States and Australia, to higher per capita VMT. Notwithstanding the problems of attempting to translate experience from abroad to the United States because of substantial differences in public preferences, laws and regulations governing land development, fuel prices, income levels, and the supply of alternative modes of travel to the automobile, the Newman and Kenworthy studies illustrate the methodological problem of analyses that rely on aggregate data to draw simple cross-sectional correlations without controlling for other variables that affect VMT (see Gómez-Ibáñez 1991 and Brownstone 2008).

Aggregate analyses such as Newman and Kenworthy's mask real differences in densities within metropolitan areas, as well as in the travel behavior of subpopulations, that vary on the basis of socio-economic characteristics. For example, central cities may house dis-

[2] The cities are metropolitan regions, not city centers. In the United States, the former are called standard metropolitan statistical areas.

proportionate shares of lower-income residents, who are less able to afford owning and operating an automobile, and younger people and older households without children whose travel is below average. On the other hand, suburban areas tend to include a disproportionate share of families, who are often in higher-income groups with higher levels of automobile ownership and travel demands for jobs, education, and extracurricular events.

Another well-known study (Holtzclaw et al. 2002) analyzes automobile ownership and use, controlling for socioeconomic variables, with results that corroborate the findings of Newman and Kenworthy. The authors use traffic zones[3] within three metropolitan areas—Chicago, Los Angeles, and San Francisco—as the geographic unit of analysis, control for household size and income effects, and draw on odometer readings (as captured by legally mandated smog checks) rather than self-reported diaries to measure VMT.[4] They find that both automobile ownership and use decline in a systematic and predictable pattern as a function of increasing residential density. These findings, however, are subject to many of the flaws of aggregate analyses. The travel analysis zones are large, with an average size of 7,000 residents per zone; limited socioeconomic variables are available at the zonal level; and key available control variables, such as income, are measured on a per capita basis. The result is to mask potentially important variability within zones, particularly with respect to household size and income differences, that could help explain automobile ownership and use patterns (Brownstone 2008). In addition, several of the independent variables are highly correlated (e.g., density measures, transit access, local shopping, center proximity, and pedestrian and bicycle friendliness), making it difficult to identify their separate effects (Holtzclaw et al. 2002).

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[3] Travel analysis zones are the unit of analysis used in metropolitan area travel demand modeling. Typically, such models do not need detailed data at the neighborhood or household level to analyze the travel impacts of various investment decisions.

[4] Brownstone (2008) notes, however, that California exempts new vehicles from smog checks for the first 2 years, thus systematically biasing VMT downward for zones with large numbers of new vehicles in two of the three metropolitan areas studied.

A more recent, widely circulated book, *Growing Cooler* (Ewing et al. 2007), includes an ambitious effort to model the effect of land use on VMT by using structural equations modeling. Two models are estimated—a cross-sectional model based on 84 urbanized areas in 2005 and a longitudinal model of the same urbanized areas for the two 10-year periods between 1985 and 2005. The data set, assembled by the Texas Transportation Institute, includes population density, highway lane miles, transit revenue miles, and real fuel prices. The authors find that greater population density, among other variables, has a negative influence on VMT. They estimate elasticities of a 0.213 percent reduction in VMT from a 1 percent increase in population density on the basis of their cross-sectional model and a 0.152 percent reduction in VMT from a 1 percent increase in population density on the basis of their longitudinal model (Ewing et al. 2007, 123). However, the coarseness of the level of analysis (urbanized area), the quality of the data, and questions about their model specification limit the reliability of these results.[5]

To minimize or eliminate the aggregation issues that cloud the relationship between the built environment and travel behavior, many studies use disaggregate data—household-level travel data and neighborhood-, census tract–, or zip code–level data on the built environment—in regression models, controlling for a much richer combination of socioeconomic variables available at the household level. However, these studies are also subject to research design and data issues discussed below, which may help explain the wide range of their results.

[5] The data on urbanized areas and VMT that are the basis for Ewing et al.'s analysis come from state reports to the Federal Highway Administration as part of the Highway Performance Monitoring System. The states are not very rigorous in remaining consistent with census boundaries and population estimates for urbanized areas. Urban VMT data are also suspect because of inconsistent sampling (the states follow their own procedures). As noted, moreover, the authors' model specification raises several questions, and structural equations models can be extremely sensitive to relatively small changes in a model specification. In the final models, for example, why is transit supply allowed to affect population density while road supply is not? Why is supply allowed to affect demand but not the converse?

Cross-Sectional Versus Longitudinal Studies

Most of the studies reviewed for this report are cross-sectional; that is, they examine the relationship between the built environment and VMT at a single point in time. Many of the studies use regression analysis to hold constant demographic and socioeconomic variables to isolate the variables of interest. Cross-sectional studies may find a statistically significant correlation between the built environment and VMT. Well-specified analyses that use disaggregate data from metropolitan areas and carefully control for socioeconomic variables and other factors that affect residential location and travel choices are valuable. Nevertheless, they cannot be used to determine the temporal relation between variables, and evidence of cause and effect cannot be assumed.

Establishing causal relationships more reliably requires a longitudinal approach, typically collecting panel data and following households over time. This research is time-consuming and expensive—several decades of data may be needed to observe large enough changes in the built environment. It is also challenging as other factors are likely to change during that time period (i.e., household characteristics, such as household size, ages of its members, income, employment and marital status), thus affecting the results. For these reasons, with the few exceptions noted in the following section, most studies have not adopted a longitudinal approach.

Self-Selection and Causality

One of the main issues that confounds study results, particularly for studies of the effects of the built environment on travel at the neighborhood or other microscale level, is self-selection. Boarnet and Crane (2001), among others, note that the observed correlation between higher-density neighborhoods and less automobile travel may be due in part to the fact that some residents who dislike driving and prefer transit or walking or bicycling may have self-selected into neighborhoods

where these travel options are available. To the extent that this is true, the causal link between density and reduced automobile travel may in reality be weaker than it appears.

The question of what difference it makes whether the effect is directly one of the built environment or of people choosing to live in certain environments is often raised. Either way, the built environment clearly has an influence. The reason the distinction matters is the need to predict with some degree of accuracy the impact of substantial changes in the built environment on travel behavior. If future policies encourage a dramatic increase in the number of people living in compact, mixed-use areas but the increase is due primarily to policy incentives or to a limited supply of compact developments rather than to an intrinsic desire to live in such areas, the VMT reductions for those responding to such policies will probably not be as great as for those actively preferring to live in such areas. Thus, if one does not account for self-selection, the impacts of an aggressive land use policy could be overestimated, and the opportunity costs of such an outcome could be high.

It is true that, over time, the built environment (e.g., living in more compact, mixed-use developments) and travel behavior (e.g., taking transit because it is convenient) could influence attitudes to be more consonant with such an environment, which in turn could reinforce the travel behavior most suited to that environment. However, it is also possible for dissonance between one's environment and preferences to increase over time and eventually prompt a move to a residential location more consonant with one's predispositions. The fact that researchers do not have a good sense of which of these two outcomes dominates, and under what circumstances, points to the need for additional longitudinal research into changes in the relationship among attitudes, the built environment, and travel behavior (as well as sociodemographic characteristics) over time.

To solve the self-selection problem, researchers ideally would randomly assign households to treatment and control groups to observe

their behavior—a method used in the medical profession in clinical trials for drug testing. Of course, assigning households to neighborhoods with different characteristics and observing their travel behavior is not feasible, so researchers have adopted numerous other methods for controlling for self-selection. Boarnet and Sarmiento (1998), for example, use instrumental variables[6] to control for choice of residential location in studying how what they term "neotraditional neighborhoods" affect nonwork automobile trip generation. They find a statistically significant negative association between retail employment density (measured at the zip code level) and nonwork automobile trips after controlling for residential location choices. This finding is replicated in a subsequent study (Boarnet and Greenwald 2000) using Portland, Oregon, data. Applying a similar approach, a more recent German study (Vance and Hedel 2007) finds statistically significant effects of commercial density, road density, and walking time to public transit on daily weekday travel, perhaps reflecting the higher densities and better access to transit of German cities (Brownstone 2008). Brownstone and Golob (2009) use a simultaneous equations model[7] to control for self-selection and a broad set of socioeconomic variables and find a statistically signifi-

[6] In technical terms, the self-selection issue is a manifestation of "endogeneity bias." Ordinary least-squares regression analysis requires that observed explanatory variables be deterministic (not random) and uncorrelated with any unobserved explanatory variables (captured by the error term of the equation). When that requirement is violated, as it is when an explanatory variable itself is a nondeterministic function of other variables in the model, the resulting coefficient estimates are biased. In the present case, the explanatory variable residential location is apt to be determined partly by such variables as attitudes toward travel—variables that are also likely to be observed or unobserved influences on travel behavior itself. Thus, residential location is endogenous. The instrumental variables technique treats this problem by purging the endogenous variable (residential location) of its correlation with other variables in the equation for travel behavior. It does so by first estimating residential location as a function of variables not expected to be associated with travel behavior. The estimated value of residential location then meets the requirements for unbiased ordinary least-squares estimation of the equation for travel behavior.

[7] A structural or simultaneous equations model recognizes that causal influences may work in more than one direction; therefore, multiple equations reflecting these causal linkages are simultaneously modeled (hence using a "structural model" rather than a single equation).

cant but small remaining effect of the built environment on VMT and fuel use.

Still other studies deal with the self-selection issue by attempting to measure preferences through attitude surveys in addition to controlling for residential location type. Bagley and Mokhtarian (2002) find little remaining effect of neighborhood type on VMT after controlling for attitudes, lifestyle preferences, and sociodemographic variables. In contrast, using a survey of neighborhood preferences and attitudes in Atlanta, Frank et al. (2007) find, after controlling for demographic variables, that survey participants who lived in walkable neighborhoods drove less than those living in automobile-oriented neighborhoods, regardless of whether they preferred this neighborhood type.[8]

A final approach attempts to control for self-selection by looking at households that move, comparing their travel behavior before and after moving to a more compact neighborhood. Using data from the Puget Sound Transportation Panel, Krizek (2003) examines the travel behavior of a sample of households that moved to neighborhoods with higher local accessibility during 1989–1997. He finds that, all else being equal, the movers significantly reduced vehicle and person miles traveled, although they took more trip tours.[9] Krizek estimates a decrease of about 5 VMT per day per household that moved to a neighborhood with better accessibility, not as large as the estimate of Frank et al.

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[8] Respondents who preferred automobile-oriented neighborhoods but lived in high-walkability neighborhoods drove about 26 miles per day as compared with their counterparts in automobile-oriented neighborhoods, who drove 43 miles per day (Frank et al. 2007, Table 9, 1911). Respondents who preferred high-walkability neighborhoods but lived in automobile-oriented neighborhoods drove 37 miles per day, more than the 26 miles per day of their counterparts in high-walkability neighborhoods but less than the 43 miles per day of those who preferred automobile-oriented neighborhoods.

[9] The study controlled for changes in life cycle and regional and workplace accessibility to focus primarily on neighborhood travel.

Measurement and Scale

Measurement issues—in particular, use of different measures of the built environment and travel—as well as the scale of analysis may also help explain why study results differ.

Measuring the Built Environment

Researchers are still attempting to identify and measure characteristics of the built environment with the greatest impact on travel behavior. Researchers have often selected easy-to-measure characteristics, such as residential or employment densities. But density may well be a proxy for other variables, such as distance from trip origins to destinations, car ownership levels, and transit service quality (Boarnet and Crane 2001). Several measures, including diversity (mix of land uses), design, and the other five D's (see Box 3-1), are needed to capture their combined effect on travel behavior. Objective measures are important because they can be readily quantified and verified. Subjective measures, such as individuals' perceptions of neighborhood safety and the quality of amenities that encourage them to walk and cycle, are also important. But many subjective measures, such as the walkability of a neighborhood or other design variables, are difficult to characterize in consistent, quantifiable ways.

Measuring Travel

Studies that examine the relationship between the built environment and travel often measure very different aspects of travel, with differing results. Researchers may study trip lengths, trip frequencies, and mode choice, and they may include automobile ownership under a broad definition of travel. Reducing VMT could be achieved by affecting each of these factors: (*a*) reducing trip lengths, (*b*) reducing trip frequencies, (*c*) reducing travel by automobile (mode shift), and (*d*) reducing the number of cars per household. The question is how more compact devel-

opment affects each of these factors. The results are likely to differ for each variable. For example, by decreasing distances between origins and destinations, higher densities should reduce trip lengths, all else being equal, but could work in the opposite direction for trip frequencies, depending on the time-cost of travel (Crane 2000).[10] Mode choice, particularly the decision to use transit, depends on threshold density levels adequate to support good transit service, as well as on socioeconomic variables (Ewing and Cervero 2001). Finally, automobile ownership levels, while highly correlated with density, are typically a function of socioeconomic characteristics first, and secondarily a function of location characteristics (Ewing and Cervero 2001). Thus, travel is not a monolithic variable to be affected by different density levels.

Scale of Analysis

Scale issues are also important. Measures of the built environment that influence VMT within a neighborhood are likely to differ from those that reduce VMT in a region. For example, local trips, particularly by nonmotorized modes, are likely to be influenced by neighborhood design (e.g., walkability, safety) and the number of desirable destinations (e.g., local shopping, restaurants, schools) in close proximity. In contrast, travel to regional destinations—deciding whether to drive or take transit to work or travel to a major shopping center—is determined primarily by the location of jobs and shopping destinations in a region relative to a household's residence (jobs–housing balance), the accessibility of transit at both trip origin and destination, and parking charges at the destination.

The magnitude of changes in travel behavior resulting from changes in the built environment also depends on scale. For example, high-

[10] Crane (2000) notes that the net effect (i.e., of increased trip frequency and reduced trip length from more compact development) on overall travel depends on such factors as the elasticity of trip/travel demand, trip purpose, traveler demographics, and travel speeds (i.e., the amount of congestion).

density neighborhood development near an extensive transit system may result in large mode shifts to transit. The overall impact of these effects, however, must be examined from the perspective of the share of all trips and travel in a region represented by transit. Improved accessibility and jobs–housing balance in a region could result in much larger reductions in VMT than changes at the neighborhood level. For example, using data from the San Francisco Bay Area, Cervero and Duncan (2006) find that improving the jobs–housing balance in the region had a far greater effect in reducing both VMT for commuting and vehicle hours traveled (VHT) than in improving access to retail and consumer services by locating them close to residences (i.e., mixed-use development in neighborhoods).[11] This finding held even after the larger share of daily VMT and VHT devoted to travel for shopping and services than to commuting was taken into account. The authors note, however, that the findings should not be interpreted as favoring a regional over a neighborhood strategy. Rather, both should be viewed as complementary land use strategies for reducing VMT and VHT.

Generalizability

Another issue that affects the findings reported in the literature, particularly studies that use disaggregate data to examine the effects of the built environment on the travel behavior of neighborhood residents, is the applicability of the findings to other settings. Neighborhoods within a particular metropolitan area rather than across areas are often selected as the unit of analysis because data may be available at a sufficiently fine-grained level. But are the characteristics of the built environment and their impact on travel behavior the same in neighborhoods in Austin (Texas) or San Francisco as are they are in neighborhoods in Atlanta or Boston? Pairing neighborhoods that have similar socioeconomic charac-

[11] Jobs–housing balance is measured as the number of jobs in the same occupational category within 4 miles of one's residence, the job accessibility radius most strongly associated with VMT reduction for work tours (Cervero and Duncan 2006).

teristics but differ in the built environment (e.g., a compact, mixed-use development versus a traditional, sprawling suburban development) in a quasi treatment control group, if such a pairing can be found, is one way of handling comparability issues. Over time, as the number of reliable studies drawn from many metropolitan areas and settings accumulates, the external validity of research results should improve.

A final issue relates to whether the results of any of the studies would apply in the future. Aging of the population, growth of immigrant populations, and the potential for sustained higher energy prices in the future and new vehicle technologies could result in development and travel patterns that differ from those of today, topics that are elaborated in Chapter 4.

LITERATURE REVIEW

This section reviews in turn five comprehensive reviews of the literature produced over the past two decades; several more recent studies; and studies focused specifically on travel effects of transit-oriented development, compact development and urban truck travel, and estimation of the effects of compact development through modeling.

Comprehensive Reviews of the Literature

Over the past two decades, numerous studies have been conducted that have analyzed travel behavior while attempting to control for measures of the built environment and socioeconomic variables that also influence this behavior. Fortunately, noted scholars have conducted five comprehensive reviews of this burgeoning literature (Badoe and Miller 2000; Crane 2000; Ewing and Cervero 2001; Handy 2005; Cao et al. 2008).

Crane (2000) categorizes studies by type of research design and assesses study results in light of the strengths and weaknesses of each approach. Badoe and Miller (2000) summarize the empirical evidence concerning impacts of urban form on travel but also look at mode use

and studies of transit impacts on urban form. Ewing and Cervero (2001) review a number of studies to examine the effects of the built environment, relative to socioeconomic variables, on four travel variables: trip frequency; trip length; mode choice; and VMT or VHT, a composite of the first three. [The authors also derive elasticities to estimate the magnitude of effects of different aspects of the built environment (regional accessibility, density, diversity, and design) on vehicle trips and VMT, which are discussed later.] Handy (2005) summarizes evidence for the proposition that new urbanism design strategies will reduce automobile use.[12] She comments on how well studies have sorted out the relative importance of socioeconomic characteristics and characteristics of the built environment in explaining travel behavior and addresses issues of causality, including self-selection. The review of Cao et al. (2008) focuses primarily on the issue of self-selection to determine whether the built environment has a statistically significant influence on travel behavior in those studies that control for socioeconomic characteristics and attitudes and preferences and, if so, whether the magnitude of that effect is identified.[13]

The findings from these reviews can be summarized with respect to two key questions, each of which is addressed below: (*a*) Is there a statistically significant effect of the built environment on VMT? and (*b*) What is the magnitude of this effect?

Significance of the Built Environment for VMT

The majority of the studies reviewed find a statistically significant effect of the built environment after controlling for socioeconomic characteristics and self-selection (see Cao et al.'s 2008 review for the latter).

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[12] She also examines three other propositions: (*a*) building more highways will contribute to more sprawl, (*b*) building more highways will lead to more driving, and (*c*) investing in light rail transit systems will increase densities.

[13] The reader is also directed to two journal articles based on this review—Cao et al. (2009), which reviews the empirical findings, and a companion paper, Mokhtarian and Cao (2008), which focuses on methodological approaches.

However, the survey authors characterize these results as "mixed." Crane notes, for example, the lack of "any transparent influences of the built environment on travel behavior that hold generally or that straightforwardly translate into policy prescriptions" (Crane 2000, 18). Handy concludes that "land use and design strategies . . . may reduce automobile use a small amount" but points to outstanding questions concerning "the degree of the connection and the direction of causality" (Handy 2005, 23, 25). Badoe and Miller (2000, 256) attribute results that vary in their robustness to weaknesses in data and methods.

Badoe and Miller (2000) and Ewing and Cervero (2001)[14] attempt to parse the findings more closely to examine the relative effects of socioeconomic characteristics and the built environment, respectively, on various aspects of travel (e.g., trip length, trip frequency, mode choice), with the following results:

• *Socioeconomic characteristics* (e.g., income, age, gender, occupation) have a significant impact on travel behavior and must be adequately represented at a disaggregate level in models that attempt to estimate the impact of the built environment on travel behavior. Ewing and Cervero note further that socioeconomic factors are dominant in trip frequency decisions, whereas the built environment appears to be more influential with respect to trip length; mode choice depends on both factors.

• *Density,* particularly employment density at destinations, has a significant impact on mode choice, with higher transit usage and walking found in high-density employment centers. The impact of residential density is more ambiguous, particularly when socioeconomic characteristics and automobile ownership are controlled for. Ewing and Cervero note as an unresolved issue whether the impact of density on travel patterns is due to density itself or to other unobserved variables with which it is correlated, including attitudes.

[14] Ewing and Cervero report results only if they are significant at or below the 0.05 probability level. Badoe and Miller do not mention such a criterion.

• *Automobile ownership* is a frequently overlooked variable that affects travel decisions. A consistent finding in the literature reviewed by Badoe and Miller is that households in higher-density neighborhoods tend to own fewer vehicles, use transit more (where available), and generate less VMT. Ewing and Cervero also point to the disutility of automobile ownership in high-density locations because of traffic congestion and limited parking.

Magnitude of Effects

The authors of the literature surveys reviewed above uncovered few studies that estimate the magnitude of the effect of the built environment on travel behavior, even when the effect is statistically significant. Ewing and Cervero (2001) take an approach different from that of the other authors: they select the best studies and, where possible, derive elasticity estimates of travel demand with respect to local density, diversity, design, and regional accessibility.[15] These estimates are then input into the U.S. Environmental Protection Agency's Smart Growth Index (SGI) Model to estimate elasticity values for each of the D's.[16] The results are small in absolute terms—a 100 percent increase in each of the first three D's is associated with 3 to 5 percent less VMT (see Table 3-1), suggesting that scale issues are important. The authors note, however, that the results should be additive.[17] It is also important to keep in

[15] Elasticities are (*a*) taken as reported in published studies, (*b*) computed from regression or logit coefficients and mean values (midpoint elasticities only, reflecting a "typical" or median value), and (*c*) derived from data sets available to the authors. The authors acknowledge the limitations of calculating elasticities at the sample mean, particularly for discrete choice models (it is a lesser problem for regression models), but note the impossibility of acquiring the original databases necessary to calculate more precise estimates for a meta-analysis that reviews scores of studies. Meta-analyses typically do not aim to provide precise estimates, but rather to give order-of-magnitude insights drawn from numerous studies.

[16] In the SGI Model, density is defined as residents plus employees divided by land area. Diversity is represented by a jobs–population balance measure. Design is represented by route directness and street network density (Ewing and Cervero 2001).

[17] According to the authors, the SGI Model controls for other built environment variables when the effect of any given variable is estimated.

TABLE 3-1 **Elasticity Estimates of Changes in VMT Relative to Changes in the Built Environment from Selected Studies and Surveys of the Literature**

Authorship	Built Environment Feature	Scale	Geographic Location	Percentage Increase in Built Environment Feature	Percentage Reduction in VMT
Ewing and Cervero (2001, 111)[a]	Density	Neighborhood	Multiple locations	100	5
	Diversity (land use mix)	Neighborhood		100	5
	Design	Neighborhood		100	3
	Density, diversity, and design	Neighborhood		100	13
	Accessibility	Regional		100	20
Bento et al. (2005, 475–477)[b]	City shape, jobs–housing balance, road density, rail supply (for rail cities)—each variable alone	Regional	114 U.S. MSAs	100	≤7
	Population centrality alone	Regional	114 U.S. MSAs (without New York)	100	15
	All built environment variables	Regional	Atlanta, GA; Boston, MA	Various	25
Brownstone and Golob (2009)[c]	Density	Regional	California	100	12

Note: MSA = metropolitan statistical area. Unless otherwise indicated, all estimates assume a doubling of the particular land use variable indicated.

[a]Ewing and Cervero's elasticity estimates represent a midpoint or 50th percentile case. They are not averaged over the sample. Ewing and Cervero also estimate the following elasticities for reduction in vehicle trips (VT): 100 percent increase in local density reduces VT by 5 percent, local diversity does so by 3 percent, and local design does so by 5 percent (Ewing and Cervero 2001, 111).

[b]Unclear how elasticities were calculated (i.e., point estimates or averages).

[c]Brownstone and Golob's elasticities are averaged over the sample. Because their model is linear for density, they are able to calculate the elasticity for a doubling of density [i.e., increasing density by 2.61 units (100 percent) of the mean reduces VMT by 2.61 × 1,171 = 3,056 miles, or about 12 percent of the mean VMT].

mind that few of the studies they analyze account for self-selection, which suggests that the built environment effects they find could be biased upward.

Ewing and Cervero (2001) find VMT to be influenced more strongly by regional accessibility, the fourth D, than by any of their local measures—with 20 percent lower VMT associated with a 100 percent improvement in destination accessibility (see Table 3-1).[18] Badoe and Miller (2000) also stress the importance of regional accessibility, that is, how well connected a given location is with activities such as work opportunities and shopping destinations. Both studies note the futility of increasing density in the middle of nowhere as a policy to reduce VMT. Reviewers of the Ewing and Cervero work question, however, whether government policy intervention could change regional spatial patterns in any meaningful way given the strength of market forces and fragmented local control of land use, a concern that is addressed in a subsequent chapter of this report.[19]

Cao et al. (2008), who review 28 studies that control for self-selection, find that virtually all the studies report a statistically significant remaining influence of the built environment on travel behavior.[20] However, none of the studies quantify the relative importance of the two factors (residential self-selection and the built environment) or the magnitude of the remaining built environment effect.

More Recent Studies

The literature review conducted for this study (see Brownstone 2008) identified a handful of more recent studies that carefully control for a broad range of socioeconomic variables in an effort to control for self-selection and test a number of attributes of the built environment to

[18] Regional accessibility is represented by an accessibility index derived with a gravity model (Ewing and Cervero 2001).
[19] See the discussion by Nelson and Niles (Ewing and Cervero 2001, 113–114).
[20] Cao et al. (2009) review 38 empirical studies but arrive at the same finding.

determine the effect on VMT.[21] Each is described in turn below, with a focus on both the statistical significance and the magnitude of effects (see also Table 3-1).

Bento et al. (2005) examine a broad range of built environment variables and socioeconomic measures to determine the effects on the annual VMT of a large sample of households living in the urbanized portion of 114 U.S. metropolitan statistical areas (MSAs). In their model, annual VMT is determined by the number of cars owned as well as the number of miles each car is driven. Measures of urban form—city shape, spatial distribution of population or population centrality, jobs–housing balance[22]—and the supply of public transit are combined with data on the socioeconomic characteristics[23] and automobile ownership and travel patterns (i.e., annual miles driven) of households drawn from the 1990 Nationwide Personal Transportation Survey (NPTS) (Bento et al. 2005).[24] The authors find that population centrality, jobs–housing balance, city shape, road density, and rail supply (for rail cities) all have a significant effect on annual household VMT.[25] The magnitude of the effect of each measure is small, however; a 10 percent change in either the urban form or the transit supply variables is associated with at most a 0.7 percent change in average annual miles driven with the exception of population centrality, which is associated

[21] Brownstone has very stringent selection criteria, including adequate controls for socioeconomic variables and self-selection bias, studies using nationally representative data (good for generalizability), and results that are statistically significant and of a sufficient magnitude to be policy relevant. This last criterion is discussed in the text above.

[22] Rather than the typical measure of urban sprawl—average population density in a metropolitan area—Bento et al. use measures of population centrality and jobs–housing balance to capture sprawl. The former is measured as the population located at various distances from the central business district weighted by that distance.

[23] Household characteristics include number of persons in the household classified by age and work status, race of the household head, and number of years of schooling completed by the most educated person in the household.

[24] An updated study using data from the 2001 National Household Travel Survey should be available in 2009.

[25] Only population centrality affects vehicle ownership, but the effect is small: a 10 percent increase in population centrality reduces annual average VMT by only 1.5 percent.

with a somewhat larger 1.5 percent change (Bento et al. 2005, 475) (see Table 3-1).

Nevertheless, if measures of urban form and transit availability are considered jointly, the effects may be considerably larger. To illustrate this point, Bento et al. use their estimated model to simulate the effect of moving their sample households from an urbanized area with measures of urban form and transit supply the same as those of Atlanta, one of the most sprawled metropolitan areas, to an urbanized area with measures the same as those of Boston, one of the most compact metropolitan areas. The result of this experiment is that annual household VMT could be lowered by as much as 25 percent (Bento et al. 2005, 478) (see also Table 3-1). The outcome is attributed to differences in public transit supply, city shape, and especially population centrality between the two cities. Such a lowering in VMT should be considered as an upper bound, however. The authors themselves note that implementing the policies necessary to make Atlanta more like Boston would be costly (e.g., requiring extensive transit investments) and that it would take decades to alter urban form in any measurable way.[26] Moreover, the simulation does not address behavioral issues. If typical Atlanta residents were to face the Boston environment, they would be unlikely to travel like typical Bostonians, at least in the near term.

Brownstone and Golob (2009) also use a rich set of socioeconomic variables to help control for self-selection and model the relationship among residential density, vehicle use, and fuel consumption for California households. They employ residential density alone (dwelling units per square mile at the census block group level show the strongest relationship among density measures) to describe the built environment

[26] An earlier study by Ewing et al. (2002), which ranks 83 U.S. cities in terms of a sprawl index composed of four components—residential density; neighborhood mix of homes, jobs, and services; strength of activity centers and downtowns; and accessibility of street networks—finds a 29 percent difference in VMT per household per day between the 10 most sprawling and the 10 least sprawling cities (the latter excluding two clear outliers—New York City and Jersey City).

because of the consistency and availability of density data. However, they acknowledge that density should probably be interpreted as a proxy for other built environment variables, such as access to employment, shopping, and other travel destinations. Brownstone and Golob draw on the California subsample of the 2001 National Household Travel Survey for data on vehicle ownership and fuel usage, land use densities, and socioeconomic characteristics of California households, thus providing a narrower geographic perspective than the national focus of Bento et al.

Brownstone and Golob find that, after controlling for socioeconomic differences, a 40 percent increase in residential density is associated with about 5 percent less annual VMT (see Table 3-1).[27] The most important exogenous influences on annual VMT and fuel consumption are the number of household drivers and the number of workers; education and income are also significant. Brownstone and Golob conclude that increasing the density of an urban area to lower VMT produces small changes that are difficult to achieve, requiring very high densities in new and infill developments that exceed historical levels.[28] As evidence, they cite Bryan et al. (2007), who show that only 30 of 456 cities[29] increased population density by more than 40 percent between 1950 and 1990.

The study of Bento et al. (2005) and one by Chen et al. (2008) (not reviewed by Brownstone) also examine the impact of the built environment on mode choice, particularly transit use, which would substitute for automobile use and thereby reduce VMT. Bento et al. link the measures of urban form and transit supply previously described to

[27] The authors also find that the density increase is associated with approximately a 6 percent reduction in fuel use. About 70 percent of the reduction is attributable to the reduction in VMT and the remaining 30 percent to household selection of more fuel-efficient vehicles.

[28] Brownstone and Golob agree with the assessment of Downs (2004, Chapter 12) that increasing densities in already built-up areas typically meets with homeowner resistance because it changes the character of the community.

[29] Cities are defined and analyzed in three ways—as political entities, as urbanized areas (census definition), and as MSAs (census definition).

the 1990 NPTS data to explain commute mode choice. They find that population centrality and transit supply have a nonnegligible effect on the share of commuting by rail, bus, and nonmotorized modes (i.e., walking and bicycling).[30] However, the overall effect on VMT for commuting is small because of the small fraction of commuters who use these modes. For example, a 10 percent increase in population centrality lowers the probability of driving by approximately 1 percentage point (Bento et al. 2005, 472). A 10 percent increase in rail and bus route miles lowers the probability of driving by only 0.03 percent when New York, which is an outlier in terms of the amount of transit service, is excluded.

Chen et al. (2008) assess the importance of density relative to other built environment variables—job accessibility with respect to the central business district (CBD)[31] and distance to transit stops from home and work—in affecting mode choice for commuting while controlling for confounding factors (self-selection). Using a data set collected from households in the New York metropolitan region (1997–1998)[32] on travel patterns and socioeconomic characteristics, the authors select only those households that made a home-based work tour on the survey day.[33] The focus on a tour or trip chain, rather than

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[30] Of the socioeconomic variables, income, education, and race have a statistically significant effect on the probability that a commuter will take transit or walk to work. Higher-income workers are more likely to drive to work, as are white workers. Higher levels of education increase the probability of commuting by rail, but the magnitude of the effect is tempered by the share of commuting by rail.

[31] Job accessibility for each census tract is calculated with the regional travel demand forecasting model. For example, job accessibility of Tract A is the weighted sum of the number of jobs in every tract (including Tract A) in the region, weighted by the distance to Tract A (Chen et al. 2008).

[32] This region comprises 28 counties in the tri-state area—New York, New Jersey, and Connecticut. Despite the perception of high levels of density in the New York metropolitan region, population density at the county level ranges from 45,499 persons per square mile in Manhattan to only 268 in Sussex County, New Jersey (Chen et al. 2008, 289).

[33] Thus, households whose members walk or use a bicycle exclusively are excluded on the grounds that these tours are limited and thus not comparable with those by transit or automobile. Those households that do not own a vehicle and thus comprise captive transit riders are also excluded.

a single trip, is a unique feature of their research, better representing how commuters actually travel.

The authors find that indeed residential self-selection is a key factor in interpreting the importance of the built environment for travel behavior. However, after controlling for self-selection, job accessibility via transit remains statistically significant (at a confidence level of 0.05) and the most important of the built environment variables, reducing the propensity to commute by car. Density is also significant, but only employment density at work, corroborating findings of earlier studies (see Badoe and Miller 2000 and Ewing and Cervero 2001); also significant is distance to transit stations from home and work. Chen et al. (2008) also test the impact of tour complexity on mode choice and find that increasing the number of stops in a tour significantly increases the propensity to commute by car.

Two other studies examine the effect of the built environment on automobile ownership, which indirectly affects VMT. Bhat and Guo (2007) jointly model residential location and automobile ownership decisions by using data for Alameda County from the 2000 San Francisco Bay Area Travel Survey and other related sources. After applying extensive controls for self-selection,[34] the authors find that both household characteristics (primarily household income) and built environment characteristics were influential in car ownership decisions, although the former had a more dominant effect. Household and employment density, however, had a statistically significant but small effect on propensity for car ownership.[35] Bhat and Guo attribute this result largely to the high correlation between density and other built environment measures, such as local transportation network measures (e.g., transit

[34] Brownstone (2008) includes this study in his review largely as an example of how to deal with self-selection bias.

[35] An earlier study (Bhat and Sen 2006), also using travel data from the San Francisco Bay Area, finds that members of households in denser areas are less inclined to drive sport utility vehicles and pickup trucks.

availability and access time and street block density), suggesting that density is a partial proxy for these measures.[36]

Fang (2008) examines the impact of changes in the built environment, specifically higher residential density, on the number of vehicles and VMT by vehicle category (e.g., cars and trucks)[37] for California households. Drawing on data from the California subsample of the 2001 National Household Travel Survey, Fang finds that a 50 percent increase in residential density is associated with a statistically significant but small reduction in household truck holdings (i.e., a 1.2 percent reduction) and a larger change in truck VMT (nearly an 8 percent reduction) than in car VMT (1.32 percent) (Fang 2008, 744). These findings are in line with those of Bento et al. (2005), who find that various measures of urban form had a small impact (elasticities less than 0.1) on the number of vehicles owned and VMT.

To summarize the results from recent studies, those studies that carefully control for socioeconomic characteristics and self-selection effects find that the built environment has a statistically significant, but often modest, effect on VMT. Some studies (Brownstone and Golob 2009; Chen et al. 2008) investigate only the effect of a single measure of the built environment—density—and the authors acknowledge that other attributes of the built environment might augment the results or that density itself is a proxy for these other measures. One of the most thorough studies in terms of inclusion of numerous built environment variables—that of Bento et al. (2005)—finds small effects when each variable is considered singly, but the authors suggest that if the variables were changed simultaneously, VMT per household could be lowered by as much as 25 percent. Implementing the policies necessary to bring about changes of such magnitude, however, presents a considerable challenge, a topic addressed in a subsequent section.

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[36] In fact, when the local transportation network measures are removed, the researchers find a negative and strongly significant effect of household and employment density on propensity for automobile ownership.

[37] Truck is defined as a van, sport utility vehicle, or pickup truck.

Studies of Travel Effects of Transit-Oriented Development

Several recent studies (Bento et al. 2005; Chen et al. 2008) point to the importance of transit supply and good access to transit in conjunction with land use as critical variables affecting mode choice and hence VMT. This section reviews the literature on the travel effects of transit-oriented development (TOD). TODs are mixed-use developments designed to maximize access to public transit, including good access to rail transit stations and bus stops, with relatively high densities close to transit stops and other urban design features that encourage pedestrian and other nonmotorized travel.[38]

A recent report of the Transit Cooperative Research Program (Arrington and Cervero 2008) summarizes the literature on the travel performance of TODs. Few if any of these studies, however, control for socioeconomic differences or self-selection bias. With that caveat in mind, the reviewers find that TOD commuters typically use transit two to five times more than other commuters in a region, although the transit mode share can vary from 5 percent to 50 percent (Arrington and Cervero 2008, 11). The share of nonwork trips by transit is similarly two to five times higher, although the transit mode shares are lower (2 percent to 20 percent). The primary reason suggested for the wide range of mode shares is differences across regions in the extensiveness of transit service and the relative travel times involved in using transit compared with the automobile. Thus, the authors of the literature review conclude that the location of a TOD in a region—its accessibility to desired locations—and the quality of connecting transit service are more important in influencing travel patterns than are the characteristics of the TOD itself (e.g., mixed uses, walkability).

[38] Not all centers, particularly those in suburban locations, however, are designed with transit. Even some of the newest-generation suburban centers feature expanded pedestrian options and the three D's but have limited or inconvenient transit (Dunphy 2007). If increased transit use is sought, TOD sites need to be selected from the outset with transit in mind, or where a planned expansion of local transit is likely.

The higher mode shares and thus VMT reductions found in many TODs must be kept in perspective. First, as the literature review points out, a primary reason for higher TOD transit use is self-selection; many residents locate in TODs precisely because they want to use transit. For example, surveys of TOD residents have found that, for those who previously drove to work (presumably because they did not live close to transit), 52 percent switched to commuting by transit upon moving within a ½-mile walking distance of a rail station (Arrington and Cervero 2008, 12).[39] Second, the demographic profile of TOD residents is often different from the profile of residents in surrounding communities. The majority of TOD residents are childless singles or couples—often younger working professionals or older "empty nesters." Smaller households typically own fewer cars, and proximity to good transit service can reduce the need for multiple vehicles. These findings are borne out by the statistics: TOD households own almost half the number of cars of other households and are almost twice as likely not to own any car (Arrington and Cervero 2008, 44).

The literature review also examines the effect of land use and design features—mixed land uses, traffic calming, short blocks, street furniture—on travel patterns, transit ridership, and the decision to locate in a TOD. For work trips, proximity to transit and employment densities at trip ends exert a stronger influence on transit use than land use mix, population density at trip origins, or quality of the walking environment (Arrington and Cervero 2008). Moreover, relative travel time (transit versus automobile) is more important than any land use variable, including density, diversity of uses, and design. The authors find some evidence that mixed uses and urban design features (e.g., a more walkable environment) influence nonwork trips and may therefore play a role in attracting TOD residents.

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[39] For those whose job location had not changed, however, some 56 percent of TOD residents within the ½-mile station radius had taken transit to work at their previous residence, suggesting that other factors were responsible for their move.

Another study involving a survey of households that moved to TODs within the past 5 years in three California cities—Los Angeles, San Francisco, and San Diego—finds that the three primary reasons for choosing to live in a TOD were the quality and cost of housing and the quality of the neighborhood (Lund 2006). Only about one-third of respondents reported access to transit as one of the top three reasons, and the San Francisco Bay Area, particularly along the heavy rail lines of the Bay Area Rapid Transit system, was overrepresented, reflecting the high level of transit service in that region.[40] In comparison with the population as a whole, however, TOD residents used transit at a relatively high rate. When regional and sociodemographic influences were controlled for, those who cited access to transit as one of their top three reasons for choosing to live in a TOD were nearly 20 times more likely to travel by rail than those who did not cite this factor. The author acknowledges that the results should be tempered by a low response rate[41] and by the somewhat different socioeconomic profile of TOD residents, including higher annual household income, more professionals and office workers, smaller mean household size, and fewer Hispanics relative to the surrounding population (Lund 2006). The results are also a good example of self-selection.

Studies of Compact Development and Urban Truck Travel

Most of the studies reviewed in this chapter focus on personal travel. The committee also commissioned a paper to examine how compact

[40] Respondents in the Los Angeles region were more likely to choose to live in a TOD for highway than for transit access (21.2 percent and 19.3 percent, respectively). In San Diego, highway and transit access were cited with nearly identical frequencies (25 percent and 24.8 percent, respectively). In the San Francisco Bay Area, access to transit was far more important than access to highways (52 percent versus 20.5 percent) as a reason for locating in a TOD (Lund 2006).

[41] The author notes that of 6,225 surveys distributed, a total of 826 or 13.3 percent were successfully completed and returned. In addition, the sample was limited to those buildings where the researcher was allowed to distribute the surveys, and thus the responses could be biased.

development might affect urban freight movement and commercial traffic (Bronzini 2008). Commercial and freight truck traffic typically accounts for between 3 and 10 percent of urban highway VMT, but truck traffic can represent as much as 50 percent of average daily traffic on major freight connectors to ports, airports, and other intermodal facilities. Because of the much lower fuel economy (miles per gallon) of trucks compared with automobiles, truck travel accounts for nearly one-quarter (23 percent) of carbon dioxide emissions from highway travel in the nation's 100 largest metropolitan areas (Southworth et al. 2008).

No studies were found that directly address the topic of compact development and urban truck travel, but an analysis by Bronzini of a data set on truck traffic in the 100 largest U.S. metropolitan areas (Southworth et al. 2008) finds that truck VMT per capita tends to decline as population increases. The author concludes that large urban areas (as measured by population) tend to have higher densities, thereby promoting shorter trip lengths. This finding suggests that more compact development could be effective in lowering truck VMT per capita. The effect is probably greater for commercial than freight traffic because the latter includes a substantial component of through traffic.[42] However, the strong relationship between population and truck VMT makes it difficult to identify any separate, additional effect of land use on VMT.[43]

For 97 of the nation's 100 largest metropolitan areas, Southworth et al. (2008) find a relationship between carbon emissions from truck

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[42] In fact, according to statistics compiled by the Federal Highway Administration, VMT for single-unit trucks, which roughly equates to commercial vehicles, increased more rapidly (by 42 percent) than all other vehicle categories between 1996 and 2006—faster than VMT for combination trucks (39 percent); light-duty vehicles, some of which may be used for business rather than personal use (41 percent); or passenger vehicles (23 percent) (see Table 1 in Bronzini 2008). In 2006, however, single-unit trucks accounted for only 2.2 percent of vehicle travel on U.S. urban highways. This number is likely to be an undercount, though, because current data sets do not include light-duty trucks (i.e., sport utility vehicles, minivans, and pickup trucks) used for business purposes and thus are not able to capture this segment of urban traffic (Southworth and Wigan 2008).

[43] Regressing truck VMT against the square root of population explains nearly 75 percent of the variation in truck VMT in 19 metropolitan areas with major container ports or air cargo airports (Bronzini 2008).

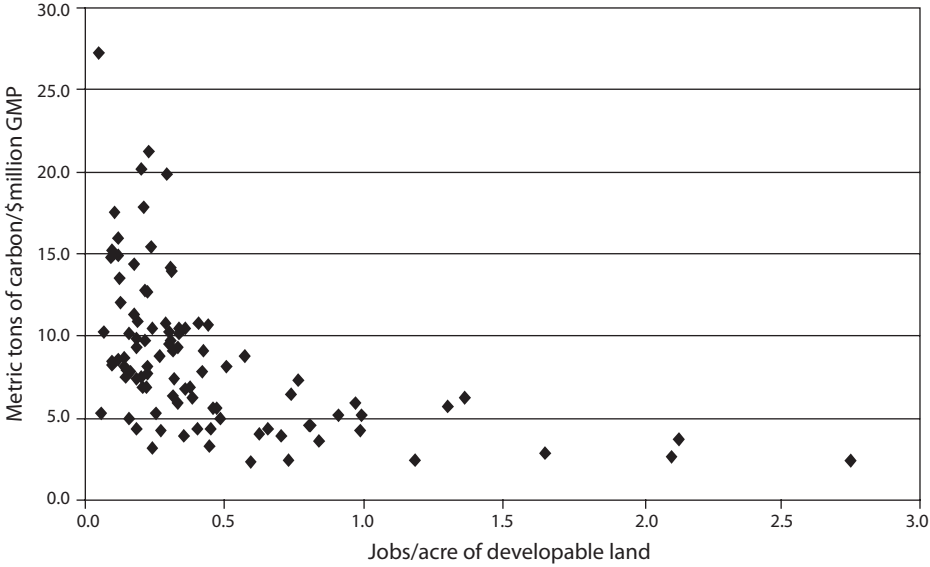

FIGURE 3-1 **Carbon from truck travel within metropolitan areas (GMP = gross metropolitan product in 2005 dollars).**

Source: Southworth et al. 2008, 27.

traffic per gross metropolitan product (GMP)[44] and the number of jobs per developed acre of land (see Figure 3-1). As job density increases, VMT-based carbon emissions per dollar of economic activity decline.[45] However, there is a good deal of variability at specific density levels, indicating the importance of other factors affecting truck carbon emissions.

Before definitive quantitative conclusions can be drawn, more research is needed to understand the mechanisms by which higher-density development could affect truck travel and logistics patterns

[44] GMP is a measure of an area's economic output, comprising the market value of all final goods and services within a metropolitan area for a given time period. Data on GMPs were officially released for the first time by the Bureau of Economic Analysis in late 2007, reporting 2005 data.

[45] Regressing truck carbon emissions per unit of economic activity against job density explained 49 percent of the variation in truck carbon emissions.

in metropolitan areas (e.g., urban freight villages where workers live near jobs, commercial centers near airports, land bridges to expedite the shift of truck traffic away from major ports or airports to exurban warehouses and distribution centers). In addition, simulations of different urban land use patterns and the resulting effects on freight and commercial truck VMT are recommended, including studies of specific urbanized areas.

Other Modeling Approaches to Estimating Effects of Compact Development

A number of different types of models can provide insight into the relationship between land development patterns and travel. So far, the committee has focused mainly on elasticities derived from disaggregate analyses in which travel behavior is modeled as a function of the built environment and socioeconomic characteristics. Models are also useful for taking complex scenarios and systematically analyzing the effects of changes in individual parameters—for example, how changes in residential density alone or in combination with other policies (such as transit investment and pricing policies) might affect VMT and mode choice. However, as discussed subsequently, many models, particularly those used by metropolitan planning organizations (MPOs), are highly aggregate and not behaviorally based (TRB 2007). Nevertheless, to the extent that the models are calibrated with current local data and make their assumptions transparent, they are useful for analyzing the relative importance of various policy options for desired objectives.

The traditional four-step travel forecasting models used by most MPOs were developed during a time of major capital investment in transportation infrastructure in the 1960s and 1970s when the primary concern was the appropriate scaling and location of major highway and transit system capacity expansions (TRB 2007).[46] Today,

[46] The four steps are trip generation, trip distribution, mode choice, and assignment, using travel analysis zones as the geographic unit of analysis.

however, MPOs face expanded forecasting requirements, among them, particularly in growing regions, the need to model the impacts on travel of land use policies, such as increases in overall density, urban growth boundaries, intensification around rail stations, and more mixed housing and employment (TRB 2007). While almost all MPOs require forecasts of population, households, and employment as input to their trip generation and travel forecasts, only some of the larger MPOs have adopted integrated urban models that combine advanced land use and transportation models with feedback effects to address this need. These models require significant investment in data assembly, model development, and technical support staff and thus are not widespread in practice (TRB 2007). Most travel forecasting models have limited ability to represent the effects of land use, transit, parking fees or other pricing strategies, and urban freight traffic (Rodier 2009).[47]

Sacramento, California, is notable for its use of advanced travel models to analyze various alternative "futures" as part of developing long-term investment plans. Specifically, the models have been used to examine the effectiveness of land use policies, both alone and in conjunction with investments in transit and automobile pricing policies, to reduce regional automobile travel and vehicle emissions (Rodier et al. 2002). A scenario involving TODs and some 75 miles of new light rail investment showed a significant decrease in automobile trips from increased transit use and greater nonmotorized travel. However, a light rail and pricing scenario[48] showed similar modal shares but much larger reductions in VMT, primarily from a reduction in the length of trips. Model results indicated that land use policies and transit investments could reduce VMT by 5 to 7 percent over a 20-year time horizon compared with the status quo scenario. The

[47] In some areas, truck trips are growing at twice the rate of trips made by personal vehicle, but urban goods movement is poorly understood and modeled (TRB 2007).

[48] The pricing measures assumed a CBD parking surcharge and a 30 percent increase in vehicle operating costs, simulating a gas tax increase (Rodier et al. 2002).

addition of pricing increased the VMT reduction to 9 to 10 percent (Rodier et al. 2002, 252).[49]

A recent review of the U.S. and international modeling literature on the effects of land use, transit, and automobile pricing policies on vehicle kilometers traveled (VKT) and greenhouse gas reductions reports model results for time horizons of 10, 20, 30, and 40 years relative to business-as-usual, base case scenarios (Rodier 2009). On the basis of the median study result, Rodier finds that land use policies only (e.g., increased residential housing density, urban growth boundary) reduced VKT by 0.5 percent to 1.7 percent during a time horizon of 10 to 40 years, respectively.[50] A combination of policies that included land use, transit, and pricing yielded much higher median reductions in VKT of 14.5 percent to 24.1 percent over the same 10- to 40-year time horizon. Rodier concludes by noting that metropolitan area context matters with regard to the effectiveness of various policies (e.g., whether areas have viable alternatives to automobile travel, such as transit) and cautions against generalizing the results of strategies effective in some metropolitan areas, particularly in European cities, to other areas where conditions differ (Rodier 2009).

As part of its charge, the committee was asked to examine the potential benefits of using location efficiency models in transportation infrastructure planning and investment analyses (see Appendix A). These

[49] These reductions in VMT cannot be compared with the elasticity estimates derived from the literature review (see Table 3-1), because the former are based on applications of aggregate models that differ substantively from the disaggregate models on which the elasticity estimates are based. For example, simulated system-level changes such as "adding 75 miles of new light rail investment" are not generally translated into "percentage changes in density" (which would need to be averaged across the region, somehow) or some other indicator, which is what would be needed to put the resulting change in VMT into terms comparable to an elasticity. For a given set of assumptions, however, they do show the relative magnitude of effects of alternative policies.

[50] However, the author notes sharp differences in the individual study results. Reductions in VKT were small in those areas with relatively high densities and extensive transit systems (e.g., Washington, D.C., Helsinki) but much higher than the median in areas like the sprawling and rapidly growing Sacramento region, where transit is more limited and an aggressive urban growth boundary was modeled (Rodier 2009).

models are focused specifically on the relationship between residential land use patterns and automobile ownership and use. The original model development was sponsored by the Center for Neighborhood Technology, working in cooperation with the Natural Resources Defense Council and the Surface Transportation Policy Project in 1997. An important objective of the model at that time was to support the Location Efficient Mortgage program of Fannie Mae.[51] The model, designed by Holtzclaw et al. and described in the 2002 study previously discussed, predicts household vehicle ownership and use in three metropolitan areas—Chicago, Los Angeles, and San Francisco—on the basis of household income and size, residential density, availability of transit, and pedestrian and bicycle friendliness of communities. Higher-density locations with good transit access were found to have lower automobile ownership and use, hence the greater efficiency of such locations. As noted earlier, however, the model depends on data collected at an overly aggregate level that mask important variability with respect to household and land use characteristics that could help explain automobile ownership and use patterns. As currently constructed, the location efficiency model of Holtzclaw et al. is too coarse to guide transportation plans and investments.

CASE STUDIES

Many of the studies reviewed in the previous sections suggest that reducing VMT in any significant way through changes in the built environment would require a broad range of measures, from increasing density, to substantial investment in transit, to pricing policies that better reflect the externalities of automobile travel. The committee identified two locations that have had considerable success in implementing such policies—Portland, Oregon, and Arlington County, Virginia. Case studies of each are summarized in this section

[51] With a location efficient mortgage, a household could buy a more expensive home in a location efficient area by committing its estimated savings from reduced travel to repaying the mortgage, interest, taxes, and insurance. The program had some traction in Seattle, Chicago, San Francisco, and Los Angeles, but it failed to become a widely available product.

and described in detail in Annex 3-1. The case studies are descriptive in nature; they do not represent analytic assessments that carefully control for socioeconomic factors or the role of self-selection in examining the effects of changes in the built environment on travel behavior. Also, the two case study sites differ in scale. Portland is a regional area, while the Arlington TODs are local corridors within a single county. Nevertheless, the case studies are instructive in documenting what can be accomplished, particularly in changing housing and travel patterns, and in revealing the enormous challenges involved.

Portland, Oregon

Portland is often cited as the poster child for "smart growth" policies. Two landmark decisions in the mid-1970s put Portland on the path toward controlling regionwide growth and achieving more compact development: (*a*) state legislation requiring that every city and county establish urban growth boundaries to protect both farm- and forestland and (*b*) redirection of a major freeway expansion plan for Portland that resulted in a new light rail transit system. A plan was developed to create a series of compact developments along rail corridors—supported by zoning, parking, and design policies—to revitalize the CBD, link the downtown with new developments and new developments with each other, and create a multimodal transportation system. The final element was the creation of Metro, an elected regional governance body, which not only operated as the area's MPO but also held the power of the purse, with broad taxing authority and responsibility for implementing the area's ambitious development plans.

The evidence indicates that Portland's policies to steer growth into more compact, mixed-use development have paid off, not only in revitalizing the downtown and many of its neighborhoods but also in changing travel behavior, the primary concern of this study. For example, while daily VMT per capita has risen sharply in the United States as a whole, it has declined in the Portland metro area since about 1996 (see Annex 3-1 Figure 1). According to data from the U.S.

and Oregon Departments of Transportation, Portland metropolitan area residents traveled about 17 percent fewer miles per day than the U.S. national average in 2007, the most recent year for which national data are available. High levels of transit ridership are an important contributor. Between 1993 and 2003, transit ridership increased by 55 percent, while Portland's population grew by 21 percent and VMT by 19 percent (Gustafson 2007). But the growth in transit ridership accounts for only a fraction of the reported reduction in VMT, which suggests that land use policies played a key role. Over the same period, according to Metro's Data Resource Center, population density levels increased by 18 percent, from 3,136 to 3,721 persons per square mile, holding constant the urban growth area boundary.[52] A large fraction of the increase came from constructing single-family housing on small lots.[53] The relatively small size of the Portland urban area, due to the urban growth boundary, has also resulted in shorter average trip lengths.

Portland demonstrates that the built environment can be changed in ways that encourage more compact development and less automobile dependence, but its experience may be difficult to replicate widely. As this case study points out, the success of Portland's strategy depended on strong state planning legislation, an ambitious investment in a light rail system that received substantial federal assistance and strong citizen support, and a unique regional governance entity to ensure that plans were carried out.

Arlington County, Virginia, TOD Corridors

In 2002, Arlington County received the U.S. Environmental Protection Agency's national award for Smart Growth Achievement in recognition

[52] In fact, the boundary increased by about 21,000 gross acres. When 2003 densities for the larger boundary are computed—3,411 persons per square mile—the density increase is only 8.8 percent. Downs (2004) notes that, as of the 2000 U.S. census, Portland ranked 24th among the 50 largest urbanized areas in population density increase from the 1990 census.

[53] According to the American Housing Survey, nearly three-fourths of the new dwelling units constructed in the Portland metropolitan area between 1998 and 2002 were built on lots smaller than ¼ acre, and 65 percent of these were single-family dwelling units.

of its high-quality TODs. The success of the TODs developed along transit corridors, in terms of both mixed-use development and high levels of transit ridership, is a good illustration of the importance of accessibility and quality of transit service in reducing automobile travel.

The origins of TOD in Arlington County can be traced to early recognition (in the 1970s) by Arlington County planners and Metrorail itself of the development potential of deteriorating corridors with underutilized real estate and the opportunity to use the new rail transit system to promote revitalization. In particular, the decision to locate Metrorail along two major arterials—the Rosslyn–Ballston Metro Corridor and the Jefferson Davis Corridor—instead of down the median of Interstate 66 enabled the county to transform corridors of closely spaced stations into high-density, mixed-use town centers. By 2003, the county had 52 joint development projects created around dozens of Metrorail stations.

Good planning and transit investment have made Arlington County's Metrorail corridors magnets for office, retail, and mid- and high-rise residential development. Since 1980, for example, county office space has nearly doubled to about 44 million square feet, with almost 80 percent located within the two Metrorail corridors (Arlington County Planning Department 2008). Housing growth in the corridors has occurred at two to three times the rate of growth of the regional population, with the result that in 2003, there were 1.06 jobs for every employed county resident.[54] The Rosslyn–Ballston corridor has also emerged as one of Northern Virginia's primary retail destinations.

The effect on travel patterns has been impressive. According to the 2000 U.S. census, 39 percent of those living in the Metrorail corridors use transit to get to work, and another 10 percent walk or bicycle; only 40 percent commute alone. In comparison, outside the Metrorail corridors, about 17 percent commute by transit, about

[54] Arlington County itself has a population density of about 8,062 per square mile, one of the highest densities in the country (Arlington County Planning Department 2008).

5 percent walk or bicycle, and nearly 61 percent commute alone to work. (These comparisons, however, do not take into account the very different population profiles of these areas or the issue of self-selection.) In addition, growth in traffic volumes along the major arterials in the TODs has largely been kept in check, the result of good-quality transit service and market-rate parking charges. However, more needs to be done to improve these arterials for pedestrian traffic.

Like Portland, Arlington County demonstrates what can be done through a combination of land use plans and transit investment to promote development and at the same time reduce automobile travel. The county's success can be attributed to leadership and early recognition of development potential; good planning and design, including rezoning of land adjacent to Metrorail stations to allow high-density development; a healthy economic base; and above all, the foresight to take advantage of massive investment in a new regional transit system to channel development.

FINDINGS

Both logic and empirical evidence suggest that developing more compactly, that is, at higher population and employment densities, lowers VMT. Trip origins and destinations become closer, on average, and thus trip lengths become shorter, on average. Shorter trips can increase trip frequencies, but empirical evidence suggests that the increase is not enough to offset the reduction in VMT that comes from reduced trip lengths alone. Shorter trips also may lower VMT by making walking and bicycling more competitive alternatives to the automobile, while higher densities make it easier to support public transit. The effects of compact development on VMT can be enhanced when it is combined with other measures, such as mixing land uses to bring housing closer to jobs and shopping; developing at densities that can support transit; designing street networks that provide good connectivity between destinations and well-located transit stops and that accommodate non-

vehicular travel; and demand management measures, such as reducing the supply and increasing the cost of parking.

An extensive literature on the relationship between the built environment and household travel has developed, but capturing the nature and the magnitude of the link between the two has proved elusive. Problems of measurement, issues of scale, and adequate controls for confounding variables (e.g., socioeconomic factors, self-selection) have resulted in widely varying results concerning the importance of changes in land use and the magnitude of their effects on travel. The predominance of cross-sectional analyses has precluded establishing cause and effect between a change in the built environment and a change in VMT.

Recent studies, which have attempted to control for many of these problems, have found statistically significant but modest effects of the built environment on VMT—on the order of a 5 to 12 percent lowering of household VMT associated with a doubling (100 percent increase) of residential density in a metropolitan area. Some of these studies, however, have focused on only one attribute of the built environment—density. While density could be a proxy for other variables, it is unlikely to represent all the land use and related transportation measures necessary to bring about a significant change in VMT. Doubling residential density alone without also increasing other variables, such as the amount of mixed uses and the quality and accessibility of transit, will not bring about a significant change in travel.

One study that does a good job of capturing these multiple factors (Bento et al. 2005), including the spatial distribution of population or population centrality, jobs–housing balance, and the supply of public transit in a region, finds that, if implemented together, these measures could result in a significant lowering of VMT. Using the example of Boston, one of the densest metropolitan areas, and Atlanta, one of the most sprawling, the researchers simulate the effect of moving sample households from a city with the urban form and transit supply characteristics of Atlanta to a city with the characteristics of Boston, with the effect that VMT could be lowered by as much as 25 percent, an estimate

that the committee uses subsequently as an upper bound in its own scenarios. Of course, the simulation does not take behavioral issues into consideration. The typical Atlanta resident facing a Boston environment would not necessarily travel like a Bostonian, although both attitudes and behavior would likely be influenced by the built environment over time.

Moreover, making a thought experiment a reality poses considerable challenges. As the examples of Portland and Arlington County demonstrate, dramatic changes in the built environment and travel patterns can be achieved. However, they require significant and sustained political commitment, substantial transportation infrastructure investments, and decades to show results. Replicating these successes in other metropolitan areas is likely to pose similar challenges. Nevertheless, demographic changes over the next 30 to 50 years may provide opportunities for changing housing preferences and travel patterns in ways that are more favorable to compact development and reduced automobile travel, the topic of the next chapter.

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Abbreviation

TRB Transportation Research Board

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Annex 3-1

Details of Case Studies

PORTLAND, OREGON

The state of Oregon and the Portland metropolitan area in particular are well known for progressive growth management policies and pioneering leadership in compact, mixed-use development efforts. These efforts have their roots in the mid-1970s, when a Governor's Task Force on Transportation redirected a major freeway expansion plan toward planning for a multimodal transportation system and when the state legislature enacted Senate Bill 100. That bill required every city and county to adopt a comprehensive plan that met 19 statewide planning goals, including a requirement to establish "urban growth boundaries" (UGBs) to limit the extent of urbanization and protect farm- and forestlands outside these boundaries (Cotugno and Benner forthcoming).

Portland now operates under the 2040 Growth Management Strategy, which calls for focusing expected population growth in existing built-up areas and requires local governments to limit parking and adopt zoning and planning changes consistent with the strategy. The goal is that by 2040, two-thirds of jobs and 40 percent of households will be located in and around centers and corridors served by light rail transit (LRT) and bus. Leadership to develop this strategy is focused on a unique form of elected regional governance through Metro. In addition to being the region's metropolitan planning organization, Metro has broad authority to ensure that local land use plans are consistent with the regional vision, has broad taxing powers, and plays a lead role in developing the LRT system and implementing TOD and open-space acquisition programs (A. Cotugno, personal communication).

Beginning in 1980, Tri-Met (the regional transit authority), Metro, the City of Portland, the City of Gresham, and Multnomah County

initiated their Transit Station Area Planning Program, which included market studies, coordination with other regional planning efforts, and station area plans (including legally binding requirements for minimum densities, parking maximums, and design guidelines), and sought to identify, create, and promote opportunities for TODs along the planned LRT corridors. Since that time, the region has been pursuing a steady LRT, commuter rail, and streetcar expansion program, which has evolved as decision makers have gained experience with using rail investments to achieve broader community objectives (Cervero et al. 2004).

Development along the 15-mile Eastside LRT line, opened in 1986, has been primarily infill, whereas the 18-mile Westside LRT, opened in 1998, was built largely into greenfields. The latter was one of the first efforts in the nation to combine extensive LRT expansion into the suburbs with deliberate TOD around the stations, connecting previously isolated communities to downtown and to each other and creating new mixed-use pockets of development in the middle of traditional suburbia (Cervero et al. 2004). In 2001, extension of a 5-mile segment to the airport provided the opportunity for a public–private partnership to finance the LRT construction and leverage the development of surplus airport property. In 2004, an inner-city 6-mile extension to the north provided a tool for revitalization in a low-income neighborhood. The newest extension, a 6.5-mile line to the south, is being built on a freeway right-of-way that was set aside for a transit corridor 30 years ago when the Interstate beltway was built (A. Cotugno, personal communication). Two of the most notable examples of TOD in the region, the Pearl District and Orenco Station, are discussed below.

The Pearl District arose from a decision to use construction of the Portland streetcar line as a means to leverage large-scale redevelopment of a functionally obsolete warehouse and industrial zone in downtown Portland. The city entered into an innovative agreement with developers, requiring them to meet ambitious housing density levels

to ensure a supply of affordable housing,[55] donate land for parks and greenspace, and help pay for removal of a highway viaduct and construction of the streetcar line. The Pearl District has met all expectations for becoming a vibrant, desirable place to live. It currently contains approximately 5,500 housing units, along with 21,000 jobs and 1 million square feet of new commercial and retail space. As a result of its popularity, the district now has the most expensive housing in the Portland region as well as the highest density in the city, at approximately 120 housing units per acre.

Orenco Station was designated one of a number of "town centers" along the Westside LRT line in the 2040 regional plan and is generally viewed as the most ambitious and successful such community to date. It contains 1,800 homes, mixed with office and retail spaces, in the town of Hillsboro, situated close to a large employment center in the metropolitan area's high-tech corridor. In response to market surveys indicating preferences for walkable streets and community-oriented spaces, the developers experimented with design elements such as communal greenspaces, narrow streets, houses located close to sidewalks, and garages placed behind homes. Free LRT passes are provided to all newcomers for their first year to encourage the use of transit. Orenco Station has won numerous national planning awards, and its housing units have commanded as much as a 25 percent premium over larger suburban homes in the area (NRDC 2001).

Metro's TOD policies are thought to be one of the major factors in attracting people and businesses to the region. Over the decade of the 1990s, the number of college-educated 25- to 34-year-olds increased by 50 percent in the Portland metropolitan area—five times more rapidly

[55] The development agreement provided that the developers had to build a certain amount of subsidized housing and some market-rate, lower-cost housing. The developers donated land for publicly subsidized buildings, which are permanently subsidized and managed by the housing agency. They also built some very small units on the lower floors of some of the high-rises so that while their rents will fluctuate over time, they will be more affordable than the larger units on the upper floors.

than in the nation as a whole, with the fastest increase occurring in the city's close-in neighborhoods (Cortright and Coletta 2004). At the same time, Portland's streetcar line became an important catalyst for development at much higher densities than seen previously. More than half of all the central city development within the past decade has been within one block of the streetcar line.

A wide array of studies has demonstrated the effect of these land use and transportation developments on travel behavior. While VMT per person has been increasing nationally, it has been declining in the Portland metropolitan area since about 1996 (see Annex 3-1 Figure 1). According to data from the U.S. and Oregon Departments of Transportation, Portland area residents traveled about 17 percent fewer miles per day than the national average for other urbanized areas in 2007, the most recent year for which national data are available. Portland is one of the few regions in the country where transit ridership is growing more rapidly than VMT, and bicycle use has also shown rapid growth.[56]

From 1993 to 2003, Portland's population grew by 21 percent, its average VMT grew by 19 percent, while its transit ridership increased by 55 percent (Gustafson 2007). But the growth in transit ridership accounts for only a fraction of the reported reduction in VMT, which suggests that land use policies played a key role. Over the same period, according to Metro's Data Resource Center, population density levels increased by 18 percent, from 3,136 to 3,721 persons per square mile, holding constant the urban growth area boundary.[57] A large fraction of

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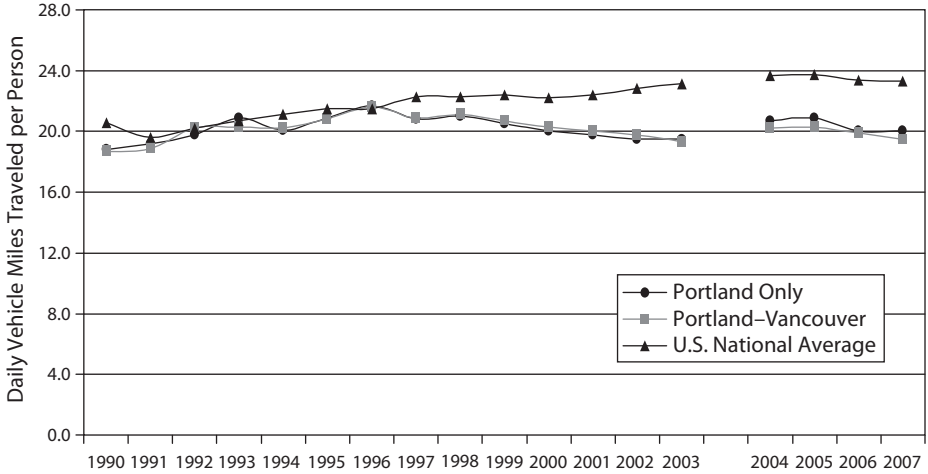
[56] Since 2000, daily bicycle trips have grown nearly threefold on Portland's four main bicycle-friendly bridges across the Willamette River, from 6,015 trips to 16,711 trips (Portland Bicycle Counts Report 2008), while the bikeway network has grown by less than one-quarter, from 222.5 bikeway miles in 2000 to 274 bikeway miles in 2008. In 2008, bicycles represented 13 percent of the combined daily bicycle and automobile trips, up from only 4.6 percent of all combined trips in 2000.

[57] In fact, the boundary increased by about 21,000 gross acres. If population density is calculated on the basis of the new UGB in 2003, population density is 3,411 persons per square mile, and the increase in density from 1993 falls to 8.8 percent. Downs (2004) notes that, as of the 2000 U.S. census, Portland ranked 24th among the 50 largest urbanized areas in population density increase from the 1990 census.



ANNEX 3-1 FIGURE 1 **Daily VMT per person by urbanized area, 1990–2007, Portland, Oregon, only; Portland–Vancouver, Oregon–Washington; and U.S. national average.**

[Before 2004, the 1990 census information was used to calculate the urbanized population for the Highway Performance Monitoring System (HPMS) submittal from which VMT is calculated. The only official population report for the urbanized area of Portland comes every 10 years from the U.S. census. The 2000 census data were reported in 2002, but because the urban boundary was not finalized in time, the HPMS report that was based on the 2000 census data was not included until the 2004 submittal. The method used to calculate the urbanized population each year is to apply the ratio of the total city population in 2000 to the urbanized population in 2000 to the total city population in 2004, 2005, 2006, etc., until an official new urbanized number is available from the 2010 census. The 2001–2003 population estimates were based on the 1990 ratio of city to urbanized areas. There was probably not a sudden jump in VMT for Portland and Portland–Vancouver from 2003 to 2004, but more likely a gradual increase that had been occurring over time and that had not been measured with the correct standard (the 2000 census data) until the 2004 data set was available. The break in the series from 2003 to 2004 denotes the break in trend.]

Source: FHWA 2009, Table HM-72.

the increase came from the construction of single-family housing on small lots.[58] The relatively small size of the Portland urban area, due to the UGB, has also resulted in shorter average trip lengths.

Several studies have examined the travel behavior of Portland residents before and after moving to housing located adjacent to an

[58] According to the American Housing Survey, nearly three-fourths of the new lots constructed in the Portland metropolitan area between 1998 and 2002 were built on lots smaller than ¼ acre, and 65 percent of these were single-family dwellings.

LRT station. In all such cases, residents reported that moving led to a significant increase in their use of rail transit and a concomitant decrease in automobile use (Podobnik 2002; Switzer 2002; Dill 2006; Evans et al. 2007). A related study examines travel behavior in two particular neighborhoods before and after the LRT system began running (in 1990 and 2000, respectively). In Orenco Station, residents' automobile mode share dropped from 100 percent to 86 percent, and in Beaverton Central station, it dropped from 81 percent to 73 percent (Evans et al. 2007). None of these studies, however, controlled for self-selection.

Results of a travel behavior survey of more than 7,500 households in four counties (Clackmas, Multnomah, and Washington Counties in Oregon and Clark County in Washington) clearly indicate that good transit service and mixed-use neighborhoods have had a significant influence on reducing automobile use and ownership (see Annex 3-1 Table 1). In a more recent survey of residents living near stations along the Westside LRT line, 23 to 33 percent reported using transit as their

ANNEX 3-1 TABLE 1 **Mode Share, VMT per Capita, and Automobile Ownership, Portland Region**

Area	Transit Mode Share (percent)	Walking Mode Share (percent)	Automobile Mode Share (percent)	VMT per Capita	Automobile Ownership per Household
Neighborhoods with mixed use and good transit	11.5	27.0	58.1	9.80	0.93
Neighborhoods with good transit only	7.9	15.2	74.4	13.28	1.50
Remainder of Multnomah County	3.5	9.7	81.5	17.34	1.74
Remainder of the region	1.2	6.1	87.3	21.79	1.93

Source: 1994 Metro Travel Behavior Survey for all trip types.

primary commute mode, compared with less than 10 percent of workers in the neighboring suburbs of Hillsboro and Beaverton and 15 percent of Portland workers overall (Dill 2006).

However, not all aspects of the Portland region's planning efforts have gone smoothly. Some TOD projects (such as the Round and Center Commons) have faced significant financial struggles, and many would not have succeeded without significant public subsidies, including a 10-year tax abatement offered for new developments within walking distance of a rail station. Critics charge that the dense development policies have led to rapidly increasing congestion, unaffordable housing prices, and destruction of urban open spaces. And there have been recurring attempts by some civic and business interests over the past couple of decades to weaken or repeal key aspects of the growth management system.

Despite these struggles, however, the Portland region is still highly regarded for the scale and extent of sustained commitment to TOD and innovative planning regulations. The region offers some important lessons for how to create well-designed mixed-use communities that are nodes along successful regional corridors of compact development and not just isolated islands of development. The Portland metropolitan area's success is due to a host of political, regulatory, and economic factors, some of which are unique to the region but all of which may still offer useful lessons for other parts of the country:

- Early leadership from a visionary governor and a supportive state legislature willing to pass strong state planning laws, including urban growth boundaries;
- Strong public support for LRT investments and advocacy from citizens groups (in particular, the 1000 Friends of Oregon) capable of litigating when relevant authorities were not following planning requirements;
- Unique powers of Metro to influence planning and investments for regional transportation and land use;

• Strong congressional representation (e.g., as an aid for obtaining federal Transit New Start program funds); and

• Local and regional policy makers willing to go beyond just channeling growth around transit by pressing developers to increase density, quality of design, and mix of uses in TOD zones, and the persistent use of transit infrastructure investments as a means to enhance community revitalization.

ARLINGTON COUNTY, VIRGINIA, TOD CORRIDORS

The Washington, D.C., area's 103-mile, 86-station Metrorail system is arguably the nation's best example of a modern rapid transit system built specifically to incorporate a goal of shaping regional growth. The system, which opened in 1976, is overseen by the Washington Metropolitan Area Transit Authority (WMATA), an independent regional transportation authority involving coordination among the District of Columbia, Maryland, and Virginia.

TOD leadership was exercised early on by Metrorail's leaders and county planners, who realized in the 1970s that deteriorating corridors and large swaths of underutilized real estate in the region were ripe for redevelopment and provided an opportunity for revitalization through transit investment. Long before the rail system became operational, WMATA's leaders adopted policies to create a public–private program for promoting development adjacent to Metrorail stations, creating a real estate development department that was given the resources to build a portfolio of holdings and encouraged to pursue joint development opportunities. By 2003, 52 joint development projects had been created around dozens of Metrorail stations.

While successful TOD zones can be found throughout the region (particularly within downtown Washington, D.C., and in Montgomery County, Maryland), Arlington County, Virginia, in particular, is widely hailed as one of the nation's best TOD success stories. When the Metrorail

lines were being planned initially, a key decision was made to reorient the planned rail line from running along the county's major highway corridor, Interstate 66, to follow the Rosslyn–Ballston Metrorail corridor of five closely spaced stations that each could be developed into high-density, mixed-use town centers. A second Metrorail corridor along Fairfax Drive—the Jefferson Davis corridor—included stations at Pentagon City and Crystal City.

As these plans have been implemented, Arlington County has experienced major growth and renewal and is now among the most densely populated jurisdictions in the country (estimated at 8,062 persons per square mile in 2008). Since 1980, county office space has nearly doubled to about 44 million square feet, with almost 80 percent located within the two Metrorail corridors (Arlington County Planning Department 2008). Housing growth in the corridors has occurred two to three times more rapidly than the growth of the regional population, with the result that in 2003 there were 1.06 jobs for every employed county resident (Cervero et al. 2004). These trends are attributable in part to the growth of the region in general and the attraction of Arlington as a desirable location close to downtown Washington, but they also reflect the role of the Metrorail corridors as powerful magnets for development. The Arlington County Department of Public Works, for example, estimates that the presence of Metrorail stations attracted nearly $3 billion in real estate development between 1973 and 1990. More than 60 percent of the remaining office development capacity and almost 70 percent of the remaining residential development capacity are forecast to occur within the Metrorail corridors.

Transit ridership has paralleled the growth in development at major stations. Today, Arlington County has one of the highest percentages of transit use in the nation. Of those living along the Metrorail corridors, approximately 39 percent use transit to commute, and 10 percent walk or bike (Cervero et al. 2004). Outside the corridors, only 17 percent commute by transit and 5 percent walk or bike—but these are high transit ridership and walking percentages for most counties.

Of course, the region faces ongoing challenges. These include a lack of affordable housing and some inconsistencies between land use and transportation planning efforts (for instance, some roads near Metrorail stations are more accommodating of high-speed traffic than of pedestrians). The Arlington corridor's Metrorail lines increasingly struggle with serious overcrowding because there are not enough cars and tracks to meet the booming ridership demand. This shortfall stems in part from inherent design problems but also from more general budget problems. The Washington Metrorail system is virtually the only major transit system in the nation that receives no dedicated stream of revenue for capital or operating costs; rather, it is dependent on operating subsidies from its member jurisdictions, having to compete for the same pool of state and local government general fund revenues that subsidize public safety, education, parks, and many other needs. This situation leaves the system continually vulnerable to the vagaries of local budgeting, often scrambling to fill revenue gaps and unable to address system maintenance and upgrading needs. Despite these challenges, most planners look to the Washington Metrorail system in general, and Arlington County in particular, as a model of TOD, which can provide important lessons for other regions of the country.

Some of Arlington County's success may be attributable to unique local factors such as strong, stable support among the county board, manager, and other key local officials; a large base of locally rooted jobs in federal government agencies and related contracting organizations; and a manageable physical size (approximately 26 square miles) that made it possible for planners and officials to have a good grasp of the territory and communicate effectively with the community. The primary key to Arlington's success, however, has been adherence to textbook planning principles. This has included the careful preparation of a general land use plan that set the broad policy framework for all development decisions along targeted growth axes, together with sector plans for orchestrating development activities (including land use and zoning ordinances, urban design, transportation planning, and open-space

guidelines) within quarter-mile "bulls-eyes" of each Metrorail station. These plans have been instrumental in communicating to investors and residents about the types of developments planned and creating a sense of integrity with respect to plans and policies. Ongoing review and revision of the original plans have ensured that developments evolve in response to changing community goals and market conditions. Related keys to success have included the following:

- A variety of strategies to attract private investments around stations, such as targeted infrastructure improvements and incentive-based, permissive zoning measures;
- Rezoning of land adjacent to stations to high density while maintaining relatively low density and protecting greenspace in surrounding neighborhoods;
- Dedication to continually pressing for top-quality design for housing and office developments, with a strong focus on creating attractive, walkable spaces; and
- Proactive public outreach and community involvement, with business alliances, neighborhood groups, and individual residents frequently being invited to express their opinions on the design and scale of new developments through neighborhood meetings, workshops, and interactive websites.

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Abbreviations

FHWA	Federal Highway Administration
NRDC	National Resources Defense Council

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4 | Future Residential Development Patterns

This chapter explores the potential for more compact, mixed-use development and reduced automobile travel. It first examines the opportunities for growth in the demand for compact developments, starting with demographic trends—primarily the aging of the population and immigration—that will shape housing needs and preferences, the location of housing, and travel well into the middle of this century and beyond. The discussion then turns to best estimates of new housing units needed by 2030 and 2050, some of which could be developed at higher densities. These estimates form the basis for the scenarios developed in the next chapter to estimate potential effects on vehicle miles traveled (VMT), energy use, and carbon dioxide (CO_2) emissions. Also discussed are the potential effects of higher energy prices and measures to curb greenhouse gas (GHG) emissions on development patterns. Although the future provides many opportunities for change, the various impediments to the supply of compact development are discussed next. The resulting apparent undersupply of more compact development is then considered, followed by strategies for addressing impediments and increasing the supply of compact, mixed-use development. The chapter ends with a summary of key findings.

OPPORTUNITIES FOR GROWTH IN DEMAND FOR COMPACT DEVELOPMENT

The primary opportunity for changing development patterns lies in the number of new housing units that will be constructed. Millions of new units will be required every year, both because the population is projected to grow (largely as a result of immigration) and because some housing units are torn down and replaced every year. Demographic and economic trends, particularly the retirement of the baby boom generation, the increasing importance of immigrants, and higher energy prices, could result in a larger share of these new units being built in more compact, mixed-use developments.

Demographic Trends

Aging of the Population

Aging of the baby boom generation over the next several decades will result in a historically unprecedented generational shift with profound implications for the housing market in the United States.[1] By 2010, the leading edge of the boomers will pass the age of 65, and growth of the elderly population will substantially exceed that of younger adults (see Table 4-1). As they have in every decade since the 1970s, the boomers will dominate changes in the housing market until at least 2030 as they downsize and eventually withdraw entirely from home ownership. Because of the size of the boomer cohort, nearly every state will experience these trends (Pitkin and Myers 2008).

Two effects are of particular interest in this study. First, starting in about 2015, the boomers may begin to sell off their large supply of housing, primarily in low-density suburban areas, as they move to smaller units (Pitkin and Myers 2008). Second, new construction will likely cater to the demand of seniors for retirement housing, following

[1] This section draws heavily on a paper by Pitkin and Myers (2008) commissioned for this study.

TABLE 4-1 **Population Growth Each Decade and by Dominant Age Group, 1960–2050 (in millions except as indicated)**

	Population Growth			Dominant Age Group		
Decade	Total 25+[a]	Ages 25–64	Ages 65+	Age Group	Growth	Percent of Total
1960–1970	10.6	7.1	3.4	55–64	3.1	28.9
1970–1980	22.9	17.3	5.6	25–34	12.1	53.0
1980–1990	25.1	19.6	5.5	35–44	12.0	47.7
1990–2000	24.0	20.2	3.8	45–54	12.8	53.5
2000–2010	21.4	16.3	5.2	55–64	11.8	54.8
2010–2020	22.1	7.8	14.4	65–74	10.5	47.5
2020–2030	19.2	2.4	16.8	75–84	8.3	43.4
2030–2040	20.1	11.5	8.6	85+	5.8	28.9
2040–2050	19.0	12.3	6.7	85+	5.5	28.7

Note: Since 1970, when the leading edge of the baby boomers turned 25, and continuing until 2030, when the leading edge will turn 85, this generation accounts for more than 40 percent of the growth in the U.S. population each decade.

[a]Those age 24 and younger are excluded because few persons in this age group are homeowners.

Source: Pitkin and Myers 2008, Table 4.

the general principle that future housing development demand is shaped by growth at the margin rather than by the average growth in new households.[2]

These effects could represent an important opportunity for shifts to denser development patterns as boomers downsize and move to smaller housing units and possibly to more central, walkable locations (Myers and Gearin 2001). These preferences could shift even more strongly once such new retirement-friendly developments are available

[2] The idea is that only 1 to 2 percent of all households each year live in newly constructed units, and it is this small minority to which developers cater. Thus, a demographic change such as the demand of boomers for retirement housing has the potential to drive major shifts in development patterns if it involves distinctly different preferences from the growth categories of prior decades (Pitkin and Myers 2008).

in greater numbers in the market and boomers become more familiar with them. Recent studies suggest, however, that the jury is still out on whether boomers will move in large numbers to city centers (Engelhardt 2006; Frey 2007).[3] On the one hand, perhaps more than past retiring generations, the boomers possess the education, wealth, interest in amenities, and potential to continue to work and pursue leisure activities longer to be attracted to cities. Nevertheless, they are the first truly "suburban generation," born and raised in the suburbs, and it is unclear whether they will be interested in moving to a city environment (Frey 2007, 15). As yet there is little evidence from current retirees of any net shift of population toward central cities, nor has the amount of new construction been sufficient to indicate a structural shift in the location of new urban development (Engelhardt 2006; Pitkin and Myers 2008).

Regardless of whether the boomers retire to central cities, their travel will be reduced as they age. The 2001 National Household Travel Survey found that licensed drivers age 65 and older drove an average of about 7,700 miles annually, more than 40 percent fewer miles than the next lowest age group (55 to 64) (Hu and Reuscher 2004, Table 23). Older drivers also took fewer daily person trips (3.4 on average)—about one-quarter fewer than the 55 to 64 age group (Hu and Reuscher 2004, Table 13). The trend over time, however, has been toward increased VMT and trip taking by older drivers (Hu and Reuscher 2004, Tables 13 and 23). The extent to which the boomers will drive more than current retirees depends on their continuing suburban lifestyle; their health; and their propensity to prolong working, either full- or part-

[3] Although it is unclear where the boomers will move within metropolitan areas (suburbs or center cities), Census Bureau projections for 2000 to 2030 suggest that aging in place—in the same state and metropolitan area, if not in the same house or community—rather than migration will drive the growth rates of senior populations in states (Frey 2007). The fastest overall growth of senior populations is projected for a group of western states (not including California, where congestion and housing prices are already high) and certain southern states (Texas, Georgia, and Florida), where large numbers of senior and presenior populations (55 to 64 years of age) already reside.

time. If future cohorts of retirees are healthier and wealthier, as many expect, they will likely drive longer. To the extent they choose to live in more urban settings with mixed uses and good transit, their continued mobility will also enable them to travel by other transportation modes (e.g., transit, walking).

Immigration

Immigrant populations have risen sharply in recent years and are younger than the existing population on average. As noted, they are the primary source of U.S. population growth, helping to offset the nation's aging population. Immigrant populations will also play an important role in future housing demand and provide another opportunity for denser development patterns.

Immigration levels increased sharply between 1997 and 2006 to an average annual net flow of about 1.16 million per year, with the result that the foreign-born share of the U.S. population has more than doubled from its historic observed minimum in 1970 to 13.1 percent in 2006 (Pitkin and Myers 2008, 22). The foreign-born share of new entrants to the housing market has increased accordingly, to about 25 percent in 2006 (Pitkin and Myers 2008, 23).

Projecting the future housing demand of foreign-born households involves many uncertainties, not the least of which is forecasting immigration flows. The latter can be significantly altered by changes in U.S. laws regulating immigration, border enforcement, numbers of illegal immigrants, the demand for labor in the United States, and population and economic growth in source countries. Pitkin and Myers (2008) recommend use of an intermediate-range population forecast, which projects a foreign-born population in the range of 13 to 16 percent of the total population by 2030, growing to 14 to 19 percent by 2050 (see Table 4-2). Individuals of Hispanic origin represent the dominant immigrant group. Together with native-born Hispanics, they are projected to represent 20 to 23 percent of the total U.S. population by 2030 and 22 to 29 percent by 2050.

TABLE 4-2 **Population of the United States by Nativity and Ethnicity, 2006 and Projected for 2030 and 2050 (in millions except as indicated)**

		2030		2050	
	2006, Observed[a]	**Census[b]**	**Pew[c]**	**Census[b]**	**Pew[c]**
Total population	298.8	363.6	371.8	419.9	438.2
Percent foreign born	12.5	12.8	16.0	13.8	18.6
Percent Hispanic, native and foreign born	14.7	20.1	22.5	22.3	29.2

[a]U.S. Census Bureau estimate for July 1, 2006; percent foreign born from American Community Survey 2006.

[b]Census 2004 Interim. Foreign-born share inferred from Census 2000, Middle and High series on which the Interim series immigration is based.

[c]Pew (Passel–Cohn) Main.

Source: Pitkin and Myers 2008, Table 6.

Immigrant flows have tended to be geographically concentrated, with new immigrants settling near groups with the same ethnicity. Before the 1990s, densely settled areas in the northeast and west were the dominant destination. Since about 1990, new immigrants, especially those of Hispanic origin, have been locating in the south and midwest in much greater numbers than previously (Pitkin and Myers 2008). Nevertheless, and of direct relevance to this study, foreign- and native-born Hispanics are much more likely to locate in central cities and remain there than are non-Hispanics of similar nativity status (Figure 4-1). In fact, between 2000 and 2004, Los Angeles and New York still accounted for nearly one-quarter of the increase in the U.S. foreign-born population (Frey 2007).

The housing patterns of foreign-born householders, Hispanic and non-Hispanic alike, differ substantially from those of the native born, in part reflecting the greater propensity of immigrant populations to locate in central cities. For example, immigrants who arrived in the United States in the previous 10 years are about three times as likely to live in multifamily housing (Pitkin and Myers 2008, 26). This large

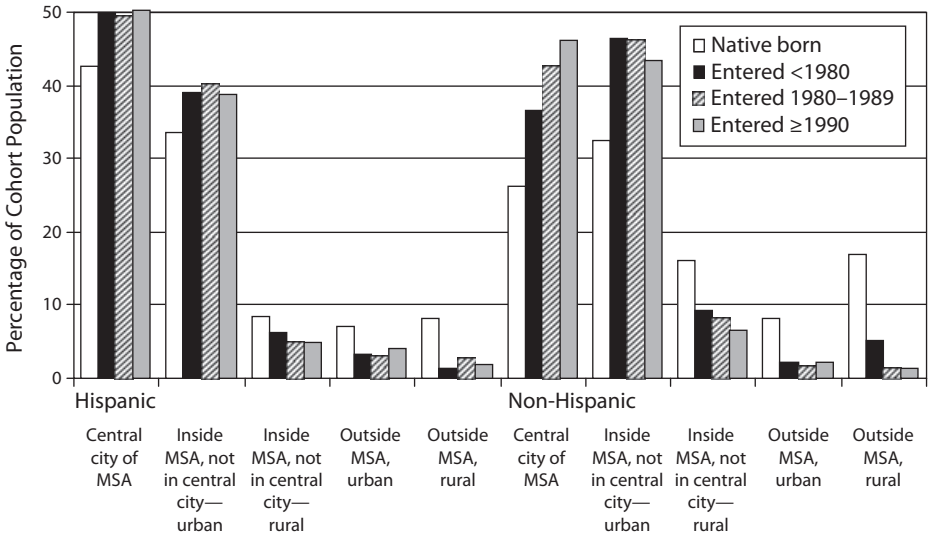

FIGURE 4-1 **Distribution of population among metropolitan locations, 2003, by origin, nativity, and period of entry (MSA = metropolitan statistical area).**

Source: Pitkin and Myers 2008, Figure 7.

difference, however, is short-lived, falling by more than half within a decade of arrival, reflecting income growth and assimilation of immigrant populations (see Figure 4-2). The convergence pattern of Hispanic immigrants is thought to be somewhat slower because of continuing educational and income gaps, but the evidence here is mixed (see Smith 2006 and Perreira et al. 2006, for example, in Pitkin and Myers 2008).

A similar pattern of differences and then convergence toward the mean is found in the travel behavior of immigrant populations. For example, a study of immigrant populations in California, where the foreign-born population now represents more than one-quarter (26 percent) of the total, found that recent immigrants, regardless of race or ethnicity, are significantly more likely to commute by transit than are native-born adults of a similar race or ethnicity, controlling for other determinants of mode choice (Blumenberg and Shiki 2007). After their first 5 years in the United States, however, immigrant

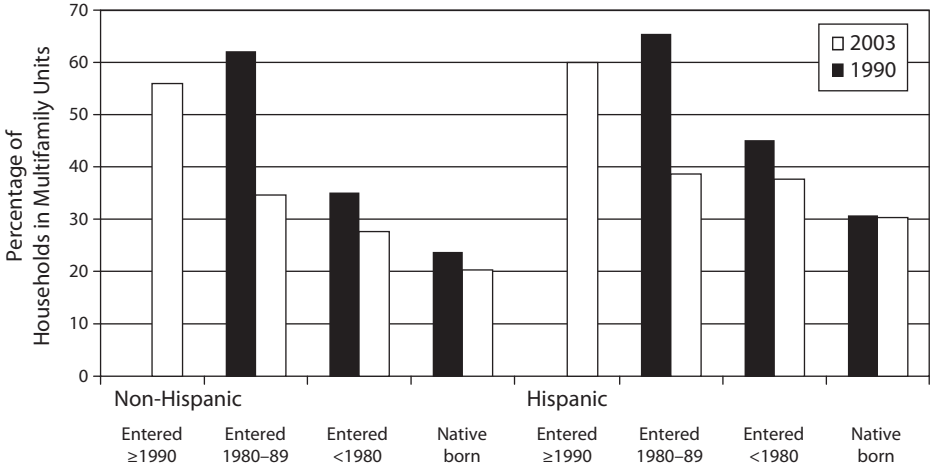

FIGURE 4-2 **Households in multifamily units, by origin and nativity of householder, 1990 and 2003.**

Source: Pitkin and Myers 2008, Figure 5.

populations, much like their native-born counterparts, begin to purchase and use automobiles as their economic status rises (Blumenberg and Shiki 2007). The rate of assimilation for different ethnicities varies considerably, though, even after controlling for income. Asian immigrants, for example, move rapidly to automobile use. Hispanics, who make up close to one-third (32 percent) of California's population, tend to use transit more than do native-born commuters even after 20 years in the United States, which perhaps suggests cultural differences for this group (Blumenberg and Shiki 2007).

The Youth Market

Another opportunity for more compact, mixed-use development may be found in young adults. Although young adults who are entering the housing market are less numerous than the baby boom generation, they appear to exhibit a stronger preference than their predecessors for urban living (Pitkin and Myers 2008). The amenities and sophistication of many cities are magnets for the often young, highly educated niche

market of nontraditional households, variously termed the "creative class" (Florida 2002) and "knowledge workers" (Storper and Manville 2006; Cervero 2007). The resurgence in apartment construction in many central cities (Birch 2002 in Pitkin and Myers 2008) is consistent with growing preferences for more compact development and more central locations. The amount of new construction has not yet been sufficient, however, to demonstrate a significant shift in development patterns (Pitkin and Myers 2008).

High Energy Prices

The demand for more compact development might also be encouraged by a future that could include sustained higher energy costs or the lingering effects of the current subprime mortgage crisis.[4] What if, for example, higher energy prices persist—both gasoline prices at the pump and residential heating and cooling costs—or a significant carbon tax is imposed to reduce GHG emissions? In the short to medium term, consumers would likely respond by driving less, reducing VMT, and purchasing more fuel-efficient vehicles. In the longer term, higher energy prices could motivate residents and businesses to relocate to more densely developed areas, both to reduce travel distances and to increase opportunities for travel by alternative modes (e.g., transit, walking, bicycling).

What evidence is available that these changes will occur? The Congressional Budget Office (CBO) published two studies in 2008 examining consumer response to the most recent upward trend in gasoline prices that began in 2003.[5] The first study examines changes

[4] No studies could be found on the impact of the mortgage crisis on long-term housing demand and, in particular, on the location of housing within metropolitan areas. One could hypothesize that the supply of lower- and moderate-income units, which tend to be attached housing or housing on smaller lots, would increase as a result of foreclosures. Much of this housing currently exists in central cities, in older suburban areas, or at the metropolitan fringe.
[5] Prior gasoline price increases occurred in 1974 and 1979 in conjunction with Mideast oil supply interruptions and again in 1990 (CBO 2008b).

from 2003, when gasoline cost $1.50 per gallon, to 2006, when it cost $3 per gallon (CBO 2008b). The second study is an update that examines consumer response to the increase in the price of gasoline to $4 per gallon by May 2008 (CBO 2008a). CBO finds that consumers were less responsive to the price of gasoline, particularly in the short term, than they had been several decades ago. CBO attributes this finding to growth in real income, which has made the cost of gasoline a smaller fraction of consumers' disposable income; improved fuel economy; and the development of distant suburbs, which has made some consumers more reliant on the automobile (CBO 2008b). Nevertheless, CBO cites evidence that motorists cut back on the number of trips, and with gasoline at $4, they drove less than in previous years.[6] In addition, there was a shift to cars and away from less fuel-efficient sport utility vehicles and minivans. The share of light trucks fell from about 55 percent of the light-duty vehicle fleet in 2004, to below 52 percent by 2006, to a seasonally adjusted annual rate of 44 percent when gasoline prices rose above $4 per gallon in 2008 (CBO 2008a; CBO 2008b).

CBO also quantifies the relationship between gasoline prices and fuel consumption. Estimates of the short-run elasticity of demand for gasoline indicate a modest response; each 10 percent increase in the retail price of gasoline is estimated to have reduced consumption by about 0.6 percent (CBO 2008b). Estimates of the long-run elasticity of demand for gasoline indicate that a sustained increase of 10 percent in price would reduce gasoline consumption by about 4 percent. The substantially larger long-term effect is attributed to the ability of consumers to make more significant changes, such as purchasing more fuel-efficient vehicles and moving jobs or residences or both to

[6] On the basis of a sample of California freeways, CBO found that between 2003 and 2006, freeway drivers adjusted to higher gasoline prices by making fewer trips and by driving more slowly. Every 50 cent increase in price resulted in about a 0.7 percent decline in weekday freeway trips in areas where rail transit was available (CBO 2008b). With sharply higher prices in 2008, VMT declined nationwide according to statistics collected by the Federal Highway Administration, a phenomenon not seen since the 1970s (CBO 2008a).

reduce their commuting and other trip distances. For the effect to be fully realized, however, CBO notes that prices would have to remain sufficiently high for about 15 years for the entire stock of passenger vehicles to be replaced (CBO 2008b).

CBO also examines the impact of higher gasoline prices on possible government policies to reduce gasoline consumption and CO_2 emissions, including taxes and more stringent fuel-efficiency [corporate average fuel economy (CAFE)] standards. CBO notes that a gasoline tax increase, or a carbon tax under a cap and trade system, would have to be very high to make a difference in motorist behavior, both because such taxes represent a relatively small share of the total price of gasoline[7] and because Americans have limited alternatives to automobile travel. In Europe, for example, high energy prices have probably contributed to higher-density developments, and high taxation has sustained these prices. Moreover, because of more stringent CAFE standards promulgated as part of the Energy Independence and Security Act of 2007, which require manufacturers to increase the fuel-efficiency of passenger vehicles to an average of at least 35 miles per gallon by 2020, CBO concludes that carbon taxes on CO_2 emissions envisioned in current climate change legislation would probably have little or no effect on average fuel economy (CBO 2008a).[8] Nevertheless, were it politically feasible, raising gasoline prices would encourage motorists to drive less. In contrast, the CAFE standards should encourage driving by reducing gasoline costs (motorists can drive farther on a gallon of gasoline), although CBO notes that the "rebound" effect may be small (CBO 2008a).

Small and Van Dender (2007a; 2007b) explore the size of the rebound effect by decomposing the effects of an increase in fuel prices into two

[7] The average gasoline tax, including state levies, is about 46 cents per gallon, 18.4 cents of which is the federal tax (CBO 2008b).

[8] CBO estimates that gasoline prices would have to rise above $6.50 per gallon—from a $2.00–$2.50 per gallon tax added to $4.00 per gallon gasoline—for the average fuel economy of new vehicles to approach the 35 miles per gallon required by the new CAFE standards (CBO 2008a).

components: (*a*) reduced travel or VMT and (*b*) a fuel-efficiency effect (i.e., drivers choose more fuel-efficient vehicles). If the net effect of the two is to reduce the cost of driving, drivers may drive more (the rebound effect).

Using cross-sectional, time-series annual data for U.S. states from 1966 through 2004 on VMT, fuel intensity, real fuel prices, real per capita income, population, and urbanization, among other variables, Small and Van Dender (2007a; 2007b) estimate the price elasticity of gasoline as well as its two components.[9] They find that the short-term[10] price elasticity of gasoline is about –0.074; that is, if the price of gasoline doubles (increases by 100 percent), consumers cut back on gasoline use by a little more than 7 percent. Over the longer term, a doubling of fuel prices is estimated to result in a much larger 36 percent reduction in gasoline consumption. These results are consistent with those found by CBO.

When these elasticities are further decomposed into the two components discussed above, Small and Van Dender find that the rebound effect was modest and declined as income rose.[11] In other words, very little of the cutback in gasoline consumption was due to changes in VMT; much more was due to changes in fuel efficiency—the effect of either changes in vehicle choice or government policy (CAFE). One of the primary reasons for the modest overall price effect was the steady rise in income over the period, which made fuel costs a smaller share of consumer budgets. What are the implications for the future?

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[9] The first article analyzes data through 2001; the second extends the analysis through 2004.

[10] Short term is measured over a decade or more to allow consumers time to replace vehicles with more fuel-efficient ones (Small and Van Dender 2007b).

[11] For example, over the 39-year period between 1966 and 2004, the rebound effect from improved vehicle fuel efficiency resulted in a modest 4.1 percent increase in driving in the short run and a 21 percent increase in the long run (Small and Van Dender 2007a). The researchers isolate the income effect when they analyze the data from 2000 to 2004 only, a time when per capita income was rising and fuel costs were declining in real terms. The rebound effect dropped sharply over this 5-year period, by about one-quarter of its size over the earlier period, reflecting primarily the increase in income and secondarily the decline in fuel costs over the period.

Small and Van Dender (2007b) conclude that as long as incomes continue to rise, the price elasticity of gasoline will continue to fall slowly, and the rebound effect will decline, even if gasoline prices rise.

In summary, the evidence with regard to the effect of higher energy prices on VMT suggests that consumers do respond to rises in the price of gasoline by driving less and by shifting to more fuel-efficient vehicles. However, the latter effect has been much greater in the past than the former. If energy prices were to rise significantly and stay at these levels, then reducing travel and relocating to a more dense location where many destinations were closer and alternatives to driving more numerous would be a rational response. Nevertheless, as long as real income continues to rise, transportation costs will represent a relatively small share of consumer and business budgets and thus will continue to be just one of many factors that drive residential and business location decisions.[12]

FORECASTING THE DEMAND FOR NEW HOUSING

If the implications of sustained higher fuel prices for future housing demand are uncertain and seem likely to be modest, the implications of the aging of the population and continued immigration for the total number of housing units are substantial and more readily quantified. Forecasts typically comprise two elements: (*a*) projections of the number of new households that provide the demand for new housing units and (*b*) estimates of net replacement units. The latter is composed of housing unit gains from conversions from nonresidential use and splitting of existing housing units, less the removal of units as a result of damage and demolition (Pitkin and Myers 2008).

Estimates of new construction are strongly dependent on demographic trends, particularly changes in the numbers, characteristics, size, and age of households. Few forecasters, however, make quantitative projections

[12] Of course, the share represented by energy prices will vary by income level on the consumer side and by type of enterprise on the business side.

beyond 2030, and for good reason (Pitkin and Myers 2008). Most of the people who will be old enough to form households in 2030 have already been born, and mortality rates are not expected to change dramatically. The main unknowns are the projected number of households in that year and the fraction of adult immigrants who will form households.[13] Projecting further into the future requires making assumptions about future fertility rates and the propensity for household formation of those who are as yet unborn. Nevertheless, such uncertainties can be handled by providing ranges.

Using a well-supported macrosimulation model, Zeng et al. (2006) (cited by Pitkin and Myers 2008, 11) project an increase of about 40 percent in the number of U.S. households by 2030 and a 45 percent to 83 percent increase by 2050, reflecting the greater uncertainty of estimates further into the future (see Table 4-3).[14] The estimates reflect the aging of the population and the resulting changes in household composition, including a rapid increase in one-person households and in the numbers of those aged 65 and older and living alone (see Table 4-3). Low and high estimates for many of these factors are also provided, including estimates of the size of immigrant populations (the latter, which uses census estimates, is not shown on the table).

Pitkin and Myers (2008, 14) also estimate net housing replacement rates. They start by examining historical rates of housing loss and replacement (i.e., from 1980 to 2006) on the basis of census data. The average annual net replacement rate for that period (excluding mobile homes) was 0.4 percent. The authors project net replacement rates substantially below current levels, or about 0.2 percent annually (Pitkin

[13] Pitkin and Myers (2008) cite evidence from Masnick and Di (2003) that quite large assumed differences in projected levels of immigration (e.g., ±250,000 per year) would have only a modest (±7 percent) impact on baseline projected 2000–2020 growth in the total number of households. Masnick and Di conclude that most future household growth will come from those already resident in the United States.

[14] The model projects numbers of various household types on the basis of demographic rates, including fertility, mortality, union formation, and divorce. The researchers address the issue of uncertainty by providing ranges for each projection.

TABLE 4-3 **Projected New U.S. Households by Type, 2030 and 2050 (in millions)**

Year	Total Number of Households	One-Person Households	Married-Couple Households	Households with Persons ≥65 Years Old and Living Alone
2000	105.2	27.1	57.8	3.6
2030	142.8–153.2	38.3–48.4	61.9–82.6	4.7–5.7
2050	152.8–192.0	43.2–57.0	58.2–107.3	4.2–6.8

Source: Zeng et al. 2006 in Pitkin and Myers 2008, Table 1.

and Myers 2008). Their forecast is based on projected higher costs of building materials and reduced capital availability, which will make the existing housing stock more valuable and resistant to change. Their forecast also reflects the rapid increase in one-person households and greater demand for smaller housing units, which, in their judgment, will favor adaptive splitting and reuse of existing housing units rather than replacements in new locations.[15]

Another well-known forecaster of housing demand, Nelson (2004; 2006), closely matches the estimates of new housing units by Zeng et al. (2006), although Nelson's forecasts do not extend beyond 2030. [Ewing et al. (2007) extend these estimates to 2050 by using Nelson's work as well as their own projections.] Table 4-4 compares the different estimates. The totals are similar, as are the shares of new housing units estimated to be needed by 2030 and 2050. The primary sources of the differences in the estimates are (*a*) the number of net replacement units and (*b*) the types of units that will be built. Nelson projects net replacement rates of 0.58 percent per year, well above current rates (Nelson 2004 in Pitkin and Myers 2008). He also believes that there will be a sea change in preferences, with all new housing and replacement

[15] The large supply of suburban houses vacated by retiring boomers could provide affordable housing for some immigrant populations, as well as young adults, in the future.

TABLE 4-4 **Comparison of Estimates of New Housing Units, 2030–2050 (in millions)**

	Pitkin and Myers	Nelson and Ewing et al.
2030		
New units for population growth	37.6–48.0	38.8
Net replacement units	8.2–8.7[a]	20.1[b]
Total new and replacement units	45.8–56.7	58.9
Percent of 2000 dwelling units	43.5–53.9[c]	50.8[c]
2050		
New units for population growth	47.6–86.8	52.0
Net replacement units	14.8–18.6[a]	37.0[b]
Total new and replacement units	62.4–105.4	89.0
Percent of 2000 dwelling units	59.3–100.2[c]	71.8[d]

[a]Pitkin and Myers assume a net replacement rate of 0.2 percent per year.

[b]Nelson assumes a net replacement rate of 0.58 percent per year. Ewing et al. extrapolate this rate to 2050.

[c]Pitkin and Myers' 2000 base is all occupied housing units (105.2 million), while Nelson's 2000 base is all housing units (115.9 million).

[d]The base year of Ewing et al. is 2005 (124 million housing units from the American Housing Survey). Using census population estimates for the same year, they derive a ratio of units per capita, which they then apply to census population estimates for 2050, assuming household size will not change substantially.

Sources: Pitkin and Myers 2008; Nelson 2004; Ewing et al. 2007.

units divided equally between attached units (apartments, townhouses, and condominiums) and small-lot houses (on less than one-sixth of an acre). The result will be a major reversal of current trends, which favor suburban areas, to a move back to urban centers. Pitkin and Myers (2008) are critical of these assumptions for the reasons discussed above, as well as of Nelson's strong reliance on changing preferences, rather than a combination of changing demographics and preferences, as the driver of future household demand.

Nelson (2004) also estimates a large increase in commercial and institutional space by 2030. He projects that about 96.4 billion square feet will be added, nearly as much as existed in 2000 (106.7 billion square feet). While the committee recognizes the importance of commercial space that complements more compact development,

it was unable to predict how this space would be distributed within metropolitan areas and thus focused solely on residential development.

IMPEDIMENTS TO THE SUPPLY OF COMPACT DEVELOPMENT

If the millions of new housing units required each year provide an opportunity to build more compactly, doing so will require overcoming numerous impediments to change, many of which are on the supply side.

Durability of the Housing Stock

The durability of the housing stock makes it difficult to change development patterns, at least in the short and medium terms. In contrast to passenger vehicles, whose median age in 2007 was 9.2 years,[16] housing typically lasts 50 years or longer (Brown et al. 2005). The longevity of existing housing is often coupled with the negative receptivity of existing homeowners to change, particularly to increasing density levels in their communities, which is frequently perceived as threatening the value of their homes. More generally, most U.S. metropolitan areas have mature land use patterns and transportation systems that make change difficult, except at the margin. The maturity and durability of metropolitan development patterns help explain why policies to change land use have incremental effects that only cumulate over a long time frame.

Local Zoning Regulations

Local zoning regulations are a significant impediment to more compact, mixed-use development in many U.S. communities. Land use planning

[16] R. L. Polk, which tracks vehicle age and other automotive characteristics, reported increased vehicle durability across all vehicle types. The median age of light-duty trucks was slightly lower, 7.1 years (UPI Business News 2008).

and regulations are controlled by local governments. The authority to create zoning and subdivision controls and building regulations, which have the force of law, is a powerful tool in establishing the design requirements and physical context of a community's development. The two most important impediments to more compact development from current zoning regulations are development densities and mixing of land uses.

Zoning was introduced by urban reformers in the United States in the early 20th century to help alleviate the impacts of urban overcrowding on disease and illness—hence the focus on limiting development densities and segregating incompatible land uses, such as residential and high-polluting industrial uses (see TRB 2005). The product of lower-density development and separation of land uses, however, was often long distances between destinations, creating dependence on the automobile.

As they evolved, zoning regulations also operated to reinforce economic and racial separation. Exclusionary zoning in wealthier communities restricted multifamily housing, for example, by establishing minimum lot sizes or housing square footage, which had the effect of keeping housing prices high and thus excluding lower-income families (NRC 1999; Pendall et al. 2006). Once in place, such zoning regulations tended to be reinforcing; homeowners viewed efforts to incorporate more affordable multifamily housing as a threat to their property values (Fischel 1999 in NRC 1999).

It is difficult to overcome such exclusionary zoning by persuading local governments to permit higher-density development. As Downs (2004) points out, most local governments have strong incentives to support the land use preferences of their own citizens and ignore the needs of the metropolitan area as a whole. As noted, many homeowners appear to prefer single-family, detached housing and the perceived amenities of suburban living (e.g., access to open space and recreation, less congestion) and view zoning changes, particularly those allowing increased density, as threats to the value of their homes and the

ambience of their neighborhoods.[17] Policies adopted by territorially broader levels of government, especially state governments, that are focused on encouraging higher-density development in areas of new growth should be more successful (Downs 2004). However, states are reluctant to overrule local governments on such issues as zoning by mandating growth boundaries or other metropolitan planning measures with teeth. There is a strong tradition of deference on these matters, which may explain why metropolitanwide or state policies that attempt to control land use are not widespread.

Engineering Requirements, Street Design, and Parking

Municipal street designs and parking regulations, which often tend to emphasize the needs of motorized travel at the expense of other modes, have also had an important impact on the design of communities (Meyer and Dumbaugh 2004). Municipal street design requirements favor minimum street widths to provide accessibility for fire trucks, long straight sight lines, and street layouts that discourage through traffic.[18] The result has been to reduce the desirability and safety of nonmotorized forms of transport, such as walking and bicycling, and limit the connectivity of streets, tending to isolate residential from other land uses.

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[17] Indeed, according to the 2007 American Housing Survey, some 83 percent of owner-occupied housing is made up of detached single-family units, and nearly 70 percent is located in suburban areas, with the highest share in the south followed by the midwest (HUD and U.S. Census Bureau 2008, Table 3-1). In contrast, only 25 percent of renter-occupied housing units, which represent 32 percent of total occupied housing units, are detached single-family units. Fewer than half (49 percent) are located in suburban areas (HUD and U.S. Census Bureau 2008, Table 4-1).

[18] Early municipal street designs incorporated in guidelines issued by the U.S. Federal Housing Administration in 1935 recommended that residential streets be designed to "discourage through traffic, have a minimum paved width of 24 feet, use cul-de-sacs as much as possible, and avoid excessive planting in the front yards to have a 'more pleasing and unified effect along the street' " (FHA 1935 in TRB 2005). Wide streets were believed necessary to accommodate the worst-case emergency scenario—two high-rise ladder trucks jockeying for position on a dead-end street (Duany et al. 2000 in Meyer and Dumbaugh 2004).

Most community zoning codes for new development require that a minimum number of parking spaces be provided per housing unit or per 1,000 square feet, reflecting the maximum demand for parking (Meyer and Dumbaugh 2004). Parking requirements, which Shoup calls a "blind spot" and "unstudied link between transportation and land use," are calculated on the basis of meeting peak demand for free parking, not on how many spaces drivers will demand at a price that covers the cost of the spaces. In most cases, this number is greater than what is needed to handle normal demand and results in an oversupply of parking, particularly in suburban areas (Shoup 2005, 3). Minimum parking requirements encourage driving to most destinations and take up space that could be used for neighborhood amenities, such as parks and greenspaces (TRB 2005).

The Institute of Transportation Engineers' (ITE) trip generation rates are the standard by which local traffic impacts of new development are typically estimated and parking requirements and development impact fees are set. Generally, the data used to set trip rates are drawn from suburban areas with free and plentiful parking, low-density land uses, and minimal transit service (Cervero and Arrington 2008; Smith 2009). A recent study of vehicle trip generation rates in 17 transit-oriented developments (TODs) in five U.S. metropolitan areas found that vehicle trip rates were significantly overstated (Arrington and Cervero 2008). TOD housing projects averaged 44 percent fewer trips than estimated by the ITE manual.[19] The researchers recommend that both traffic impact fees and parking requirements be reevaluated, potentially reducing the development costs of many TODs (Cervero and Arrington 2008, 1).[20]

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[19] It would be incorrect, however, to attribute the smaller number of trips entirely to the physical characteristics of the TODs. The cited study does not control for socioeconomic characteristics or self-selection.

[20] Trip generation rates were measured for a "typical" weekday period and varied from 70 to 90 percent lower for TOD projects near a downtown, to 15 to 20 percent lower for those in low-density suburbs (Cervero and Arrington 2008).

APPARENT UNDERSUPPLY OF HIGHER-DENSITY, MIXED-USE DEVELOPMENTS

The impediments discussed in the previous section, particularly exclusionary zoning regulations, have resulted in an apparent undersupply of higher density, mixed-use developments. Downs (1999) and Levine (2006), for example, challenge the notion that the low-density, automobile-dependent pattern that dominates U.S. metropolitan areas simply reflects consumer preferences operating through the free market. Instead, they argue that land development is one of the most regulated sectors of the U.S. economy. Rather than operating freely, land use markets have limited the supply of alternative higher-density, mixed-use developments (Levine and Inam 2004; Levine 2006).

A survey of developers conducted in conjunction with the Urban Land Institute in 2001 provides evidence of this market bias (Levine and Inam 2004). Developers reported considerable market interest in compact developments but an inadequate supply.[21] The two most important reasons cited were government regulations hostile to such developments and neighborhood opposition (Levine and Inam 2004). For developers that actually proposed more compact developments and were granted variances, more than 80 percent of the modifications involved reduced density, higher than any other category and signaling strong resistance to this design feature.[22] If regulations could be relaxed, developers identified close-in suburbs rather than the metropolitan fringe as areas with the most potential for more compact development.

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[21] Of the nationwide sample of respondents (693), most estimated that at least 10 percent of households are interested in more compact development; more than one-third saw a potential market of at least 25 percent, with the highest levels of interest in the dense northeast and mid-Atlantic regions (Levine and Inam 2004, 415).

[22] Other modifications included reduction in mixed-use character (47 percent), change in the variety of housing types (29 percent), change in the share of mixed-use development or attached housing (33 percent), and change in pedestrian or transit orientation (19 percent) (Levine and Inam 2004, 421).

Since the 2001 survey, several other surveys have found increasing support among U.S. households for more compact development.[23] Using data from Porter Novelli's 2003 and 2005 annual consumer behavior surveys, for example, Handy et al. (2008) find a statistically significant shift in favor of more compact development between survey years, signaling a substantial change in attitude.[24] After sociodemographic characteristics are controlled for, support was most positively related to expectations for child-friendliness in such communities and most negatively related to their likelihood of having space limitations (Handy et al. 2008). The researchers cite three reasons why the evidence of strong and increasing support for more compact development has not always translated into a greater supply of such housing. First, stated support in a survey does not always translate into political support for change. Second, even when there is such support, modifications in laws, regulations, codes, and the like are necessary and often difficult to effect. Finally, development itself is a slow process; even if policy changes are enacted, a meaningful increase in the supply of housing is likely to take several years (Handy et al. 2008).

Where well-designed compact, mixed-use developments are built, they can command a price premium. A few studies have attempted to explore the relationship between housing prices and development types. Eppli and Tu (1999 in TRB 2005) compare sales transactions and characteristics of homes in compact developments in four regionally

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[23] Many of these surveys have been conducted by the National Association of Realtors and Smart Growth America, which advocates for more compact development. They have revealed high levels of support for more transit- and pedestrian-friendly communities, primarily in response to growing congestion and commute times.

[24] In 2003, 44 percent of respondents expressed support for the development of traditionally designed or more compact communities in areas where they lived. This support increased to 59 percent in 2005. The authors acknowledge the limitations of this type of stated-preference question and the low explanatory power of the factors that contribute to or detract from support for these communities in their models (Handy et al. 2008).

diverse areas with those of homes in nearby conventional suburban neighborhoods. Properties in Kentlands, a compact development in Maryland, sold for $30,000 to $40,000 more, on average, than homes in the surrounding conventional suburbs, even after site traits, housing characteristics, unit quality, neighborhood, and other market factors were controlled for. More recent research by the National Center for Smart Growth Research and Education at the University of Maryland found that home buyers will pay a substantial price premium to live in communities that emphasize quality design and walkable neighborhoods (Song and Knaap 2003). However, home buyers do not favor higher densities or certain other characteristics, such as commercial, multifamily, and public uses (relative to single-family uses) or proximity to major transportation arterials.

A recent study (Yang 2008) of Portland, Oregon, a model of smart growth, and Charlotte, North Carolina, one of the most sprawling metropolitan areas, explores the relationship among neighborhood satisfaction, density, and mixed land uses at both the neighborhood and block levels.[25] The results suggest that context and spatial scale are important planning variables. At the neighborhood level, density and mixed land uses are associated with higher neighborhood satisfaction in Portland but lower neighborhood satisfaction in Charlotte (Yang 2008). At the block level, single-family detached housing is associated with higher neighborhood satisfaction in both metropolitan areas, suggesting that homeowners value the greater spaciousness and privacy of single-family housing. The results indicate that compact developments that increase density by reducing lot sizes but retain single-family housing may have greater appeal to homeowners.

[25] Using a multilevel data set that combines individual household information with neighborhood contextual variables drawn from the 2002 American Housing Survey and the 2000 census, Yang examines the effects of block and neighborhood housing density, land use mix, mix of housing structure types, and street network connectivity on residents' rating of neighborhood satisfaction in Portland compared with Charlotte.

STRATEGIES FOR OVERCOMING IMPEDIMENTS TO COMPACT DEVELOPMENT

In this section, the committee discusses broad strategies for increasing the supply of compact, mixed-use developments in areas of new development and as strategic infill. The strategies are not intended to be an exhaustive list; instead, they address the key impediments to compact development discussed in the prior section.

Focusing on New Housing

Although the longevity of existing housing slows the process of recycling existing units into more compact developments, substantial progress can be made by simply focusing on new housing units, built either in new neighborhoods or as strategic infill in existing neighborhoods (e.g., in inner suburbs or near major transit stops and along major highway corridors or interchanges). As Table 4-4 shows, even as early as 2030 the projected new construction for population growth, and to a much lesser extent net replacement units,[26] can represent more than 40 to 50 percent of the housing units that existed in 2000.

Building more compactly does not necessarily mean the demise of single-family housing or the loss of housing value. Single-family housing built on smaller lot sizes, for example, can both meet some households' preferences for lower-density housing and reduce trip lengths, on average. Moreover, current preferences of some households for large single-family lot sizes are not immutable. As noted previously, over the next several decades, the suburban baby boomers will start downsizing to smaller housing units, dominating changes in the housing market, given their numbers. Their changing preferences for

[26] The estimates prepared for this study by Pitkin and Myers (2008) project a relatively small amount of replacement housing. Moreover, many of these units are in existing communities where efforts to provide higher-density infill housing could meet with opposition from existing homeowners.

smaller units and more accessible locations (where shopping is within walking distance or a short trip away) are likely to be reinforced as more compact, mixed-use developments are built.

Relaxing Zoning Restrictions

Relaxing zoning regulations to enable more compact, mixed-use development for those who would like to locate in such communities will require changes on many fronts—not the least of which will be to educate the public, elected officials, realtors, developers, and financial institutions as to how these communities can be financed and developed.

Even when a coalition of interests supportive of more compact development exists, changing conventional zoning requirements and development codes can be time-consuming and politically difficult. Existing local residents and their representatives needed to be persuaded that higher-density neighborhoods will not be detrimental to their own housing values and interests. Instead of overturning long-standing zoning regulations and ordinances, it may be easier to win support through more targeted approaches, such as parallel or overlay zoning[27] and incentives (Meyer and Dumbaugh 2004; see Box 4-1). Overlay zones selectively change zoning, typically allowing greater densities, while keeping the underlying zoning intact. Zoning regulations in TODs, such as the incentive program of the Metropolitan Transportation Commission in the San Francisco Bay Area described in the box, are a good example of this approach.

Using overlay zoning as a policy to increase development densities across metropolitan areas, however, is likely to produce piecemeal results. Broader growth management initiatives, such as urban growth boundaries and greenway corridors at the metropolitan area fringe, offer a more comprehensive strategy to help contain the growth of

[27] Overlay districts are a planning tool providing for special zoning requirements that are an exception to the underlying zoning and are tailored to the characteristics of a particular area (e.g., special architectural character) or complementary to a particular public policy (e.g., higher-density building near rail transit stations).

Box 4-1

TWO APPROACHES TO RELAXATION OF ZONING REGULATIONS

Overlay districts. Changing a community's land use zoning is often a difficult political undertaking. One of the approaches used to provide a higher level of urban design while maintaining the underlying zoning is to use overlay zones targeting specific development characteristics. A good example is Portland, Oregon's, Light Rail Transit Station Zone (Portland Metro 2000). This overlay zone "allows for more intense and efficient use of land at increased densities for the mutual reinforcement of public investments and private development. Uses and development are regulated to create a more intense built-up environment, oriented to pedestrians, and ensuring a density and intensity that is transit supportive." Actions include prohibition of parking garages within a specified distance of a station, a 50 percent reduction in the minimum number of parking spaces required within 500 feet of a light rail alignment, and required streetscape landscaping to a high level.

Compact development incentives. Restructuring long-standing land use ordinances that have been the basic approach to community development is also difficult. A more appealing approach for encouraging more compact development and use of nonmotorized transportation is to provide incentives to both developers and communities. In specified districts, for example, developers could receive income tax credits for certain types of development, reductions in permit fees and other procedural requirements, and relaxation of other zoning requirements that

(continued on next page)

Box 4-1 *(continued)*

TWO APPROACHES TO RELAXATION OF ZONING REGULATIONS

might save the developer money. Regional planning agencies could reward communities that provided approvals for more compact developments. In the San Francisco Bay Area, for example, the Metropolitan Transportation Commission—that area's metropolitan planning organization—provides a given amount of money to a community for every bedroom constructed within a given distance of a transit station. These funds can be used by the community for any purpose. By using incentives, policy makers participate in the development market, but not in the traditional regulatory way.

Source: Meyer and Dumbaugh 2004 in TRB 2005.

new suburban low-density development. Here too, though, when such policies are imposed by local communities in isolation, growth may simply leapfrog into exurban areas beyond local urban growth or greenbelt boundaries. Successful implementation of policies aimed at steering new growth into areas of existing development without creating such development elsewhere in a region requires a strong regional or state role in land use planning (Downs 2004). The significant role of Oregon and that state's governor in the success of Portland's urban growth boundary was discussed in the previous chapter.[28] Several other

[28] Even Oregon's largely successful statewide land use planning initiatives have experienced significant setbacks and resistance. Passage of Measure 37 (compensation for "downzoning") in 2004 by a substantial 61 percent majority, for example, was viewed by many as a repudiation by voters of the state's heavy-handed planning efforts (DeGrove 2005). By a slightly larger margin (62 percent), however, voters replaced Measure 37 in 2007 with Measure 49 after becoming aware of the likely rural development effects of Measure 37, significantly reducing the scope of the latter.

states and counties within states have adopted less stringent measures that encourage, but do not mandate, more compact development and preservation of farmland. In Maryland, for example, Montgomery County's Agricultural Reserve Program, created in 1980, has preserved more than half of the county's 93,000 acres of viable farmland at the metropolitan area fringe through transfer of development rights and easement purchases.[29]

A comprehensive survey of local land use regulations in the 50 largest U.S. metropolitan areas found that urban containment programs and measures to control new development, such as growth boundaries or building caps and moratoriums, are far less pervasive than zoning regulations and comprehensive planning (Pendall et al. 2006). At the national level, for example, only an estimated 16 percent of jurisdictions have urban containment programs. However, these jurisdictions tend to be more populous and expansive than others, accounting for 27 percent of the total metropolitan population surveyed and 38 percent of the land area. Only a small fraction of jurisdictions, representing an equally small fraction of population and land area, have permit caps or building moratoriums.[30]

Nevertheless, states and regions are becoming more proactive about managing growth than they were in the past. Ten states have instituted laws enabling, and in some cases requiring, local governments to adopt growth management measures consistent with state goals. Another 15 states have reformed their planning laws over the past 30 years to encourage stronger local planning (Pendall et al. 2006). At the local level, impact fees, which link permission for new development to the imposition of fees for infrastructure provision, have become one of the most common tools for land use regulation. They are imposed

[29] The county downzoned land in the rural upcounty area from one unit per 5 acres to one unit per 25 acres. Landowners were allowed to sell the difference in development rights to downcounty areas where greater density was allowed (Smart Growth Network 2003).

[30] For example, only about 2 percent of the jurisdictions surveyed, with 4 percent of the residents and 3 percent of the land area, have permit caps (Pendall et al. 2006).

by 37 percent of survey respondents, representing 56 percent of the population and 46 percent of the land area of the 50 largest U.S. metropolitan areas (Pendall et al. 2006).

California recently became the first state to enact legislation aimed at curbing GHG emissions through land use controls.[31] Governor Schwarzenegger directed the California Air Resources Board, which has responsibility for regulating air pollution in the state, to work with California's 18 metropolitan planning organizations to set and achieve GHG emissions reduction targets for 2020 and 2035. The legislation promotes sustainable community strategies, that is, more compact land use patterns coupled with transit investments, with the objective of reducing automobile trip lengths by bringing people closer to destinations and providing alternative transportation modes. The current recommended target reduction for 2020 from such strategies is small, however—about 5 million metric tons of CO_2 equivalent, or approximately 3 percent of the 30 percent reduction needed by 2020 if the state's GHG emissions are to be returned to 1990 levels (CARB 2008). The long-term goal is to put California on a path to reducing GHG emissions to 80 percent below 1990 levels by 2050.

Making Compact, Mixed-Use Developments More Attractive to Developers and Lenders

Another approach for increasing support for compact, mixed-use developments is to cater to households that have indicated support for such developments. This is a long-term, iterative process, however; increasing supply ought to increase support, but support is needed

[31] SB-375 directs the California Air Resources Board to set targets for reducing GHG emissions attributable to VMT for California's 18 metropolitan planning organizations. A companion funding bill, SB-732, provides a framework for coordinating state spending to promote planning for sustainable communities and implementation of urban greening projects (Center for Clean Air Policy, October 2008 newsletter, www.ccap.org/docs/news/138/News%20from%20the%20Center%20for%20Clean%20Air%20Policy%20--%20Oct.%2008%20--%20FINAL%202.pdf). Both bills were passed in September 2008.

to increase supply. Nevertheless, the more it can be shown that such developments can be profitable and not lower surrounding property values, the more acceptable they are likely to become (Meyer and Dumbaugh 2004). This is particularly important for developers and financial institutions, which are risk averse in normal financial times and even more so in the current financial environment of limited credit. Typically, developers and lenders look for projects that are compatible with other developments in local markets (i.e., that meet local zoning and subdivision controls). Financing of mixed-use developments can be particularly problematic because many developers and lenders have experience in dealing with only one type of development (Meyer and Dumbaugh 2004 and Kirby and Hollander 2004 in TRB 2005). An informal survey of institutional lenders in the Atlanta, Seattle, and Boston markets conducted by Meyer and Dumbaugh (2004) revealed that lenders are not averse to more compact developments as long as such developments are not expressly prohibited by local zoning and are not the first such development in an area. The presence of profitable existing compact developments in a local market and evidence of other supporting public and private investments (e.g., transit) should increase the acceptability of similar new projects (Smith-Heimer and Golem 2001).

As the case studies of Portland, Oregon, and Arlington County, Virginia, detailed in the previous chapter illustrate, complementary coordinated public infrastructure investments and development incentives can facilitate the development of more compact, mixed-use communities. In both cases, extensive new rail transit investment was the catalyst for more compact development. Not all urban areas have similar opportunities for such extensive transit investments. Nevertheless, well-targeted investments in public parks and open spaces, sidewalks and walking paths, and other amenities can help make compact developments, either new developments or strategic infill, more pedestrian- and bicycle-friendly. Provision should also be made for upgrading existing infrastructure, including streets and water and

sewer lines, to the extent that compact development occurs in already developed areas, straining the capacity of the existing infrastructure.

Implementing Integrated Street Design and Reduced Parking Requirements

In recent years, transportation engineers have attempted to modify the design of local streets in recognition of their role in shaping the travel patterns of the communities they serve. As part of the movement toward more context-sensitive design,[32] strategies such as traffic calming, which has been used for many decades, and "complete streets," a more recent policy and design approach, are oriented toward serving the needs of all users, not just vehicular traffic, and have begun to take hold. Traffic calming, which is appropriate for new as well as existing developments, is aimed at slowing traffic speeds in residential neighborhoods and near schools through self-enforcing physical devices.[33] Complete streets are roadways designed and operated for the safety and access of all users, including pedestrians and bicyclists, as well as motorists.[34] Use of street grid patterns in new developments, rather than cul-de-sacs, improves street connectivity and access to neighborhood commercial uses where they exist. Improved connectivity encourages more walking, bicycling, and transit use (where available). It can also result in modest reductions in VMT from shorter trip distances and, more important, reduce congestion on main routes. Organizations that develop traffic engineering standards

[32] Context-sensitive design refers to roadway standards and development practices that are flexible and sensitive to community values, helping to ensure that design projects not only move users safely and efficiently but also are in harmony with the natural and human environments (Victoria Transport Policy Institute, TDM Encyclopedia, www.vtpi.org/tdm/tdm57.htm).

[33] Examples include vertical deflections (speed humps and bumps and raised intersections); horizontal deflections (serpentines, bends, and deviations in a road); road narrowing (via neckdowns and chokers); and medians, central islands, and traffic circles.

[34] Complete streets typically contain the following features: sidewalks, bicycle lanes, wide shoulders, crosswalks, bus pullouts or special bus lanes, and center medians.

and guidelines—ITE, the Federal Highway Administration, and the American Association of State Highway and Transportation Officials—have all issued design guidance and manuals on these topics.

Removing "excess" parking can also create more walkable streets and provide more space for other community uses, such as parks and greenspaces. Some municipal governments have begun to establish maximum rather than minimum parking requirements for new developments to curb what they perceive as an oversupply of parking. However, care must be taken to balance parking needs with other uses and to ensure that alternative modes of transport are available (Smith 2009). It is not surprising that minimum parking requirements are being questioned in TODs, where good transit service is typically available. Some cities, such as Portland, Oregon, have developed sophisticated maximum parking requirement ordinances that vary within the city depending on the characteristics of different districts and the distance of a land use from mass transit.[35]

FINDINGS

This chapter has examined whether decentralization and suburbanization of the population, which have characterized the development of metropolitan areas for decades, are likely to continue. Projections to 2030 and, with less certainty, to 2050 indicate that housing preferences and travel patterns may change in ways that support higher-density development and reduced VMT, although by how much is unclear.

The aging of the population, in particular the aging of the baby boom generation, will have a profound impact on the housing market for many decades once the leading edge of the boomers passes the age of 65 in 2010. The boomers will begin to sell off their large supply of

[35] Portland's maximum allowed parking spaces ordinance can be viewed online at www.portlandonline.com/auditor/index.cfm?c=28148.

low-density, suburban housing as they downsize to smaller units in more compact settings or move to retirement communities. They will also drive less as they age. The jury is out, however, on whether this first truly suburban generation will leave the suburbs for center city locations or age in place or near family members.

The foreign-born share of the population is projected to continue to grow to between 13 and 16 percent of the U.S. population by 2030 and to as much as 20 percent of the population by 2050. Immigrant populations, particularly Hispanics, the dominant group, have housing preferences and travel patterns different from those of native-born populations. Recent immigrants tend to live in multifamily housing, Hispanics locate disproportionately in central cities, and all immigrant groups are heavy users of public transportation where it is available. As they become assimilated, however, immigrant groups tend to converge toward the population mean in their housing and transportation preferences.

Young adults who are entering the housing market represent another potential market for more compact development. Although less numerous than the boomers, they appear to be exhibiting stronger preferences than their predecessors for urban living.

The future may also be characterized by sustained higher real energy prices, which could remain well outside the norm of the past 30 years. Evidence from past energy spikes suggests that in the short and medium terms, motorists cut back on the number of trips they take and buy more fuel-efficient vehicles, the latter effect predominating. Whether they would move jobs or residences to reduce travel and energy costs has not been observed because high energy prices have not persisted. As long as incomes continue to rise, however, and transportation costs remain a relatively small share of household budgets on average, high energy prices will be only one of many factors that drive residential and employment location decisions.

In summary, a population that is aging and includes more immigrants and young adults with urban preferences is likely to be more inclined

to live in more compact developments, own fewer automobiles, drive less, and use alternative modes of transportation. Should they occur, sustained higher energy prices would reinforce these trends.

Taking advantage of this potential shift in housing preferences and travel patterns will require addressing numerous impediments to change. Local zoning regulations, particularly regulations that restrict density levels and mixing of land uses, represent one of the most significant impediments to more compact, mixed-use development. Street designs and parking requirements focused on automotive travel reinforce automobile-oriented development. The result of such impediments, particularly exclusionary zoning, is an apparent undersupply of higher density, mixed-use developments, despite evidence from survey research of increased interest in such communities.

Some of these impediments can and are being addressed with new context-sensitive zoning, municipal street designs and parking requirements that reflect the needs of all users, and targeted public infrastructure investments to encourage private development. More stringent measures, such as urban growth boundaries, are being instituted in a few locations characterized by strong regional and state roles in land use planning and growth management. But land use policies aimed at effecting sweeping changes in metropolitan area development patterns are likely to be slowed by political resistance from existing homeowners and local governments that reflect their interests, a lack of metropolitan and state government initiatives that could provide incentives on a large enough scale to counter local resistance, and the durability and value of the existing housing stock itself.

The greatest opportunities for building more compact, mixed-use developments are likely to lie in new housing construction and replacement units in areas already experiencing density increases, such as inner suburbs and developments near transit stops and along major highway corridors or interchanges. The next chapter presents an attempt to measure the potential size of this market and the likely effects on reducing VMT, energy use, and CO_2 emissions.

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Abbreviations

CARB	California Air Resources Board
CBO	Congressional Budget Office
FHA	Federal Housing Administration
HUD	U.S. Department of Housing and Urban Development
NRC	National Research Council
TRB	Transportation Research Board
UPI	United Press International

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5 | Potential Effects of More Compact Development Patterns on Vehicle Miles Traveled, Energy Use, and CO_2 Emissions

In this chapter, estimates are developed of the potential magnitude of reductions in vehicle miles traveled (VMT), energy use, and carbon dioxide (CO_2) emissions from more compact, mixed-use development, looking forward to 2030 and to 2050. The chapter begins with a brief summary of two previous well-known estimates of the national-level impacts of more compact development. Then, the committee's own development scenarios are elaborated, and results are summarized. The primary focus is on likely changes in travel behavior and related effects on VMT, energy use, and CO_2 emissions. In addition, more compact development is likely to reduce energy use and CO_2 emissions by improving the energy efficiency of buildings, a topic that is also briefly considered. The third section provides a more general discussion of other benefits and costs of more compact, mixed-use development patterns; no attempt is made to quantify these benefits and costs, which was beyond the scope of this study. The chapter ends with a series of findings.

PREVIOUS NATIONAL-LEVEL ESTIMATES OF REDUCTIONS IN TRAVEL, ENERGY USE, AND CO_2 EMISSIONS

Analysis Structure and Key Assumptions

Any estimate of the effect of compact, mixed-use development on future VMT, energy use, and CO_2 emissions requires three sets of assumptions. The first concerns the quantity and characteristics of the new housing

and commercial developments that will be built between now and the end of the forecast period. How many new housing units are likely to be built, and how many of those new units will be in compact, mixed-use developments? The demographic, economic, and political factors that affect the quantity and character of new development were the subject of Chapter 4 of this report.

The second set of assumptions concerns the number of vehicle miles driven by households in different types of developments. Will the number of vehicle miles driven by the average household in existing types of developments continue to increase as it has in the past, or will it slow down or stop? And how many fewer vehicle miles will households in the new compact, mixed-use developments travel? The empirical evidence on the reduction in VMT attributable to compact, mixed-use development was summarized in Chapter 3 of this report. The committee did not account for any behavioral feedback effects, but the sensitivity of key assumptions is tested.

If estimates of reductions in VMT are to be translated into savings in energy use and CO_2 emissions, one must make a further set of assumptions about the fuels and fuel economy of future vehicles. Will cars continue to be powered by internal combustion engines or hybrids running on fossil fuels, or will all-electric, hydrogen, or other more novel forms of propulsion emerge to play a significant role? And whatever fuels are used, what will be their carbon content and CO_2 emissions per VMT? The savings in energy and CO_2 emissions from the use of vehicles that do not use fossil fuels will depend in part on the energy source. For example, the electricity to run an electric vehicle may be generated by a CO_2-emitting, coal-fired electric plant. Ideally, the full life-cycle costs of alternative energy sources should be considered in computing energy and emissions savings.

Previous National Estimates

Two previous studies attempt to estimate the reduction in VMT that might result from more compact development. In *Costs of Sprawl—2000,*

Burchell et al. (2002) produce comprehensive estimates of the various costs of sprawl in 2025 by developing scenarios of controlled growth and uncontrolled growth (business-as-usual sprawl) and then comparing the differences. One component of the cost of sprawl estimated in this study involves the extra travel costs associated with increased travel in spread-out areas, which are based on VMT estimates for the above two scenarios.

The changes in land development in the study's controlled-growth scenario are complex, which makes it difficult to compare this study with others. Controlled growth cuts sprawl in all nonurban counties by 25 percent compared with their historic trends. For intracounty sprawl, growth is directed toward more urbanized development within the county by increasing the density of this development by 20 percent. Shifting growth by 2025 from sprawling to controlled-growth counties moves 11 percent of new housing (2.6 million households) and 6 percent of jobs (3.1 million jobs).

To estimate travel effects, Burchell et al. estimate a regression model that predicts personal miles of travel as a function of development type (urban, suburban, exurban, rural), income, gender, and household size. Separate models are developed for personally owned vehicles and transit. The models are calibrated by using individual data from the 1995 Nationwide Personal Transportation Survey, but the variables describing the built environment of households are limited, and there is no control for self-selection. (Perhaps as a result, these models explain a small share of the overall variance in the data: the models have an adjusted R^2 of about 0.06.) The models predict that shifting residences and jobs from the sprawl to the controlled-growth scenario would reduce person miles of travel by about 4 percent overall. The 4 percent reduction results from combining a 5 percent reduction in travel in personally owned vehicles with a 19 percent increase in travel by transit by 2025.

In a more recent study entitled *Growing Cooler,* Ewing et al. (2007) develop an estimate of the amount of CO_2 that could be reduced by encouraging much greater compact development between 2005 and

2050. They estimate that 89 million additional dwelling units and 190 billion additional square feet of nonresidential space will be built between 2005 and 2050, or about a 70 percent increase over the existing residential stock. They then assume that between 60 and 90 percent of all new development will be compact.

The authors further estimate that VMT per capita will be 30 percent less in compact than in conventional developments [primarily on the basis of the earlier Ewing and Cervero (2001) meta-analysis].[1] They also project that VMT within urban areas will account for four-fifths of total VMT by 2050, noting that compact development will affect urban (not rural) VMT and that the United States will become more urbanized by 2050. Finally, the authors estimate that the CO_2 emissions savings will be about 90 percent as large as the VMT reduction, attributing the difference to CO_2 penalties associated with lower vehicle operating speeds in more compact areas, among other reasons. By multiplying out these factors, the authors arrive at an overall reduction of 7 to 10 percent in future U.S. transportation-related CO_2 emissions resulting from more compact development.

Comparing the estimates of the above two studies would require limiting the Ewing et al. estimates to the VMT reduction resulting from compact development and ignoring the CO_2 reduction factors described above. Doing so results in an estimated VMT reduction of 12.7 percent by 2050 from Ewing et al. compared with a 4 percent reduction in personal travel in private vehicles by 2025 from Burchell et al. The estimates were derived with totally different methods and apply to different time periods. That said, they appear to be in the same ballpark. If Burchell et al.'s estimates were extended another 25 years, they would presumably be of similar magnitude in 2050 to those of Ewing et al.

[1] The Ewing and Cervero (2001) meta-analysis finds an elasticity of VMT with respect to accessibility of –0.20. Ewing et al. increase the elasticity estimate to –0.30 to account for the absence of compactness measures other than density (e.g., land use mix, availability of transit) that should also reduce VMT.

COMMITTEE'S SCENARIOS AND RESULTS

Assumptions and Scenarios

This committee developed its own estimates of the potential savings in VMT, energy use, and CO_2 emissions from more compact, mixed-use development, drawing on its review of the literature and the papers commissioned for this study. The committee's estimates are focused on residential development patterns only.[2] Two scenarios were developed relative to a base case. The base case assumes that current land use and travel patterns, which are heavily weighted toward suburban development and automobile-dependent travel, will continue into the future, producing a further decline in the overall average density of metropolitan areas, while the two alternative scenarios assume more compact, mixed-use development patterns.

Two forecasting periods are analyzed: the first to 2030 and the second to 2050. The starting point selected was 2000 because firm data exist on the number of households (from the U.S. census) and their travel patterns [VMT per household from the 2001 National Household Travel Survey (NHTS)] (Hu and Reuscher 2004). Uncertainties grow over time. For example, the 2050 estimates are less certain than the 2030 estimates because of uncertainties as to the numbers of households,[3] their demographic and socioeconomic composition, and technological innovations that could change the nature of travel (e.g., extent of

[2] The committee recognized the importance of commercial development, in particular that in employment subcenters that are readily accessible to housing. More compact development would presumably create more demand for commercial space to serve such developments. Nevertheless, addressing the uncertainties with regard to both the amount and the location of new commercial development (in existing or new employment subcenters or in strip development) and performing the modeling required to estimate potential reductions in VMT from improved access to commercial space were beyond the resources of this study.

[3] For 2030 the range of household projections is relatively small. As projections are extended further into the future, a growing proportion of those who will be of household-forming age are yet to be born, and their numbers depend on future fertility rates. As a result, the uncertainties multiply and cumulate, and the range of the household projections becomes wider (Pitkin and Myers 2008).

hybrid vehicles, introduction of new technologies such as fuel cells, use of alternative fuels with sharply reduced carbon content). Nevertheless, the longer time frame is shown to demonstrate that new development patterns (i.e., more compact, mixed-use development) can make a difference, and even the very small percentage changes by 2030 compound to more significant ones by 2050. At the same time, significant changes require decades to unfold because of the durability of the built environment.

The base case and the two scenarios all assume the same growth in the number of housing units during the forecast periods but differ as to the proportion of new and replacement units that will be built in compact, mixed-use developments. The increase in total housing units is based on the projections provided by Pitkin and Myers (2008) in the paper commissioned for this study and is reported as a range, with a broader spread in 2050 than 2030 because of the greater uncertainties.[4] The base case assumes that all new (and replacement) housing will be built at the average density of new development during the 1990s, which was about 30 percent below average density levels at the end of the decade.[5] The two alternative scenarios channel some fraction of the new growth from new household formation and from replacement of existing housing units into more compact development.[6] Scenario 1,

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[4] The growth in new households closely follows Nelson's projections to 2030 (Nelson 2004; Nelson 2006) and extends them to 2050 (see Tables 4-3 and 4-4 in Chapter 4). Estimates of average annual replacement units are considerably lower than those of Nelson (2004) for the reasons noted in Chapter 4, with the result that 2030 total estimates of all new units with potential for more compact development are more conservative than Nelson's. Nelson also believes that all new and replacement housing units will be more compactly developed (e.g., as attached or small-lot units) (see the discussion in Chapter 4).

[5] See Appendix C for a more complete discussion of density trends in metropolitan areas. Table C-1 summarizes three ways in which the density of new and existing development can be computed from the two primary data sources—the National Resources Inventory and the U.S. Census of Population and Housing. The average of the three estimates of the density of new development is used here (i.e., new development is about 70 percent as dense as the average density at the end of the 1990s).

[6] Where replacement units are involved, either the new unit could be built more compactly than the one it replaces (e.g., a single unit could be split into two) if zoning permits, or the homeowner could sell the replacement unit and move to a unit in a more compactly developed area.

the low-end estimate, assumes that only one-quarter of the new growth will be more compactly developed (i.e., density will be doubled from the baseline assumption of a continued decrease in density), similar to the shares assumed in *Costs of Sprawl—2000*.[7] Scenario 2, the high-end estimate, assumes that three-quarters of the new growth will be more compactly developed, roughly the midpoint of the estimate in *Growing Cooler*.

All three scenarios assume that the driving patterns of those who live in existing housing will remain unchanged at 21,187 miles per household per year, the figure reported in the 2001 NHTS (Hu and Reuscher 2004). Between the 1990 Nationwide Personal Transportation Survey and the more recent 2001 NHTS, VMT per household rose by about 1.4 percent per year, but it appears reasonable to expect the growth to slow or stop given the aging of the population, the saturation of vehicle ownership (ownership levels nearing, on average, one vehicle for one licensed driver), and smaller household sizes.[8] The sensitivity of the results to this assumption is tested later.

Those living in new housing in more compact developments—with higher densities, more walkable neighborhoods, and good transit access—are assumed to drive less. Scenario 1 assumes a 12 percent reduction in household VMT for new housing built at double the average density of existing housing. Scenario 2 assumes a 25 percent reduction, which brackets the reductions at a regional scale found in the literature (see Table 3-1 in Chapter 3).[9] A third scenario was considered,

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[7] The share assumptions are similar, but the methods for computing the effects are very different. Burchell et al. (2002) use a regression modeling approach to estimate travel effects.

[8] The 1990 Nationwide Personal Transportation Survey reported annual VMT of 18,161 per household, implying an average annual growth rate of 1.41 percent between the 1990 and 2001 survey years (Hu and Reuscher 2004).

[9] The 12 percent reduction comes from the Brownstone and Golob (2009) study, which calculates the reduction in VMT from a doubling of density. The larger "best case" 25 percent reduction comes from the Bento et al. (2005) study, which calculates the reduction in VMT from changes in population centrality, jobs–housing balance, supply of transit, and other built environment and transportation variables. See the discussion of both studies in Chapter 3.

which assumes only a 5 percent reduction in VMT for households living in more compact developments, the lower bound of the elasticity estimates in the literature (see Table 3-1).

Those living in new housing built at lower-than-average densities, continuing the recent trend, are assumed to drive more than existing households. The assumption is that the majority of this housing will be built at the urban fringe, with little access to transit and longer trip distances on average.[10]

The energy use estimates in the committee's scenarios use data from a recent National Research Council (NRC) study (NRC 2008), which develops several scenarios to estimate the maximum practicable penetration rate for fuel cell vehicles and alternative technologies to reduce U.S. oil use and CO_2 emissions to 2050. The committee uses the reference case from that NRC study.[11] This scenario assumes improvements in gasoline internal combustion engine technology to meet the new corporate average fuel economy (CAFE) standards by 2020, expected in compliance with the Energy Independence and Security Act of 2007.[12] After 2020, fuel economy continues to

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[10] More specifically, Scenario 1 assumes that the annual household VMT of new housing built at lower densities would be 8.4 percent higher (12 percent × 0.70) than the average for existing households, or 22,967 (21,187 × 1.084) VMT per household per year. In this scenario, households living in new housing built in compact developments would travel 12 percent less, or 20,211 (22,967 × 0.88) VMT per year. Similarly, Scenario 2 assumes that the annual household VMT of new housing built at lower densities would be 17.5 percent higher (25 percent × 0.70) than the average for existing households, or 24,895 (21,187 × 1.175) VMT per household per year. In this scenario, those living in new housing built in compact developments would travel 25 percent less, or 18,671 (24,895 × 0.75) VMT per year. Both scenarios assume that the new housing built at lower densities would be 70 percent as dense as the average density at the end of the 1990s (see Footnote 5 for further detail).

[11] The reference case is based on projections from the *Annual Energy Outlook* (high gasoline price scenario) to 2030 and from an adaptation of the Argonne National Laboratory's VISION model for 2031 to 2050. The reference case assumes that gasoline prices rise to $3.19 per gallon in 2020, $3.54 per gallon in 2030, and $3.96 per gallon in 2050.

[12] Achieving this target means raising the average miles per gallon (mpg) of new cars and light trucks to 35 mpg by 2020, or an on-road average of about 20 percent less, or 28 mpg. Since this report was completed, the Obama administration has proposed an accelerated schedule to reach the 2020 target by 2016.

grow but slowly, with some introduction of gasoline hybrid vehicles and some use of biofuels (blending up to 10 percent ethanol), but no introduction of hydrogen fuel cell vehicles or other advanced technologies. The sensitivity of the results is tested in a later section using a more aggressive fuel economy scenario.

Estimates of CO_2 emissions are derived from the fuel use projections on the basis of Environmental Protection Agency (EPA 2005) estimates of the carbon content of gasoline, the main fuel used by cars and light trucks.[13] Changes in the mix of fuels used by the fleet, including the share and formulation of gasoline, will affect the level of CO_2 emissions. The committee recognizes this potential but has not conducted an independent assessment or made its own expert judgment. Rather, it assumes that gasoline will remain the main transport fuel for the next 20 to 30 years at least and that using its carbon content for developing the scenario estimates makes the most sense. The committee recognizes, however, that if the carbon content of fuels falls in the future, which is certainly the intent of current and proposed federal policies, then the CO_2 savings the committee estimates from reduced travel due to changes in urban form become smaller. The same relationship holds true for improvements in vehicle fuel economy generally.

The committee's scenarios assume that reductions in energy use and CO_2 emissions are proportional to VMT. This assumption is a simplification in that density is likely to lead to changes in vehicle mix and driving conditions that could affect the relationship of VMT to energy use and CO_2 emissions. For example, as discussed in Chapter 3, there is evidence that density will encourage the purchase of smaller and hence more fuel-efficient vehicles, so that the reduction in energy use may be more than proportionate to the reduction in VMT. Density may also increase stop-and-go driving and lower speeds under more congested conditions in higher-density areas, which would increase

[13] The Environmental Protection Agency estimates that 1 gallon of gasoline produces 19.4 pounds, or 0.00879978 metric tons, of CO_2 emissions.

fuel consumption per VMT for conventional vehicles, though it would reduce fuel consumption per VMT sharply were hybrid vehicles to be widely adopted. The committee has not estimated differences in future energy use that might arise if hybrids are highly successful, rather assuming that conventional powertrains will dominate long into the future.[14]

Results

Tables 5-1 and 5-2 summarize the results of the committee's scenario analysis to 2030 and to 2050, respectively (Scenarios 1 and 2). Significant differences in magnitude are achieved only in Scenario 2 with its assumption of a doubling of density for 75 percent of new housing that is channeled to more compact development and an associated reduction in VMT of 25 percent for these households. Under these assumptions, reductions in VMT, energy use, and CO_2 emissions of nearly 8 percent can be achieved by 2030. These savings cumulate and grow to more than 8 to 11 percent by 2050, illustrating on the one hand the longevity of the built environment and, on the other, the cumulative effect of land use changes (see Figures 5-1 to 5-3, which show how the reductions change both by scenario and over time).[15] In Scenario 1, with its assumption of a doubling of density for 25 percent of new housing that is channeled to more compact development and an associated reduction in VMT of 12 percent for these households, reductions in VMT, energy use, and CO_2 emissions of 1 to 1.2 percent can be achieved by 2030, growing

[14] This assumption is tested in the sensitivity analysis in the section following the presentation of results.

[15] In all cases, only the scenarios assuming that 75 percent of the new growth will be in compact, mixed-use developments are shown. The differences between the scenarios and the baseline for the low-end estimates, which assume that only 25 percent of the new growth will be in more compact, mixed-use developments, are too small to illustrate graphically. The slight decline in fuel use after 2005 reflects the entry of a small number of high-mpg gasoline hybrid vehicles in the reference case fleet mix. The decline in fuel use after 2010 reflects the introduction of fuel economy improvements to meet the more stringent CAFE standards.

TABLE 5-1 **Scenario Analysis, 2000–2030, Assumptions and Results**

	Year	Base Case	Scenario 1	Scenario 2
		New Development		
Assumptions				
Percent growth in housing units		36%–46%	36%–46%	36%–46%
Housing units (in millions)	2000 2030	105.2 142.8–153.2	105.2 142.8–153.2	105.2 142.8–153.2
Percent of 2030 units new and replacement		32%–37%	32%–37%	32%–37%
New and replacement units (in millions)	2030	45.8–56.7	45.8–56.7	45.8–56.7
Percent of new and replacement units compact		0%	25%	75%
New and replacement units compact (in millions)	2030	0.0–0.0	11.5–14.2	34.4–42.5
		Changes in VMT		
Assumptions				
Percent change in VMT/household in existing development		0%	0%	0%
VMT/household in existing development	2000 2030	21,187 21,187	21,187 21,187	21,187 21,187
Percent change in VMT/household in new noncompact development			8.4%	17.5%
VMT/household in new noncompact development	2030		22,967[a]	24,895[a]
Percent reduction in VMT/household in new compact development			–12%	–25%
VMT/household in new compact development	2030		20,211[b]	18,671[b]

	Year	Base Case	Scenario 1	Scenario 2
Results				
Percent change in VMT between 2000 and 2030		39.4%–50.2%	38.0%–48.4%	
VMT (in billions of miles)	2000	2,228.9	2,228.9	
	2030 (1)[c]	3,106.9–3,346.8	3,075.4–3,307.7	
		43.4%–55.1%		33.8%–43.2%
	2000	2,228.9		2,228.9
	2030 (2)[d]	3,195.1–3,456.1		2,981.6–3,191.4
Percent change in VMT in 2030 from base case			–1.0% to –1.2%	–6.7% to –7.7%
Change in VMT from base case (in billions of miles)	2030		–31.5 to –39.1	–213.5 to –264.7
Changes in Energy Use and CO_2 Emissions				
Assumptions				
Percent change in fleet mpg by 2030		58.5%	58.5%	58.5%
Fleet mpg	2000	19.5	19.5	19.5
	2030	30.9	30.9	30.9
Percent change in carbon content of fuel between 2000 and 2030		0%	0%	0%
Results				
Percent change in fuel use between 2000 and 2030		–12.0% to –5.2%	–12.9% to –6.3%	
Fuel use (in billions of gallons)	2000	114.3	114.3	
	2030 (1)[c]	100.5–108.3	99.5–107.0	
		–9.5% to –2.1%		–15.6% to –9.6%
	2000	114.3		114.3
	2030 (2)[d]	103.4–111.9		96.5–103.3
Percent change in fuel use in 2030 from base case			–1.0 to –1.2%	–6.7 to –7.7%
Change in fuel use from base case (in billions of gallons)	2030		–1.0 to –1.3	–6.9 to –8.6

(continued on next page)

TABLE 5-1 *(continued)* **Scenario Analysis, 2000–2030, Assumptions and Results**

	Year	Base Case	Scenario 1	Scenario 2
Percent change in CO_2 emissions between 2000 and 2030		–12.0% to –5.2%	–12.9% to –6.3%	
CO_2 emissions (millions of metric tons)	2000	1,006	1,006	
	2030 (1)[c]	885–953	876–942	
		–9.5% to –2.1%		–15.6% to –9.6%
	2000	1,006		1,006
	2030 (2)[d]	910–984		849–909
Percent change in CO_2 emissions from base case			–1.0% to –1.2%	–6.7% to –7.7%
CO_2 emissions (millions of metric tons)	2030		–8.9 to –11	–61 to –75

[a]In Scenario 1, VMT per household in new noncompact developments is assumed to be 8.4 percent higher (12 percent × .70) than the average for existing households, or 22,967 (21,187 × 1.084) VMT per household per year. In Scenario 2, VMT per household in new noncompact developments is assumed to be 17.5 percent higher (25 percent × .70) than the average for existing households, or 24,895 (21,187 × 1.175) VMT per household per year.

[b]In Scenario 1, VMT per household in new compact developments is assumed to be 12 percent less than the baseline of new noncompact development households, or 20,211 (22,967 × .88). In Scenario 2, VMT per household in new compact developments is assumed to be 25 percent less than the baseline of new noncompact development households, or 18,671 (24,895 × .75).

[c]The baseline projections for 2030 reflect the assumptions described in Footnote *a*.

[d]The baseline projections for 2030 reflect the assumptions described in Footnote *b*.

to 1.3 to 1.7 percent by 2050. The results for Scenario 3 (not shown separately in tabular form), which assumes a doubling of density for 25 percent of new housing that is channeled to more compact development and an associated reduction in VMT of only 5 percent for these households—the lowest estimate in the literature—show reductions in VMT, energy use, and CO_2 emissions of less than 1 percent, even by 2050. Thus, under a wide range of conditions, reductions in VMT, energy use, and CO_2 emissions resulting from compact, mixed-use development are estimated to be in the range of less than 1 percent to 11 percent

TABLE 5-2 **Scenario Analysis, 2000–2050, Assumptions and Results**

	Year	Base Case	Scenario 1	Scenario 2
		New Development		
Assumptions				
Percent growth in housing units		42.5%–82.5%	42.5%–82.5%	42.5%–82.5%
Housing units (in millions)	2000 2050	105.2 152.8–192.0	105.2 152.8–192.0	105.2 152.8–192.0
Percent of 2050 units new and replacement		40.8%–54.9%	40.8%–54.9%	40.8%–54.9%
New and replacement units (in millions)	2050	62.4–105.4	62.4–105.4	62.4–105.4
Percent of new and replacement units compact		0%	25%	75%
New and replacement units compact (in millions)	2050	0.0–0.0	15.6–25.8	46.8–78.4
		Changes in VMT		
Assumptions				
Percent change in VMT/household in existing development		0%	0%	0%
VMT/household in existing development	2000 2050	21,187 21,187	21,187 21,187	21,187 21,187
Percent change in VMT/household in new noncompact development			8.4%	17.5%
VMT/household in new noncompact development	2050		22,967[a]	24,895[a]
Percent reduction in VMT/household in new compact development			–12%	–25%
VMT/household in new compact development	2050		20,211[b]	18,671[b]

(continued on next page)

TABLE 5-2 *(continued)* **Scenario Analysis, 2000–2050, Assumptions and Results**

	Year	Base Case	Scenario 1	Scenario 2
Results				
Percent change in VMT between 2000 and 2050		50.2%–90.9%	48.3%–87.7%	
VMT (in billions of miles)	2000	2,228.9	2,228.9	
	2050 (1)[c]	3,348.5–4,255.4	3,305.5–4,182.8	
		55.6%–100%		42.6%–78%
	2000	2,228.9		2,228.9
	2050 (2)[d]	3,468.9–4,458.6		3,177.4–3,966.8
Percent change in VMT in 2050 from base case			–1.3% to –1.7%	–8.4% to –11.0%
Change in VMT from base case (in billions of miles)	2050		–43.0 to –72.6	–291.5 to –491.8
Changes in Energy Use and CO_2 Emissions				
Assumptions				
Percent change in fleet mpg by 2050		68.7%	68.7%	68.7%
Fleet mpg	2000	19.5	19.5	19.5
	2050	32.9	32.9	32.9
Percent change in carbon content of fuel between 2000 and 2050		0%	0%	0%
Results				
Percent change in fuel use between 2000 and 2050		–11.0% to +13.2%	–12.1% to +11.2%	
Fuel use (in billions of gallons)	2000	114.3	114.3	
	2050 (1)[c]	101.8–129.3	100.5–127.1	
		–7.8% to +18.6%		–15.5% to +5.5%
	2000	114.3		114.3
	2050 (2)[d]	105.4–135.6		96.6–120.6
Percent change in fuel use in 2050 from base case			–1.3% to –1.7%	–8.4% to –11.0%
Change in fuel use from base case (in billions of gallons)	2050		–1.3 to –2.2	–8.9 to –14.9

	Year	Base Case	Scenario 1	Scenario 2
Percent change in CO_2 emissions between 2000 and 2050		–11.0% to +13.2%	–12.1% to +11.2%	
CO_2 emissions (millions of metric tons)	2000	1,006	1,006	
	2050 (1)[c]	896–1,138	884–1,119	
		–7.8% to +18.6%		–15.5% to +5.5%
	2000	1,006		1,006
	2050 (2)[d]	928–1,193		850–1,061
Percent change in CO_2 emissions from base case			–1.3% to –1.7%	–8.4% to –11.0%
Change in CO_2 emissions from base case (millions of metric tons)	2050		–12 to –19	–78 to –132

[a]In Scenario 1, VMT per household in new noncompact developments is assumed to be 8.4 percent higher (12 percent × .70) than the average for existing households, or 22,967 (21,187 × 1.084) VMT per household per year. In Scenario 2, VMT per household in new noncompact developments is assumed to be 17.5 percent higher (25 percent × .70) than the average for existing households, or 24,895 (21,187 × 1.175) VMT per household per year.

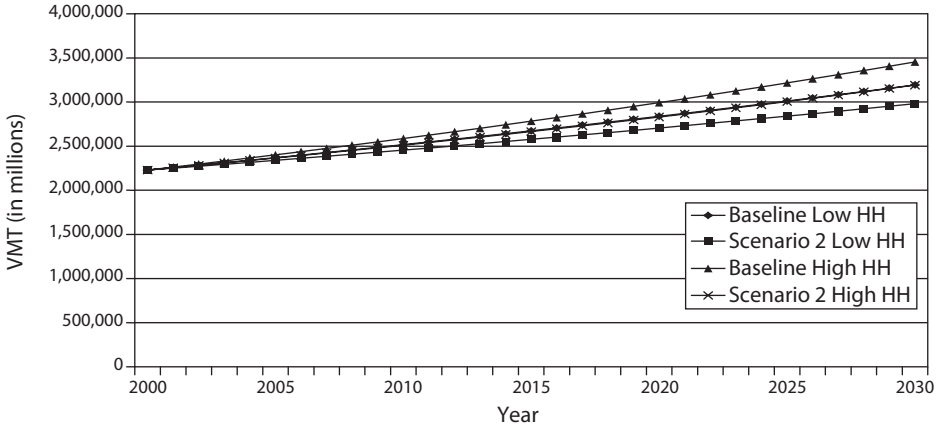
[b]In Scenario 1, VMT per household in new compact developments is assumed to be 12 percent less than the baseline of new noncompact development households, or 20,211 (22,967 × .88). In Scenario 2, VMT per household in new compact developments is assumed to be 25 percent less than the baseline of new noncompact development households, or 18,671 (24,895 × .75).

[c]The baseline projections for 2050 reflect the assumptions described in Footnote *a*.

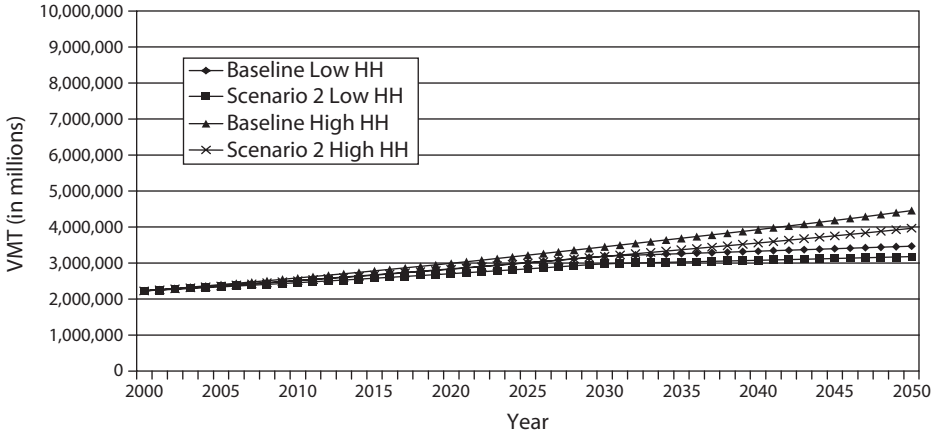
[d]The baseline projections for 2050 reflect the assumptions described in Footnote *b*.

by 2050. The possibilities for achieving these results, as well as what it means to double the density of new development, are discussed in a subsequent section.

Note that the scenarios project some reductions in energy use and CO_2 emissions even in the base case, in which the density of new development is lower than current densities. These reductions occur because the base case assumes that the fuel economy of motor vehicles increases and the growth in VMT per household in existing developments stabilizes with the aging of the baby boomers and the continuing decline in household size. Between 2000 and 2030,

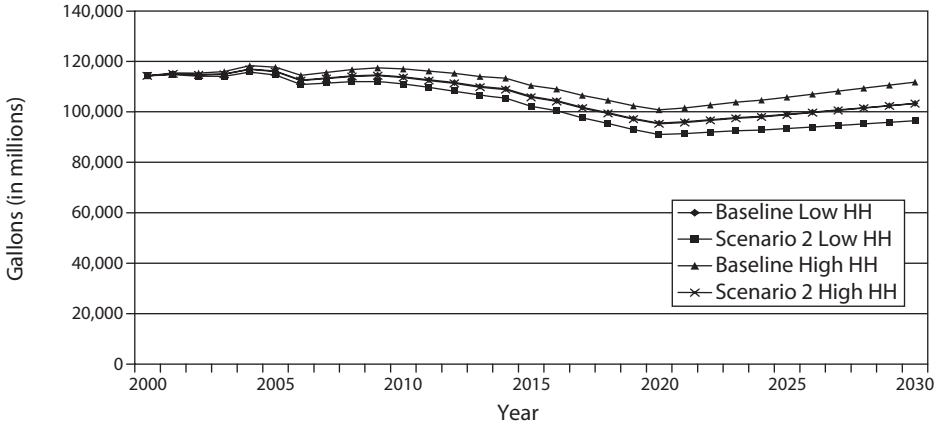


(a)

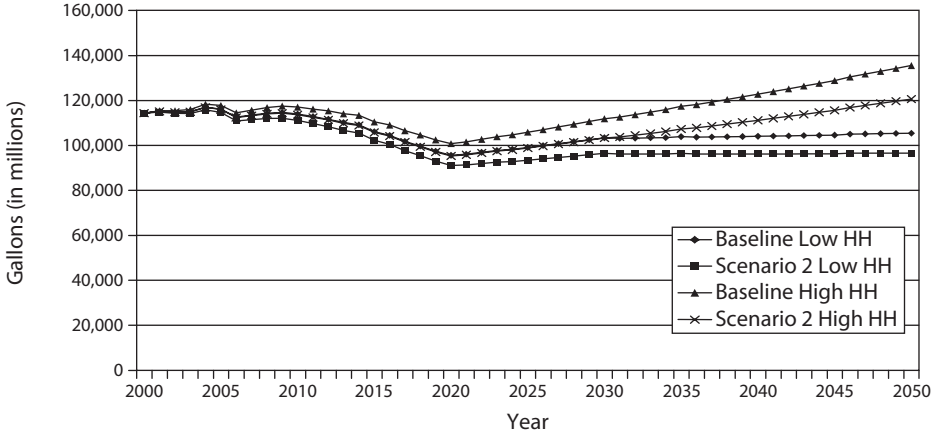


(b)

FIGURE 5-1 **Reduction in VMT for Scenario 2 for low to high range of households (HH) from baseline: (*a*) 2000–2030 and (*b*) 2000–2050. Assumes 75 percent of all new growth is compact, mixed-use development.**

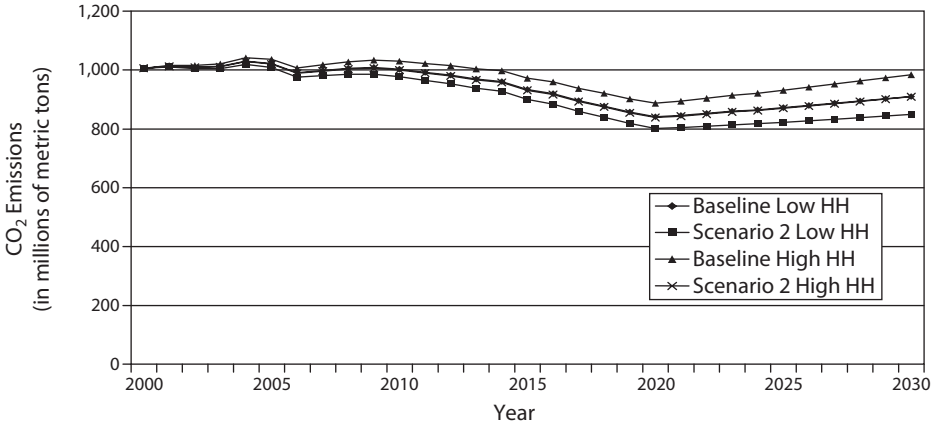


(a)

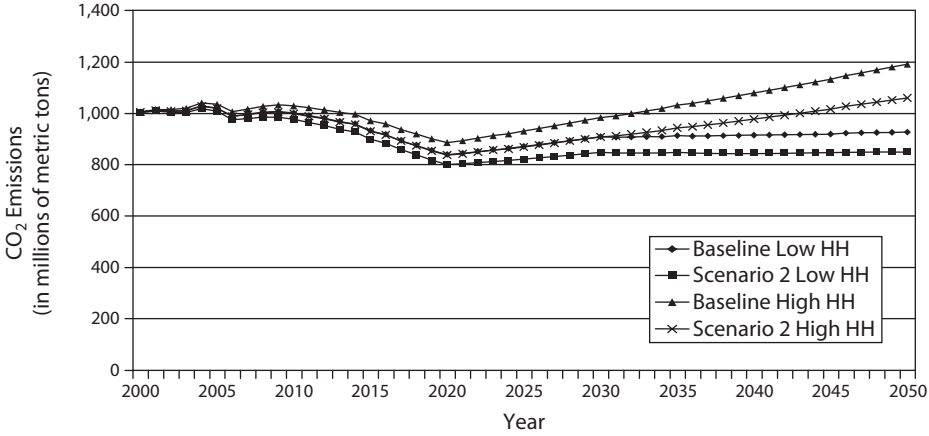


(b)

FIGURE 5-2 **Reduction in fuel use for Scenario 2 for low to high range of households (HH) from baseline: (*a*) 2000–2030 and (*b*) 2000–2050. Assumes 75 percent of all new growth is compact, mixed-use development.**



(a)



(b)

FIGURE 5-3 **Reduction in CO_2 emissions for Scenario 2 for low to high range of households (HH) from baseline: (*a*) 2000–2030 and (*b*) 2000–2050. Assumes 75 percent of all new growth is compact, mixed-use development.**

for example, total energy use and CO_2 emissions from personal motor vehicles are projected to drop by 5 to 12 percent in the base case compared with just 6 to 13 percent under Scenario 1, and from 2 to 9 percent in the base case compared with a slightly higher reduction of 10 to 16 percent under Scenario 2 (see Table 5-1). These reductions reflect the improvement in fuel economy from the new CAFE standards, which offsets the effects on energy use of the growth in households and VMT during this period. Between 2000 and 2050, however, the base case shows between an 11 percent reduction and a 13 percent increase in energy use and CO_2 emissions, compared with between a 12 percent reduction and an 11 percent increase under Scenario 1. Similarly, over the same 2000 to 2050 time period, the base case shows between an 8 percent reduction and a 19 percent increase, compared with a 15 percent reduction and a 6 percent increase under Scenario 2 (see Table 5-2). By 2050, the energy savings from the very modest improvements in fuel economy resulting from achieving the new CAFE standards in 2020 are offset by the growth in households and VMT over this period.[16]

Sensitivity Analyses

The reductions in energy use and CO_2 emissions from compact development are fairly sensitive to assumptions about future growth in both fuel efficiency and VMT per household.

Changing Fuel Economy Assumptions

Table 5-3 summarizes the results if a more aggressive fuel economy scenario is assumed. This more aggressive scenario is drawn from the NRC study (2008) discussed previously and assumes that fuel economy

[16] After 2020, mpg rises at an average annual growth rate of 0.34 percent, dropping from an average annual growth rate of 2.1 percent from 2000 to 2020.

TABLE 5-3 **Summary Results of Sensitivity Analyses, Changing Fuel Economy and VMT Assumptions**

	By 2030 (percent change)	By 2050 (percent change)
Committee's Original Scenarios		
Assumptions		
VMT per household	0	0
Fleet mpg	59	69
Results: fuel use and CO_2 emissions		
Scenario 1		
Base case in 2000	–5 to –12	–11 to +13
25 percent compact development	–6 to –13	–12 to +11
Scenario 2		
Base case in 2000	–2 to –9	–8 to +19
75 percent compact development	–10 to –15	–15 to +5
More Aggressive Fuel Economy Scenario		
Assumptions		
Fleet mpg	104	194
Results: fuel use and CO_2 emissions		
Scenario 1		
Base case in 2000	–26 to –31	–35 to –49
25 percent compact development	–27 to –32	–36 to –49
Scenario 2		
Base case in 2000	–24 to –30	–32 to –47
75 percent compact development	–30 to –34	–39 to –51
Higher VMT Growth Scenario		
Assumptions		
VMT per household	+7.8	+13.3
Results: VMT		
Scenario 1		
Base case in 2000	+39 to +62	+70 to +116
25 percent compact development	+38 to +60	+68 to +112
Scenario 2		
Base case in 2000	+54 to +67	+76 to +127
75 percent compact development	+44 to +54	+61 to +102
Results: fuel use and CO_2 emissions		
Scenario 1		
Base case in 2000	–12 to +2	+1 to +28
25 percent compact development	–13 to +1	–0.4 to +26
Scenario 2		
Base case in 2000	–2 to +5	+4 to +34
75 percent compact development	–3 to –9	–4 to +19

Note: See Annex 5-1 Tables 1 through 4 for details.

more than doubles by 2050.[17] Changing the fuel economy assumptions does not change the percentage reductions in energy use and CO_2 emissions from the base case: the compact-growth scenarios still save 1 to 8 percent by 2030 and 1 to 11 percent by 2050. But the more aggressive fuel economy assumptions more than double the reductions in energy use and CO_2 emissions between 2000 and 2030 for both the base case and the two compact-growth scenarios. Between 2000 and 2030, for example, the base case projects a reduction in energy use and CO_2 emissions of 24 to 32 percent with the more aggressive fuel economy assumptions, compared with only 2 to 12 percent with the committee's original assumptions (see Annex 5-1 Tables 1 and 2 for details). By 2050, the more aggressive improvements in fuel economy turn increases in energy use and CO_2 emissions in the committee's scenarios to reductions, more than keeping pace with projected household and VMT growth. For example, under Scenario 2—the committee's upper-bound scenario with respect to the share of expected compact development—reductions in energy use and CO_2 emissions range from 39 to 51 percent with the more aggressive fuel economy assumptions, as compared with a 15 percent reduction to a 5 percent increase under the committee's original assumptions (see Table 5-3 and Annex 5-1 Table 2). In short, over the longer time frame (i.e., to 2050), the impacts of continuing improvements in fuel economy beyond 2020 on energy use and CO_2 emissions significantly outstrip those from more compact development.

[17] The more aggressive fuel economy scenario assumes mpg improvements similar to those of the reference case used in the committee's scenarios up to 2020. From 2020 to 2050, however, it assumes an average annual mpg growth rate of 2.18, reflecting a more aggressive penetration of hybrid gasoline vehicles—which represent 23 percent of the fleet by 2030 and 80 percent by 2050—as well as more gasoline vehicles with high fuel economy. Nevertheless, the NRC report (2008) characterizes this scenario as "evolutionary"; it assumes that currently available improvements in gasoline internal combustion engine technology are used to improve fuel economy, rather than to improve power and acceleration as was the case in the past. This scenario does not assume any rebound effect (i.e., increased VMT due to increased fuel efficiency that lowers the cost of driving), which researchers have estimated to be small (see discussion in Chapter 4).

Changing VMT Assumptions

Relaxing the assumption of no growth in VMT per household causes base case VMT to grow and increases the role for compact development, although much less for energy use and CO_2 emissions than for VMT. As shown in Annex 5-1 Tables 3 and 4, the base case is modified to assume that VMT per household in existing housing increases by 0.0025 percent per year, rising from 21,187 miles in 2001, to 22,835 miles in 2030, and to 24,004 miles in 2050.[18] VMT per household in new and replacement units, both more compact and not, is adjusted accordingly. Under this growth assumption, base case VMT grows by 39 to 62 percent between 2000 and 2030 and by 70 to 116 percent between 2000 and 2050 (see Table 5-3 and Annex 5-1 Tables 3 and 4). Scenario 1 reduces VMT by only a few percentage points, even by 2050. Scenario 2 shaves 10 to 13 percentage points off a higher baseline by 2030 (as VMT increases by 44 to 54 percent) and 15 to 25 percentage points by 2050 (as VMT increases by 61 to 102 percent). The effects on energy use and CO_2 emissions are more modest because the improvements in fuel economy, even under the less aggressive reference scenario, more than offset the increases in VMT per household. Between 2000 and 2030, for example, the base case shows a 12 percent decline to a 2 percent increase in energy use and CO_2 emissions, compared with just a 13 percent decline to a 1 percent increase in Scenario 1 (see Table 5-3 and Annex 5-1 Table 3). Scenario 2 shaves another few percentage points (7 to 8) off a higher baseline. Between 2000 and 2050, Scenario 2 shows a 4 percent reduction to a 19 percent increase in energy use and CO_2 emissions, while the base case shows a 4 to 34 percent overall increase (see Table 5-3 and Annex 5-1 Table 4).

The assumption that the large base of existing households will not change their preferences is restrictive. As discussed in Chapter 4, for example, aging baby boomers will likely downsize at some point, leaving their suburban homes before they exit the housing market entirely.

[18] This average annual growth rate of VMT per household equates to the *Annual Energy Outlook* 2009 estimates of the annual growth rate of 1.5 percent in total VMT for the light-duty vehicle fleet to 2030. The same annual growth rate was assumed to 2050.

Nevertheless, if housing prices fall in response to the mismatch between the large supply of boomer suburban housing and the demand for new housing from the smaller home-buying cohorts that follow, some portion of the former is likely to be recycled to these new homeowners as well as to immigrant populations, diverting growth that could go to compact development.

Several other factors could work in the opposite direction, lowering the future value of reductions in VMT, energy use, and CO_2 emissions. First, as discussed in Chapter 4, VMT per household may actually fall as the population ages, regardless of whether households move to more densely developed locations. Depending on the size of the reduction, it could reduce the base VMT against which future reductions from compact development are calculated. Second, if the introduction of new technologies is successful—resulting in a vehicle fleet that is much more fuel-efficient than today's fleet and has a much larger mix of alternatively fueled vehicles—these changes will lower the baseline energy use and CO_2 emissions levels from which reductions from more compact development are calculated. The sensitivity analysis mentioned previously, which assumes a more aggressive fuel economy scenario, illustrates this point. Finally, to the extent that households move to more compact areas and continue to drive, they may encounter more congested conditions than in conventional developments, which will reduce vehicle speeds, increase stop-and-start driving, and thereby reduce energy efficiency, unless, of course, hybrids come to dominate the fleet.[19] These changes could be offset in more compactly developed

[19] Vyas et al. (2008) calculate average vehicle speeds from the 2001 NHTS by density category. Average vehicle speeds in highly dense areas (i.e., 10,000–25,000 persons per square mile and >25,000 persons per square mile) are about 20 and 23 mph, respectively. Average vehicle speeds of about 29 mph are found in areas with more typical suburban densities of 1,000 to 4,000 persons per square mile. The authors estimate that for a conventional gasoline passenger car, as speed drops from 48 to 20 mph, fuel consumption increases by more than 30 percent, while for a "split" hybrid (such as the Prius or Ford Fusion), the effect of the same speed change is a fuel consumption reduction of more than 10 percent. This percent reduction does not take into account the fuel-saving benefit of switching from a conventional powertrain to a hybrid; it addresses only the effect of the change in speed.

areas, however, by households owning fewer vehicles—in particular, less energy-efficient sport utility vehicles and pickup trucks—and higher transit use, particularly where rail transit is available, and are thus of less concern (see the discussion of these issues in Chapter 3).

In summary, the committee's scenario analysis shows modest but increasing reductions in VMT, energy use, and CO_2 emissions from more compact, mixed-use development that range from less than 1 percent to a maximum of about 11 percent by 2050. To the extent that energy use and CO_2 emissions are more of an issue than VMT, plausible improvements in vehicle fuel economy will generate significantly larger and more rapid improvements than increases in compact, mixed-use development. Relaxing the scenario restriction on infilling new housing within existing developments, thereby increasing density, would increase projected benefits from compact development. Additional improvements in vehicle fuel efficiency and reduction in the carbon content of fuel from greater use of alternative fuels, however, would work in the opposite direction, reducing the magnitude of benefits in energy use and CO_2 emissions from more compact development.

Plausibility of Committee's Scenarios

How plausible are the targets for compact development implicit in the committee's scenarios, that is, doubling density for 25 percent (Scenario 1) or 75 percent (Scenario 2) of new development by 2030 and 2050? To address this question, the committee examined current and historical density trends as a benchmark against which to compare projected density changes. Two national data sources were used—the National Resources Inventory (NRI) and the decennial U.S. Census of Population and Housing (see Appendix C for details on the pros and cons of each). The measure of density—the number of dwelling units (DUs) divided by land area—was calculated in several different ways. All involved drawing on census data at the metropolitan level for num-

bers of DUs—the numerator—but the two different data sources were used in the denominator.[20]

Using both data sources and all the different ways of calculating density yielded the same trends. Over the decade of the 1990s, average densities declined because the average density of new development was lower than the average density of existing development.[21] On the basis of average density weighted by population, the census data further indicate that between 1990 and 2000, nearly half of new DUs (47.5 percent) were built in census tracts having less than 1 DU per gross acre and another 20 percent in tracts with between 1 and 2 DUs per gross acre. Less than one-third (31.9 percent) of new DUs were built in tracts having 2 or more DUs per gross acre (see Table C-3 in Appendix C). On the basis of average density weighted by acres, the census data also show that between 1990 and 2000, more than three-quarters (76.5 percent) of newly developed acres were in tracts with less than 1 DU per gross acre (see Table C-3). By any measure, the majority of new development occurred in the lowest density categories.

The committee used the trend data for new development to project the densities implied in its two scenarios relative to the base case scenario that simply projects forward current trends toward low-density development. Using average densities for new development (calculated in the various ways just described), Scenario 1 assumes a doubling of average densities for 25 percent of new development. New noncompact development is assumed to have the same average density levels as the new development of the preceding decade (1990 to 2000), and existing development is assumed to have the average density levels of the housing

[20] As discussed in more detail in Appendix C, the NRI data measure DUs per acre of developed urban land. The census data measure DUs per gross acre, including land used for nonresidential purposes, but enabling land area to be classified by a range of densities. Thus, by using census data it is possible to define the number of DUs on lots of different-sized acreage. With the census data, the average density can be calculated in two ways: (*a*) weighting by population (density of the average dwelling unit) or (*b*) weighting by acres (density of the average acre).

[21] The NRI data measured changes from 1987 to 1997, the most recent year such detailed data were available.

stock in 2000 (see Table C-4). Scenario 2 uses similar calculations but assumes a doubling of densities for 75 percent of new development. The new average density levels for each scenario were then compared with the baseline scenario in 2030 and 2050. Only the results for 2050 are discussed below, since this time frame allows sufficient time for projected changes in development patterns to take hold.

Not surprisingly, the results of this analysis show that both scenarios depart from existing trends (of new development being significantly less dense than existing development). However, the doubling of density in 25 percent of new development (Scenario 1) fails to raise densities above the average density of the development that existed in 2000 and raises them only about 7 to 11 percent above the 2050 baseline (see Table C-4 for details). In comparison, doubling density in 75 percent of new development (Scenario 2) requires average densities above the average density of existing development and significantly above (20 to 33 percent) the 2050 baseline.

The more fine-grained census data enabled the committee to examine various ways in which the density targets implicit in the scenarios could be realized. For example, doubling density in 25 percent of new development (Scenario 1) could be achieved by eliminating half of all new development in census tracts in the lowest-density category (less than 1 DU per gross acre) (see Table C-5 for details). Alternatively, an infill strategy could be pursued and the target met by doubling the density in tracts with an average of 4 or more DUs per gross acre. Or the target could be met by some combination of these two possibilities. Reaching the target of Scenario 2—doubling density in 75 percent of new development—would require more drastic measures, such as eliminating all new development in the lowest-density category or doubling the density of tracts with an average of 3 or more DUs per gross acre, a more aggressive infill scenario.

In summary, both scenarios increase the density of development and thus represent a departure from current trends. New development in metropolitan areas has occurred at lower-than-average densities

for decades. Nevertheless, doubling the density of 25 percent of new development is possible, particularly by 2050. Average densities for new development would not be raised above current levels, and precedents for higher densities through smaller lot sizes and infill development near major transportation corridors can be found in growing areas such as Phoenix and Portland, Oregon. Phoenix, for example, demonstrates that a growing metropolitan area can achieve densities of the levels projected in Scenario 1 (see Box 5-1). Such higher densities are attributable to infrastructure investment decisions, land use planning, and land acquisition and banking approaches. They also reflect demographic factors and land ownership restrictions (i.e., Phoenix is encircled by large amounts of federal and state land) that are unique to Phoenix and may not be replicable in other metropolitan areas.

Doubling the density of 75 percent of new development by 2050 would be much more challenging. It would require, for example, either curtailing most large lot development or adding a significant proportion of new development as infill to achieve average densities above current levels and significantly above a 2050 baseline that continues current trends. The committee disagreed about the feasibility of doubling the density of 75 percent of new development, even by 2050. Those members who thought it was possible questioned whether densities will keep declining. Macroeconomic trends—likely higher energy prices and carbon taxes—in combination with growing public support for strategic infill, investments in transit, and higher densities along rail corridors could result in considerably higher densities by 2050. Density trends have already been reversed in some metropolitan areas, such as Portland, which have seen new single-family lot sizes decline by more than one-half since the urban growth boundary was established in 1981. Other members believed that the substantial infill or curbing of large-lot development at the urban fringe, or both, implied in achievement of the targets in Scenario 2 would require such a significant departure from current housing trends, land use policies of jurisdictions on the urban fringe, and public preferences

Box 5-1

PHOENIX AND ATLANTA

A Comparison of Density Changes in Two Rapidly Growing Metropolitan Areas

Atlanta and Phoenix were two of the most rapidly growing metropolitan areas in the United States in the 1990s. Between 1987 and 1997, the housing stock in both metropolitan areas grew by about 35 percent, but new urban development in Atlanta covered more than 505,000 acres, a 64 percent increase, whereas that in Phoenix occupied only an estimated 60,000 acres, up 18 percent between 1987 and 1997 according to data drawn from the National Resources Inventory. As a consequence, Atlanta's built environment dropped from an already low density of 1.30 housing units per urbanized acre to 1.08, while Phoenix's comparatively high density of 2.37 grew to 2.73.

Results from the 1990 and 2000 U.S. Census of Population and Housing underscore the substantial differences between residential neighborhoods in Atlanta and Phoenix. In 2000, only about one-fifth (19 percent) of the housing units in Phoenix were in low-density tracts (below 1 dwelling per acre), compared with nearly half (47 percent) in Atlanta. Although the share in Phoenix grew during the 1990s while that in Atlanta declined (from 15 and 48 percent, respectively), Atlanta's housing in this range was built at densities significantly lower than those in Phoenix, according to data from the American Housing Survey. In 2000, more than one-quarter (27 percent) of the housing in Phoenix was in tracts in the highest-density range (above 4 dwellings per acre) compared with just 6 percent in Atlanta.

Phoenix's comparatively high density is not a function of attached housing. In fact, the two metropolitan areas had roughly the same share of single-family detached and manufactured/mobile housing units in both 1990 and 2000, according to the 1990 and 2000 censuses. These two structure types accounted for 64 and 62 percent of the stock in 1990 in Atlanta and Phoenix, respectively, and grew in the 1990s to make up 69 and 66 percent of the stock, respectively.

Why did urban development occupy so much more land in Atlanta than in Phoenix? The most important public decisions have to do with land use planning, public land ownership, and infrastructure.

• Phoenix has aggressively pursued land purchases and land banking over the past several decades, using proceeds from a voter-approved dedicated sales tax to create a land trust that collars much of the northern and southern desert reaches of Phoenix. The City of Phoenix protects 30,000 acres in its desert preserves, including the South Mountain Park/Preserve, which alone accounts for 16,000 acres, making it the largest municipal park in the United States. Decision makers have provided less support for open space in the Atlanta area.

• Phoenix is adjacent or close to a large amount of federal and state land, making the remaining land more valuable and increasing incentives for density.

• Growth decisions in metropolitan Atlanta are made mainly by counties, many of which limit development density to low levels over a large portion of the metropolitan area. In metropolitan Phoenix, most development occurs in cities that allow

(continued on next page)

Box 5-1 *(continued)*

PHOENIX AND ATLANTA

A Comparison of Density Changes in Two Rapidly Growing Metropolitan Areas

development of higher-density housing; permitted single-family lot sizes are also typically smaller than in metropolitan Atlanta.

• Phoenix has a sparse rural road network and a late-developing Interstate highway system, while metropolitan Atlanta has dense rural roads and one of the earliest beltway-spoke Interstate networks. Phoenix has also invested in extensive centralized water and sewage treatment infrastructure, accommodating and even necessitating density. Atlanta's water investments, by contrast, have been more modest, and one-fifth of Atlantans have no central sewer, relying instead on septic systems that require large lots.

Phoenix's higher density and Atlanta's low density also relate to demography and ethnicity. Phoenix has more immigrants and elderly residents, who appear to accept higher-density development. Racial composition may also play a role, as most of the households that have moved into the low-density northern reaches of metropolitan Atlanta have followed a long tradition of separation from African American neighbors in the region's central cities and southern counties. Finally, Phoenix's topography is mostly flat but punctuated with steep mountains, whereas Atlanta's has more stream valleys and low hills.

that they would be unrealistic absent a strong state or regional role in growth management.

OTHER BENEFITS AND COSTS OF MORE COMPACT DEVELOPMENT

Improved Energy Efficiency of Residential Buildings

The prior sections have focused on the potential savings in energy use and CO_2 emissions from reduced travel associated with more compact, mixed-use development. Another important source of savings, directly related to more compact development, is the improved energy efficiency of residential buildings. The U.S. residential sector accounts for slightly more than one-fifth of the nation's total annual energy use and produces an equivalent share of total annual CO_2 emissions (EIA 2007).[22]

Substantial savings in energy use and CO_2 emissions can be achieved through improved building design, primarily by increasing the thickness of insulation and by realizing changes in home size that would result from more compact development (Kockelman et al. 2009). For example, moving from a single-family to a multifamily DU would result in significant energy savings. Calculations conducted for this study revealed that moving from a 2,400-ft^2 single-family home—the average home size in the United States in 2007[23]—to a 2,000-ft^2 apartment would save about 34.1 million Btu and about 3.3 metric tons of CO_2 emissions, all else being equal (see Annex 5-1 Table 5 for detailed calculations).[24] By

[22] Of the four end-use sectors—transportation, industrial, commercial, and residential—the residential sector accounted for 20.7 percent of consumer expenditures for energy and 20.4 percent of CO_2 emissions (EIA 2007, Tables 3.6 and 12.3).

[23] According to the National Association of Homebuilders (NAHB 2007), the average new one-family home is slightly larger inside metropolitan statistical areas—about 2,500 ft^2. Average home size has been rising at a rate of approximately 30 ft^2 per year over the past decade.

[24] As part of a larger paper on options for controlling greenhouse gas emissions (Kockelman et al. 2009), Charlotte Whitehead of the University of Texas at Austin, one of three student researchers, performed these computations. Using the Residential Energy Consumption Survey of the Energy Information Administration, she selected 20 sample cities, reflecting different climate zones and census regions, to develop regressions of home and apartment energy use as a function of various DU and household attributes.

comparison, downsizing from a 2,400-ft^2 single-family DU to a 2,000-ft^2 single-family unit would save only 4.1 million Btu and 0.35 metric tons of CO_2 emissions. Estimated savings are averages, however, which could vary widely from one location to another, depending on heating and cooling needs and energy sources.

The primary reason for the greater energy efficiency of multifamily DUs versus single-family homes is the reduced exposed surface area of the former. As exposed surface area increases, the amount of heat transferred either into or out of a building also increases. The same logic suggests that shorter buildings are more energy efficient than taller ones, all else being equal, because of less exposed surface area and the insulation provided by the ground soil. As the base floor area increases, however, building up becomes more energy efficient, particularly in multifamily DUs, where increasing the number of units maximizes interior volume relative to exposed wall and rooftop area. Shared walls also reduce the heating and cooling needs of individual units. Of course, multifamily units are smaller, on average, than single-family DUs.[25]

Table 5-4 shows the results of a simple calculation assuming that 75 percent of new and replacement housing units are built as 2,000-ft^2 single-family units or 2,000-ft^2 apartments instead of 2,400-ft^2 single-family units. The savings calculated represent an upper bound in that they ignore any future improvements in building efficiency from better insulation or other measures, assume that all new development is detached single-family units, and are based on the committee's most optimistic compact-growth scenario. Nevertheless, under these assumptions, 149.8 trillion to 173.9 trillion Btu per year could be saved by 2030 from downsizing to smaller single-family DUs and 1,173 trillion to 1,449 trillion Btu from moving to multifamily DUs. These energy savings translate to a reduction of 12 million to 14.8 million metric tons of CO_2 emissions and 115.1 million to

[25] The average multifamily dwelling unit is 1,078 ft^2.

TABLE 5-4 **Estimated Savings in Energy Use and CO_2 Emissions from Improved Energy Efficiency of Residential Buildings and Changes in VMT from Compact Development, 2030, 2050**

	By 2030	By 2050
Number of new and replacement housing units[a] (in millions)	45.8–56.7	62.4–105.3
Number of housing units in compact development[b] (in millions)	34.4–42.5	46.8–78.4
Savings in energy use (in trillions of Btu) from		
Moving to MFDU[c]	1,173.0–1,449.0	1,596.0–2,673.0
Downsizing to SFDU[d]	140.8–173.9	191.6–320.9
Savings in CO_2 emissions (in millions of metric tons) from		
Moving to MFDU[c]	115.1–142.2	156.6–262.3
Downsizing to SFDU[d]	12.0–14.8	16.3–27.4
Savings in fuel use (in trillions of Btu) from changes in VMT	855.6–1,066.4	1,103.6–1,847.6
Savings in CO_2 emissions (in millions of metric tons) from changes in VMT	61.0–75.0	78.0–132.0

Note: MFDU = multifamily dwelling unit; SFDU = single-family dwelling unit. See Annex 5-1 Table 5 for conversion factors.

[a]Assumes the same number of new and replacement housing units as committee scenarios.

[b]Assumes the "best case" scenario (i.e., 75 percent of new and replacement housing units will be in more compact development settings).

[c]Assumes moving from a 2,400-ft^2 single-family dwelling unit to a 2,000-ft^2 multifamily dwelling unit.

[d]Assumes moving from a 2,400-ft^2 single-family dwelling unit to a 2,000-ft^2 single-family dwelling unit.

142.2 million metric tons of CO_2 emissions, respectively.[26] By 2050, the energy savings from downsizing to smaller single-family DUs or moving to multifamily DUs grow to 191.6 trillion to 320.9 trillion Btu and 1,596 trillion to 2.673 trillion Btu, respectively, and savings in

[26] The energy savings in 2030 represent a 4 percent to a 37 percent reduction from downsizing to a smaller single-family DU and moving to a multifamily DU, respectively, from a base case that assumes no downsizing. The comparable savings in CO_2 emissions are 3 percent and 30 percent. In 2050, the energy and CO_2 emissions savings are larger in absolute terms, but not in percentage terms, because the larger absolute reductions are calculated from a larger number of base case DUs.

CO_2 emissions grow to 16.3 million to 27.4 million metric tons and 156.6 million to 262.3 million metric tons, respectively. These savings from residential building efficiencies represent significant additions to the savings realized from reduced VMT in more compact developments. Of course, the actual savings could be much less, particularly as a result of improvements in the efficiency of residential heating, cooling, and lighting systems, and they would vary from one location to another.

Other Benefits and Costs

A number of studies (Burchell et al. 2002; Burchell et al. 2005; Downs 2004) have enumerated many of the other benefits and costs of more compact, mixed-use development, or conversely, the costs (and benefits) of more sprawling development patterns. They are briefly summarized here; use is made of the organizational structure of Burchell et al. (2002, 2005). No attempt is made, however, to quantify these effects or determine whether the benefits outweigh the costs, which was beyond the scope of this study.

Land and Infrastructure

More compact development, particularly near areas that are already developed, should reduce demand for and conversion of undeveloped land to meet new housing and job needs. Chapter 2 noted the high rate of land conversion in recent decades. Reducing this growth rate would help preserve agricultural land as well as other environmentally fragile areas, such as wetlands and sensitive watersheds.

Developing more compactly would also reduce the costs of extending or upgrading infrastructure systems to support new housing and commercial development. Water and sewer trunk lines, in particular, would not have to be extended, nor local road networks expanded, although some upgrading of existing capacity might be needed if new development were directed toward already built-up areas. Water and

sewer hook-up fees, which are borne by new homeowners, would be reduced, lessening development and homeowner costs if the savings were passed on. More generally, compact development would increase the feasibility of building lower-cost housing. Medium-density units (low-rise apartments) in particular are less expensive to develop than either high-rise or low-density, single-family units and could find greater acceptance than high-rise apartment buildings in some developed areas (Downs 2004).

Health, Congestion, and Community

More compact development can provide greater incentives for walking and bicycling as travel modes, and increased physical activity is known to have positive health benefits. However, causal associations between compact development and physical activity have not been conclusively demonstrated (TRB 2005). The relationship is complex and operates through many mediating factors, such as sociodemographic characteristics, personal and cultural variables, safety and security, and time allocation. Nevertheless, in the longer run, more compactly developed environments that reduce automobile dependence should leave residents with more travel options as they face potentially higher energy costs and possible carbon taxes.

The potential benefits of more compact development in reducing congestion and pollution are more ambiguous. Reduction in congestion depends on the capacity of the existing road network, as well as on the extent of the shift to transit and other modes. Mobility in general could be affected because shifts to transit and walking are likely to increase traveler trip times, and lower levels of automobile ownership in very high-density locations may result in fewer vehicle trips. The effect on pollution reduction is also complex because many pollutants are not point specific; their concentrations are a regional phenomenon, affected by wind and weather, among other variables. Moreover, the urban heat island effect—higher temperatures associated with urban

development—is most pronounced in densely developed areas.[27] Higher temperatures, particularly in the summer, can increase the rate of both ground-level ozone formation and electricity use, particularly for cooling, which in turn means more pollution and greenhouse gas emissions from fossil fuel–burning power plants (EPA 2008). Human health effects of increased daytime surface temperatures, reduced nighttime cooling, and higher air pollution levels associated with urban heat islands include respiratory difficulties, heatstroke, and heat-related mortality (EPA 2008). Urban heat islands can also exacerbate the impact of heat waves, affecting sensitive populations, such as children and the elderly.

Another difficult-to-measure benefit of compact development is an enhanced sense of community among residents, thought to improve quality of life. The argument is that an environment in which residents live closer together and have more opportunities to interact in public spaces without resorting to automobiles should encourage more social interaction and foster a sense of community. The hypothesis is difficult to test empirically, and as Burchell et al. (2002, 15) conclude, "it cannot be said that controlled growth will lead to either improved or lower quality of life."

Housing Choices and Costs

A potential cost of more compact development is the investment in transit, particularly rail transit, necessary to support high-density development. These costs could, at least in part, offset some of the savings from expanding highway infrastructure.

The studies cited earlier note some of the other costs of more compact development. One of the first mentioned is the preference of many

[27] Urban development modifies the landscape so that buildings, roads, and other infrastructure replace open land and vegetation, and surfaces that were once permeable and moist become impermeable and dry (EPA 2008). Dense urban areas concentrate the heat produced by human activities from heating and cooling, running appliances, transportation, and industrial processes. The resulting "heat island" can create temperature differences of 1.8°F to 5.4°F between a major city and surrounding rural areas.

Americans for single-family homes and lower-density suburban settings that are often associated with related benefits, such as greater privacy, less noise, more access to open space and recreation, and in some cases, less congestion and pollution than more densely developed urban settings.[28] Restricting the amount of single-family housing through zoning or other measures that increase compact development could raise the cost of that housing, contributing to housing affordability problems.

These affordability problems may be mitigated, however, as the baby boomers withdraw from their suburban single-family homes, increasing the supply of such housing. As noted in Chapter 4, moreover, it is unclear that more compact development would greatly restrict housing choices or increase single-family housing prices because exclusionary zoning may have forced a greater mix of single-family housing units than consumers wanted in the past. Moreover, building more compact, mixed-use developments does not necessarily mean building only multifamily housing. Reducing the lot size of single-family housing should also result in VMT reductions. Finally, housing preferences may change with the aging of the population and the withdrawal of the baby boomers from their suburban homes; the coming of age of succeeding (albeit smaller) generations of young single-person households that may prefer urban living; and the socioeconomic circumstances and cultural preferences of growing immigrant populations, who often favor high-density locations. (See the discussion of these trends in Chapter 4.)

FINDINGS

Changing development patterns to encourage more compact, mixed-use development has the potential to reduce VMT, energy use, and CO_2 emissions. The question is by how much. In an upper-bound scenario,

[28] As noted previously, congestion levels depend in part on the capacity of the existing road system, and reduced pollution from automobile travel is complex to calculate.

which assumes that 75 percent of new and replacement housing units are built in more compact developments and that residents of those developments drive 25 percent less, the committee estimates that VMT and associated fuel use and CO_2 emissions would be reduced by 7 to 8 percent below the base case by 2030, growing to between 8 and 11 percent below the base case by 2050. A more moderate scenario, which assumes that 25 percent of new and replacement housing units are built in more compact developments and that residents of those developments drive 12 percent less, results in reductions in energy use and CO_2 emissions of about 1 percent below the base case by 2030, growing to between 1.3 and 1.7 percent below the base case by 2050. If the residents of compact developments drive only 5 percent less—the lower bound of available estimates—then the savings in energy use and CO_2 emissions are less than 1 percent below the base case even by 2050. Thus, the committee believes that reductions in VMT, energy use, and CO_2 emissions resulting from compact, mixed-use development would be in the range of less than 1 percent to 11 percent by 2050, although the committee members disagreed about whether the changes in development patterns and public policies necessary to achieve the high end of these findings are plausible.

All scenarios increase the density of development and thus represent a departure from current trends that produce a continued decline in density. New development in metropolitan areas has occurred at lower than the average density of existing development for decades. However, doubling the density of 25 percent of new development from this reduced level is possible, particularly by 2050. Average densities for new development would not be raised above current levels, and precedents for higher densities can be found in growing areas such as Phoenix and Portland. The committee members disagreed about the feasibility of doubling the density of 75 percent of new development, even by 2050. Those members who thought it was possible questioned whether densities will keep declining in the face of likely higher energy prices and carbon taxes and growing public support for strategic infill,

investments in transit, and higher densities along rail corridors. Other members believed that the substantial infill and curbing of large-lot development at the urban fringe implied in achieving the targets in Scenario 2 require such a significant departure from current housing trends, land use policies of jurisdictions on the urban fringe, and public preferences that they would be unrealistic absent a strong state or regional role in growth management.

Whether reductions in energy use and CO_2 emissions from VMT reductions occur rapidly or slowly, more compact development will also yield significant savings in energy use and production of CO_2 emissions by improving the energy efficiency of residential buildings. The U.S. residential sector accounts for more than one-fifth of the nation's total annual energy use and an equivalent share of CO_2 emissions. Multifamily housing is particularly energy efficient relative to single-family housing because of a combination of reduced exposed surface area per dwelling unit and shared walls and floors that reduce the heating and cooling costs of individual units. Downsizing to smaller single-family dwellings also yields savings, but much smaller than the reduction from moving to multifamily units.

The savings from reductions in VMT and greater energy efficiency of residential buildings resulting from more compact development, however, will be affected, and in most cases reduced, by other policies adopted to achieve these goals. For example, the more rapidly the energy efficiency of cars and light trucks increases, whether as a result of public policy or of higher energy prices, the smaller are the savings in energy use and CO_2 emissions from reducing VMT. Similarly, if the energy efficiency of residential heating and cooling is improved, the advantages of shifting from detached single-family homes to apartments or to smaller single-family units will also decline. Indeed, a sensitivity analysis of the committee's assumptions about fuel economy shows that more aggressive fuel economy improvements would produce savings in energy use and CO_2 emissions many times the size of those from compact development.

Changes in development patterns significant enough to substantially alter travel behavior and the energy efficiency of residential buildings entail other benefits and costs that are not quantified in this study. On the benefit side, more compact, mixed-use development should reduce infrastructure costs, increase the feasibility and cost-effectiveness of transit, and enhance the likelihood of building more moderately priced housing. Other benefits include less demand for undeveloped land and less conversion of agricultural and other environmentally fragile areas. Finally, increasing the amount of more compact, mixed-use development should provide homeowners with more transportation options and more opportunities for increasing physical activity by walking and bicycling. Less certain benefits of more compact development include reduced congestion, better air quality, and improved quality of life.

On the cost side, savings in highway infrastructure would be offset, at least in part, by increased investment in transit, particularly rail transit, to support high-density development. Moreover, many Americans appear to prefer detached single-family homes in low-density suburbs that often are associated with more privacy, greater access to open space and recreation, and less noise than characterize many urban neighborhoods. As discussed in Chapter 4, however, there is some evidence that more compact developments may currently be undersupplied because of exclusionary suburban zoning. Moreover, housing preferences may change in the future with changes in the demographic and socioeconomic characteristics of the population.

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Abbreviations

EIA	Energy Information Administration
EPA	Environmental Protection Agency
NAHB	National Association of Home Builders
NRC	National Research Council
TRB	Transportation Research Board

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Annex 5-1

Detailed Tables

ANNEX 5-1 TABLE 1 **Sensitivity Analysis, 2000–2030, Changing Fuel Economy Assumptions**

	Year	Base Case	Scenario 1	Scenario 2
		New Development		
Assumptions				
Percent growth in housing units		36%–46%	36%–46%	36%–46%
Housing units (in millions)	2000 2030	105.2 142.8–153.2	105.2 142.8–153.2	105.2 142.8–153.2
Percent of 2030 units new and replacement		32%–37%	32%–37%	32%–37%
New and replacement units (in millions)	2030	45.8–56.7	45.8–56.7	45.8–56.7
Percent of new and replacement units compact		0%	25%	75%
New and replacement units compact (in millions)	2030	0.0–0.0	11.5–14.2	34.4–42.5
		Changes in VMT		
Assumptions				
Percent change in VMT/household in existing development		0%	0%	0%
VMT/household in existing development	2000 2030	21,187 21,187	21,187 21,187	21,187 21,187
Percent change in VMT/household in new noncompact development			8.4%	17.5%
VMT/household in new noncompact development	2030		22,967[a]	24,895[a]

(continued on next page)

ANNEX 5-1 TABLE 1 *(continued)* **Sensitivity Analysis, 2000–2030, Changing Fuel Economy Assumptions**

	Year	Base Case	Scenario 1	Scenario 2
Percent reduction in VMT/household in new compact development			–12%	–25%
VMT/household in new compact development	2030		20,211[b]	18,671[b]
Results				
Percent change in VMT between 2000 and 2030		39.4%–50.2%	38.0%–48.4%	
VMT (in billions of miles)	2000	2,228.9	2,228.9	
	2030 (1)[c]	3,106.9–3,346.8	3,075.4–3,307.7	
		43.4%–55.1%		33.8%–43.2%
	2000	2,228.9		2,228.9
	2030 (2)[d]	3,195.1–3,456.1		2,981.6–3,191.4
Percent change in VMT in 2030 from base case			–1.0% to –1.2%	–6.7% to –7.7%
Change in VMT from base case (in billions of miles)	2030		–31.5 to –39.1	–213.5 to –264.7
Changes in Energy Use and CO_2 Emissions				
Assumptions				
Percent change in fleet mpg by 2030		103.6%	103.6%	103.6%
Fleet mpg	2000	19.5	19.5	19.5
	2030	39.7[c]	39.7[c]	39.7[c]
Percent change in carbon content of fuel between 2000 and 2030		0%	0%	0%
Results				
Percent change in fuel use between 2000 and 2030		–31.5% to –26.2%	–32.2% to –27.1%	

	Year	Base Case	Scenario 1	Scenario 2
Fuel use (in billions of gallons)	2000	114.3	114.3	
	2030 (1)[c]	78.3–84.3	77.5–83.3	
		–29.6% to –23.8%		–34.3% to –29.7%
	2000	114.3		114.3
	2030 (2)[d]	80.5–87.1		75.1–80.4
Percent change in fuel use in 2030 from base case			–1.0% to –1.2%	–6.7% to –7.7%
Change in fuel use from base case (in billions of gallons)	2030		–0.8 to –0.9	–6.9 to –6.7
Percent change in CO_2 emissions between 2000 and 2030		–31.5% to –26.2%	–32.2% to –27.2%	
CO_2 emissions (millions of metric tons)	2000	1,006	1,006	
	2030 (1)[c]	689–742	682–733	
		–29.6% to –23.8%		–34.3% to –29.7%
	2000	1,006		1,006
	2030 (2)[d]	708–766		661–707
Percent change in CO_2 emissions from base case			–1.0% to –1.2%	–6.7% to –7.7%
Change in CO_2 emissions from base case (millions of metric tons)	2030		–7 to –9	–47 to –59

[a]In Scenario 1, VMT per household in new noncompact developments is assumed to be 8.4 percent higher (12 percent × .70) than the average for existing households, or 22,967 (21,187 × 1.084) VMT per household per year. In Scenario 2, VMT per household in new noncompact developments is assumed to be 17.5 percent higher (25 percent × .70) than the average for existing households, or 24,895 (21,187 × 1.175) VMT per household per year.

[b]In Scenario 1, VMT per household in new compact developments is assumed to be 12 percent less than the baseline of new noncompact development households, or 20,211 (22,967 × .88). In Scenario 2, VMT per household in new compact developments is assumed to be 25 percent less than the baseline of new noncompact development households, or 18,671 (24,895 × .75).

[c]The baseline projections for 2030 reflect the assumptions described in Footnote *a*.

[d]The baseline projections for 2030 reflect the assumptions described in Footnote *b*.

ANNEX 5-1 TABLE 2 **Sensitivity Analysis, 2000–2050, Changing Fuel Economy Assumptions**

	Year	Base Case	Scenario 1	Scenario 2
		New Development		
Assumptions				
Percent growth in housing units		42.5%–82.5%	42.5%–82.5%	42.5%–82.5%
Housing units (in millions)	2000 2050	105.2 152.8–192.0	105.2 152.8–192.0	105.2 152.8–192.0
Percent of 2050 units new and replacement		40.8%–54.9%	40.8%–54.9%	40.8%–54.9%
New and replacement units (in millions)	2050	62.4–105.4	62.4–105.4	62.4–105.4
Percent of new and replacement units compact		0%	25%	75%
New and replacement units compact (in millions)	2050	0.0–0.0	15.6–25.8	46.8–78.4
		Changes in VMT		
Assumptions				
Percent change in VMT/household in existing development		0%	0%	0%
VMT/household in existing development	2000 2050	21,187 21,187	21,187 21,187	21,187 21,187
Percent change in VMT/household in new noncompact development			8.4%	17.5%
VMT/household in new noncompact development	2050		22,967[a]	24,895[a]
Percent reduction in VMT/household in new compact development			–12%	–25%

	Year	Base Case	Scenario 1	Scenario 2
VMT/household in new compact development	2050		20,211[b]	18,671[b]
Results				
Percent change in VMT between 2000 and 2050		50.2%–90.9%	48.3%–87.7%	
VMT (in billions of miles)	2000	2,228.9	2,228.9	
	2050 (1)[c]	3,348.5–4,255.4	3,305.5–4,182.8	
		55.6%–100%		42.6%–78%
	2000	2,228.9		2,228.9
	2050 (2)[d]	3,468.9–4,458.6		3,177.4–3,966.8
Percent change in VMT in 2050 from base case			–1.3% to –1.7%	–8.4% to –11.0%
Change in VMT from base case (in billions of miles)	2050		–43.0 to –72.6	–291.5 to –491.8
Changes in Energy Use and CO_2 Emissions				
Assumptions				
Percent change in fleet mpg by 2050		193.8%	193.8%	193.8%
Fleet mpg	2000	19.5	19.5	19.5
	2050	57.3[e]	57.3[e]	57.3[e]
Percent change in carbon content of fuel between 2000 and 2050		0%	0%	0%
Results				
Percent change in fuel use between 2000 and 2050		–48.9% to –35%	–49.5% to –36.1%	
Fuel use (in billions of gallons)	2000	114.3	114.3	
	2050 (1)[c]	58.4–74.3	57.7–72.9	
		–47% to –31.9%		–51.5% to –39.4%
	2000	114.3		114.3
	2050 (2)[d]	60.5–77.8		55.4–69.2

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ANNEX 5-1 TABLE 2 *(continued)* **Sensitivity Analysis, 2000–2050, Changing Fuel Economy Assumptions**

	Year	Base Case	Scenario 1	Scenario 2
Percent change in fuel use in 2050 from base case			–1.3% to –1.7%	–8.4% to –11.0%
Change in fuel use from base case (in billions of gallons)	2050		–0.8 to –1.3	–5.1 to –8.6
Percent change in CO_2 emissions between 2000 and 2050		–48.9% to –35%	–49.5% to –36.1%	
CO_2 emissions (millions of metric tons)	2000	1,006	1,006	
	2050 (1)[c]	514–654	508–642	
		–47% to –31.9%		–51.5% to –39.4%
	2000	1,006		1,006
	2050 (2)[d]	533–685		488–609
Percent change in CO_2 emissions from base case			–1.3% to –1.7%	–8.4% to –11.0%
Change in CO_2 emissions from base case (millions of metric tons)	2050		–7 to –11	–45 to –76

[a]In Scenario 1, VMT per household in new noncompact developments is assumed to be 8.4 percent higher (12 percent × .70) than the average for existing households, or 22,967 (21,187 × 1.084) VMT per household per year. In Scenario 2, VMT per household in new noncompact developments is assumed to be 17.5 percent higher (25 percent × .70) than the average for existing households, or 24,895 (21,187 × 1.175) VMT per household per year.

[b]In Scenario 1, VMT per household in new compact developments is assumed to be 12 percent less than the baseline of new noncompact development households, or 20,211 (22,967 × .88). In Scenario 2, VMT per household in new compact developments is assumed to be 25 percent less than the baseline of new noncompact development households, or 18,671 (24,895 × .75).

[c]The baseline projections for 2050 reflect the assumptions described in Footnote *a*.

[d]The baseline projections for 2050 reflect the assumptions described in Footnote *b*.

[e]Assumes more aggressive fuel economy improvements. Average fleetwide on-road fuel economy reaches 57.3 mpg by 2050 rather than 32.9 mpg, an increase of 193.8 percent versus 68.7 percent over mpg in 2000 (see text and NRC 2008 for discussion of high-efficiency fuel assumptions).

ANNEX 5-1 TABLE 3 **Sensitivity Analysis, 2000–2030, Changing VMT Assumptions**

	Year	Base Case	Scenario 1	Scenario 2
		New Development		
Assumptions				
Percent growth in housing units		36%–46%	36%–46%	36%–46%
Housing units (in millions)	2000 2030	105.2 142.8–153.2	105.2 142.8–153.2	105.2 142.8–153.2
Percent of 2030 units new and replacement		32%–37%	32%–37%	32%–37%
New and replacement units (in millions)	2030	45.8–56.7	45.8–56.7	45.8–56.7
Percent of new and replacement units compact		0%	25%	75%
New and replacement units compact (in millions)	2030	0.0–0.0	11.5–14.2	34.4–42.5
		Changes in VMT		
Assumptions				
Percent change in VMT/household in existing development		7.8%	7.8%	7.8%
VMT/household in existing development	2000 2030	21,187 22,835	21,187 22,835	21,187 22,835
Percent change in VMT/household in new noncompact development			8.4%	17.5%
VMT/household in new noncompact development	2000 2030		22,967[a] 24,753	24,895[a] 26,831
Percent reduction in VMT/household in new compact development			–12%	–25%

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ANNEX 5-1 TABLE 3 *(continued)* **Sensitivity Analysis, 2000–2030, Changing VMT Assumptions**

	Year	Base Case	Scenario 1	Scenario 2
VMT/household in new compact development	2000		20,211[b]	18,671[b]
	2030		21,783	20,123
Results				
Percent change in VMT between 2000 and 2030		39.4%–61.8%	38.0%–59.9%	
VMT (in billions of miles)	2000	2,228.9	2,228.9	
	2030 (1)[c]	3,106.9–3,607.1	3,075.4–3,565.0	
		54.5%–67.1%		44.2%–54.1%
	2000	2,228.9		2,228.9
	2030 (2)[d]	3,443.6–3,724.9		3,213.5–3,439.6
Percent change in VMT in 2030 from base case			–1.0% to –1.2%	–6.7% to –7.7%
Change in VMT from base case (in billions of miles)	2030		–31.5 to –42.1	–230.1 to –285.3
Changes in Energy Use and CO_2 Emissions				
Assumptions				
Percent change in fleet mpg by 2030		58.5%	58.5%	58.5%
Fleet mpg	2000	19.5	19.5	19.5
	2030	30.9	30.9	30.9
Percent change in carbon content of fuel between 2000 and 2030		0%	0%	0%
Results				
Percent change in fuel use between 2000 and 2030		–12.0% to +2.1%	–12.9% to +0.9%	
Fuel use (in billions of gallons)	2000	114.3	114.3	
	2030 (1)[c]	100.5–116.7	99.5–115.4	
		–2.5% to +5.5%		–9.0% to –2.6%
	2000	114.3		114.3
	2030 (2)[d]	111.4–120.5		104.0–111.3

	Year	Base Case	Scenario 1	Scenario 2
Percent change in fuel use in 2030 from base case			–1.0% to –1.2%	–6.7% to –7.7%
Change in fuel use from base case (in billions of gallons)	2030		–1.0 to –1.3	–7.4 to –9.2
Percent change in CO_2 emissions between 2000 and 2030		–12.0% to +2.1%	–12.9% to +0.9%	
CO_2 emissions (millions of metric tons)	2000	1,006	1,006	
	2030 (1)[c]	885–1,027	876–1,015	
		–2.5% to +5.5%		–9.0% to –2.6%
	2000	1,006		1,006
	2030 (2)[d]	981–1,061		915–980
Percent change in CO_2 emissions from base case			–1.0% to –1.2%	–6.7% to –7.7%
Change in CO_2 emissions from base case (millions of metric tons)	2030		–8.9 to –12	–66 to –81

[a]In Scenario 1, VMT per household in new noncompact developments is assumed to be 8.4 percent higher (12 percent × .70) than the average for existing households, or 22,967 (21,187 × 1.084) VMT per household per year. In Scenario 2, VMT per household in new noncompact developments is assumed to be 17.5 percent higher (25 percent × .70) than the average for existing households, or 24,895 (21,187 × 1.175) VMT per household per year.

[b]In Scenario 1, VMT per household in new compact developments is assumed to be 12 percent less than the baseline of new noncompact development households, or 20,211 (22,967 × .88). In Scenario 2, VMT per household in new compact developments is assumed to be 25 percent less than the baseline of new noncompact development households, or 18,671 (24,895 × .75).

[c]The baseline projections for 2030 reflect the assumptions described in Footnote *a*.

[d]The baseline projections for 2030 reflect the assumptions described in Footnote *b*.

ANNEX 5-1 TABLE 4 **Sensitivity Analysis, 2000–2050, Changing VMT Assumptions**

	Year	Base Case	Scenario 1	Scenario 2
		New Development		
Assumptions				
Percent growth in housing units		42.5%–82.5%	42.5%–82.5%	42.5%–82.5%
Housing units (in millions)	2000 2050	105.2 152.8–192.0	105.2 152.8–192.0	105.2 152.8–192.0
Percent of 2050 units new and replacement		40.8–54.9%	40.8–54.9%	40.8–54.9%
New and replacement units (in millions)	2050	62.4–105.4	62.4–105.4	62.4–105.4
Percent of new and replacement units compact		0%	25%	75%
New and replacement units compact (in millions)	2050	0.0–0.0	15.6–25.8	46.8–78.4
		Changes in VMT		
Assumptions				
Percent change in VMT/household in existing development		13.3%	13.3%	13.3%
VMT/household in existing development	2000 2050	21,187 24,004	21,187 24,004	21,187 24,004
Percent change in VMT/household in new noncompact development			8.4%	17.5%
VMT/household in new noncompact development	2000 2050		22,967[a] 26,021	24,895[a] 28,205
Percent reduction in VMT/household in new compact development			–12%	–25%

	Year	Base Case	Scenario 1	Scenario 2
VMT/household in new compact development	2000		20,211[b]	18,671[b]
	2050		22,898	21,154
Results				
Percent change in VMT between 2000 and 2050		70.2%–116.3%	68.0%–112.6%	
VMT (in billions of miles)	2000	2,228.9	2,228.9	
	2050 (1)[c]	3,793.7–4,821.3	3,745.0–4,739.0	
		76.3%–126.6%		61.5%–101.6%
	2000	2,228.9		2,228.9
	2050 (2)[d]	3,930.1–5,051.4		3,599.9–4,494.2
Percent change in VMT in 2050 from base case			–1.3% to –1.7%	–8.4% to –11.0%
Change in VMT from base case (in billions of miles)	2050		–48.7 to –82.3	–330.2 to –557.2
Changes in Energy Use and CO_2 Emissions				
Assumptions				
Percent change in fleet mpg by 2050		68.7%	68.7%	68.7%
Fleet mpg	2000	19.5	19.5	19.5
	2050	32.9	32.9	32.9
Percent change in carbon content of fuel between 2000 and 2050		0%	0%	0%
Results				
Percent change in fuel use between 2000 and 2050		+0.9% to +28.2%	–0.4% to +26%	
Fuel use (in billions of gallons)	2000	114.3	114.3	
	2050 (1)[c]	115.3–146.5	113.8–144	
		+4.5% to +34.3%		–4.3% to +19.5%
	2000	114.3		119.5
	2050 (2)[d]	119.4–153.5		109.4–136.6

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ANNEX 5-1 TABLE 4 *(continued)* **Sensitivity Analysis, 2000–2050, Changing VMT Assumptions**

	Year	Base Case	Scenario 1	Scenario 2
Percent change in fuel use in 2050 from base case			–1.3% to –1.7%	–8.4% to –11.0%
Change in fuel use from base case (in billions of gallons)	2050		–1.5 to –2.5	–10 to –16.9
Percent change in CO_2 emissions between 2000 and 2050		+0.9% to +28.2%	–0.4% to +26%	
CO_2 emissions (millions of metric tons)	2000	1,006	1,006	
	2050 (1)[c]	1,015–1,290	1,002–1,268	
		+4.5% to +34.3%		–4.3% to +19.5%
	2000	1,006		1,006
	2050 (2)[d]	1,051–1,351		963–1,202
Percent change in CO_2 emissions from base case			–1.3% to –1.7%	–8.4% to –11.0%
Change in CO_2 emissions from base case (millions of metric tons)	2050		–13 to –22	–88 to –149

[a]In Scenario 1, VMT per household in new noncompact developments is assumed to be 8.4 percent higher (12 percent × .70) than the average for existing households, or 22,967 (21,187 × 1.084) VMT per household per year. In Scenario 2, VMT per household in new noncompact developments is assumed to be 17.5 percent higher (25 percent × .70) than the average for existing households, or 24,895 (21,187 × 1.175) VMT per household per year.

[b]In Scenario 1, VMT per household in new compact developments is assumed to be 12 percent less than the baseline of new noncompact development households, or 20,211 (22,967 × .88). In Scenario 2, VMT per household in new compact developments is assumed to be 25 percent less than the baseline of new noncompact development households, or 18,671 (24,895 × .75).

[c]The baseline projections for 2050 reflect the assumptions described in Footnote *a*.

[d]The baseline projections for 2050 reflect the assumptions described in Footnote *b*.

ANNEX 5-1 TABLE 5 **Savings Calculations in Energy Use and CO_2 Emissions from Improved Residential Energy Efficiency with More Compact Growth**

	Scenario		
	Base Case: 2,400-ft² SFDU	**Move to 2,000-ft² SFDU**	**Move to 2,000-ft² MFDU**
Energy use	14,980 kW-h per unit per year (51.1 million Btu per unit per year)	14,660 kW-h per unit per year (50 million Btu per unit per year)	11,308 kW-h per unit per year (38.6 million Btu per unit per year)
	395.9 ccf ng per unit per year (40.7 million Btu per unit per year)	366.7 ccf ng per unit per year (37.7 million Btu per unit per year)	186.1 ccf ng per unit per year (19.1 million Btu per unit per year)
Subtotal energy use	92.8 million Btu per unit per year	87.7 million Btu per unit per year	57.7 million Btu per unit per year
Energy savings	—	320 kW-h (1.1 million Btu) per unit per year	3,671 kW-h (12.5 million Btu) per unit per year
	—	29.2 ccf ng (3.0 million Btu) per unit per year	209.8 ccf ng (21.6 million Btu) per unit per year
Subtotal energy savings		4.1 million Btu per unit per year	34.1 million Btu per unit per year
CO_2 emissions	24,705 lb per unit per year (11.2 metric tons per unit per year)	23,935 lb per unit per year (10.9 metric tons per unit per year)	17,330 lb per unit per year (7.9 metric tons per unit per year)
CO_2 emissions savings	—	770 lb (0.35 metric tons) per unit per year	7,376 lb (3.3 metric tons) per unit per year

Note: Btu = British thermal units; ccf ng = hundred cubic feet of natural gas; kW-h = kilowatt-hours; MFDU = multifamily dwelling unit; SFDU = single-family dwelling unit. Factors for converting energy figures to Btu: 1 kW-h of electricity = 3, 412 Btu; 1 cf of natural gas = 1,028 Btu; 1 ccf of natural gas = 102,800 Btu; 1 gallon of gasoline = 124,000 Btu. Factor for converting CO_2 emissions to metric tons: 1 metric ton of CO_2 emissions = 2,204.6 lb.

6 | Recommendations

The charge of this committee was to examine the relationship between land development patterns and motor vehicle travel and to assess whether changes in development patterns—in particular, developing more compactly—can reduce energy use and carbon dioxide (CO_2) emissions. A key focus of the study was the extent to which developing at higher densities would reduce vehicle miles traveled (VMT) by shortening trip lengths and making alternative modes of travel, such as transit and walking, more feasible. In response to its charge, the study committee reviewed the literature to determine what is known about the relationship between development patterns and VMT, commissioned papers to address topics that were not well covered in the literature, and developed its own scenarios to quantify the potential magnitude of VMT reductions and associated savings in energy use and CO_2 emissions.

POLICY RECOMMENDATION

Recommendation 1: Policies that support more compact, mixed-use development and reinforce its ability to reduce VMT, energy use, and CO_2 emissions should be encouraged.

The committee recognizes that it does not have as much verifiable scientific evidence to support this recommendation as it would like.

The committee's own scenarios suggest that compact development will generate only modest reductions in energy use and carbon emissions in the near term, although these savings will grow over time. By 2050, the committee's scenarios show that reductions in VMT, energy use, and CO_2 emissions resulting from compact, mixed-use development would be in the range of less than 1 percent to 11 percent, although the committee members disagreed about whether the changes in development patterns and public policies necessary to achieve the high end of these findings are plausible. Increasing densities and mixing land uses may be more achievable in some metropolitan areas than others. The examples of Portland, Oregon, and Phoenix show that concerted public policies to control and steer growth and strategic infrastructure investment can reverse current trends toward low-density new development. Without a strong state or regional role in growth management, however, the replication of these outcomes in other metropolitan areas is unlikely. Metropolitan areas differ widely in their geographic characteristics, land area, historical growth patterns, economic conditions, and local zoning and land use controls.

Nevertheless, climate change is a problem that is likely to be more easily dealt with sooner rather than later, and more energy-efficient development patterns may have to be part of the strategy if the nation sets ambitious goals to move toward greater energy efficiency and reduced production of greenhouse gases. Compact, mixed-use development also promises additional benefits in the form of increased energy efficiency of residential buildings and reduced pressure for highway construction thanks to lower growth in VMT, among other benefits. Moreover, such development need not entail the demise of single-family housing and could, if implemented carefully, reduce housing costs while increasing housing choices. The committee, however, has not examined the other benefits and costs of compact, mixed-use development or how the trade-offs among these benefits and costs might

vary by the specific types of compact development policies and the contexts in which they are applied.

Given the uncertainties, it would be wise to proceed carefully, monitoring the results and taking into account new research as it adds to the understanding of the benefits and costs that various compact, mixed-use development policies generate at different places and times. But given that the full energy and emissions benefits of land use changes take decades to realize, and current development patterns take years to reverse, it is important to start implementing these policies soon.

RESEARCH RECOMMENDATION

The committee was often stymied in its effort to identify causal linkages between land development patterns and VMT and to quantify the magnitude of effects on energy use and CO_2 emissions. If land use measures are to become part of the nation's strategy to achieve greater energy efficiency and reduce CO_2 emissions, more precise estimates of the effects of such policies will be required.

Recommendation 2: More carefully designed studies of the effects of land use patterns and the form and location of more compact, mixed-use development on VMT, energy use, and CO_2 emissions should be conducted so that compact development can be implemented more effectively.

In particular, the committee identified five areas in which more research would be productive:

• **Longitudinal studies:** Federally funded empirical studies based on panel data would allow better control for socioeconomic characteristics and self-selection, thus helping to isolate the effects of different

types of development patterns on travel behavior. A lack of such controls was a major shortcoming of many of the studies reviewed for this study. Most studies that find a statistically significant correlation between the built environment and VMT are cross sectional. Cross-sectional analyses that are well specified, use disaggregate data from metropolitan areas, and carefully control for socioeconomic variables and other factors that affect residential location and travel choices are valuable. Strictly speaking, however, establishing causal relationships requires a longitudinal approach that typically involves collecting panel data and following households over time to determine how a change in the built environment can lead to a change in preferences and travel behavior in the long run. Such research is time-consuming and expensive—several decades of data are probably needed to observe changes in the built environment—hence the need for sustained federal research support to collect the appropriate panel data.

Appropriate longitudinal research designs include intervention studies where a change is made to an existing community (e.g., infill at higher densities) and studies that track residents or households that move from one type of community (e.g., driving-oriented suburban) to another (e.g., more walkable and bicycle-friendly). In both cases, the main objective is to determine how these changes affect the travel behavior of residents over time. Secondarily, however, these designs help sort out the role of (possibly evolving) attitudes in understanding the impacts of changes in the built environment on travel behavior. One may find, for example, that it is mainly people with a prior disposition toward changing their behavior (but who were "stuck" in the "wrong" neighborhood before, for other reasons) who will be affected by a change in their built environment. Alternatively, one may find that only certain types of people are amenable to changes in attitude (with corresponding changes in behavior) following a change in the built environment. For either type of study, it is important

to collect baseline data (preferably on attitudes as well as behavior), ideally before the change occurs.[1]

• **Studies of spatial trends within metropolitan areas:** Studies that track changes in metropolitan areas at finer levels of spatial detail over time (e.g., the evolution of employment centers and changing patterns of freight distribution) would help determine the need and opportunities for policy intervention. This study has focused primarily on residential locations in metropolitan areas and on personal travel because these are the focus of most studies and travel surveys. As noted in Chapters 2 and 3, however, travel patterns are also influenced by the locations of employment in a region (jobs–housing balance) and their concentration in employment centers outside the central business district, particularly the transit-supportive density of commercial development at the job end of the daily commute. Changes in the spatial distribution of employment within metropolitan areas and the development of new agglomerations or suburban employment centers are difficult to identify directly with current data sources.

The mechanisms by which more compact, mixed-use development could affect truck travel and logistics patterns in metropolitan areas are also poorly understood. A paper on the subject commissioned by

[1] A decidedly second-best approach is to ask respondents retrospectively to compare their characteristics before and after the change. The characteristics of interest would be travel behavior, attitudes (travel and residential location preferences), sociodemographic traits, and possibly self-reported built environment characteristics (e.g., perceptions of pedestrian-friendliness). However, retrospective measurements of attitudes are not credible because many people cannot reliably remember attitudes held at an earlier point in time. In the case of studying movers, this in turn would prevent being able to determine whether attitudes changed at all, and if they did, whether the attitudes changed before the move and possibly helped prompt it (meaning that those whose attitudes did not change first would be less receptive to moving) or after the move, perhaps partly because of the new built environment. (These two possibilities have quite different policy implications.) Especially for studies that track movers, it is important to control for self-selection by identifying those who move because they want to live in neighborhoods where they can drive less. Because moving is often associated with other life changes—marital status, job change, family size, and age of children—it is also important to take these factors into account in interpreting changes in travel behavior.

this committee found no relevant studies. More research is needed on topics such as the development of urban freight villages where workers live near jobs and commercial centers locate near airports. Simulations of different urban land use patterns and their effects on freight and commercial truck VMT could also be useful, including studies of specific urbanized areas.

• **Before-and-after studies of policy interventions to promote more compact, mixed-use development:** Careful evaluations of pioneering efforts to promote more compact, mixed-used development would help determine what works and what does not. As described in Chapter 4, the landmark California legislation, passed in September 2008, to curb greenhouse gas emissions statewide through land use controls as well as technological measures (e.g., changing automotive power trains and reducing the carbon content of fuel) is an obvious example. That legislation promotes sustainable community strategies, that is, more compact land use patterns coupled with transit investments, with the objective of reducing automobile trip lengths by bringing people closer to destinations and providing alternative transportation modes. State air pollution regulators have been charged to work with metropolitan planning organizations to develop emissions reduction targets. Statewide targets have already been set for 2020. Baseline data should be collected soon to support the conduct of before-and-after evaluations of the wide range of approaches California metropolitan areas are likely to enact in response to new regulations.

• **Studies of threshold population and employment densities to support alternatives to automobile travel:** The effectiveness of transit-oriented development, discussed in Chapter 3, depends heavily on well-designed development near well-located transit facilities. One of the seminal studies of the densities necessary to support transit (Pushkarev and Zupan 1977) is more than 30 years old. New studies of threshold densities and more data on appropriate catchment areas to support both rail and bus transit are needed to help guide transit infrastructure investments, as well as zoning and land use plans around

stations.[2] Similar threshold information and data are needed to determine what development densities and land use patterns are optimal to support walking and bicycling. In contrast to transit use, encouraging more pedestrian and bicycle travel appears to depend more on neighborhood land use design and the presence of local shopping (TRB 2005).

• **Studies of changing housing and travel preferences:** Studies of the housing preferences and travel patterns of an aging population, new immigrant groups, and young adults are needed to help determine whether future trends will differ from those of the past. Part of the difficulty of estimating reductions in VMT, energy use, and CO_2 emissions from more compact development stems from the uncertainties involved in forecasting the residential location preferences and travel patterns of the population by 2050. For example, the baby boom generation will begin to sell off its large supply of low-density suburban housing within the next decade, but how will they downsize—to smaller-lot single-family units in suburban retirement communities or to apartments in more central walkable locations? And to what extent will they drive less relative to preceding cohorts of retirees? Monitoring the location preferences and travel behavior of this large group is critical in identifying opportunities for more compact development and alternatives to automobile travel. Similar monitoring of the residential preferences and travel behavior of immigrant populations and young adults, about which little is known, is also important. Finally, it would be useful to collect more data on how residents trade off travel and housing costs in making residential location decisions, particularly in the effort to find affordable housing.

If ambitious goals to reduce energy use and CO_2 emissions necessitate changes in land development patterns, the research outlined above should provide a more precise understanding of future household

[2] Some more recent studies have addressed these issues (e.g., Frank and Pivo 1994; TRB 1995; Ker and Ginn 2003; Kittelson and Associates et al. 2003), but the field could benefit from a more comprehensive assessment.

preferences and travel behavior that could be shaped and supported by public policy interventions (e.g., growth management policies, zoning changes) and targeted infrastructure investments.

REFERENCES

Abbreviation

TRB Transportation Research Board

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Appendix A

Study on the Relationships Among Development Patterns, Vehicle Miles Traveled, and Energy Consumption

STATEMENT OF TASK

Consistent with the congressional request in Section 1827 of the Energy Policy Act of 2005 (see below), the study will consider

1. The correlation, if any, between land development patterns and increases in vehicle miles traveled (VMT);
2. Whether petroleum use in the transportation sector can be reduced through changes in the design of development patterns; and
3. The potential benefits of
   - Information and education programs for state and local officials (including planning officials) on the potential for energy savings through planning, design, development, and infrastructure decisions;[1]
   - Incorporation of location efficiency models in transportation infrastructure planning and investments; and
   - Transportation policies and strategies to help transportation planners manage the demand for and the number and length of vehicle trips, including trips that increase the viability of other means of travel.

In addition to the scope outlined above and with the agreement of the sponsor, the study will also assess the potential reduction in GHG/

[1]As noted in Chapter 1 of the report, the committee determined that evaluation of the potential benefits of information and education programs was not feasible through a scientific assessment, because the linkage between information and education programs and policy outcomes in this arena is too tenuous to establish reliably from the literature.

CO_2 emissions from more dense development patterns. The study will describe development patterns in the context of past and recent population and employment trends that affect residential and business location and travel in a region. In addition, it will consider future demographic changes and trends in immigration that may provide opportunities for development patterns that reduce VMT or for the use of alternative transport modes, as well as the political and institutional challenges (e.g., zoning) that likely would need to be addressed to take advantage of these opportunities. Finally, the study will offer estimates of the potential VMT reductions, energy savings, and GHG/CO_2 emissions reductions from various development scenarios and the likely time period over which they might occur.

The request for this study was made in Section 1827 of the Energy Policy Act:

> (a) *In General.*—The Secretary shall enter into an arrangement with the National Academy of Sciences under which the Academy shall conduct a study to assess the implications on energy use and efficiency of land development patterns in the United States. (b) *Scope.*—The study shall consider—(1) the correlation, if any, between land development patterns and increases in vehicle miles traveled; (2) whether petroleum use in the transportation sector can be reduced through changes in the design of development patterns; (3) the potential benefits of—(A) information and education programs for State and local officials (including planning officials) on the potential for energy savings through planning, design, development, and infrastructure decisions; (B) incorporation of location efficiency models in transportation infrastructure planning and investments; and (C) transportation policies and strategies to help transportation planners manage the demand for the number and length of vehicle trips, including trips that increase the viability of other means of travel; and (4) such other considerations relating to the study topic as the National Academy of Sciences finds appropriate.

Appendix B

Commissioned Papers and Authors

Bronzini, M. S. 2008. *Relationships Between Land Use and Freight and Commercial Truck Traffic in Metropolitan Areas.* Department of Civil, Environmental, and Infrastructure Engineering, George Mason University, Fairfax, Va.

Brownstone, D. 2008. *Key Relationships Between the Built Environment and VMT.* Department of Economics, University of California, Irvine.

Giuliano, G., A. Agarwal, and C. Redfearn. 2008. *Metropolitan Spatial Trends in Employment and Housing: Literature Review.* School of Policy, Planning, and Development, University of Southern California, Los Angeles.

Kockelman, K., M. Bomberg, M. Thompson, and C. Whitehead. 2009. *GHG Emissions Control Options: Opportunities for Conservation.* Department of Civil, Architectural, and Environmental Engineering, University of Texas at Austin.

Pitkin, J., and D. Myers. 2008. *U.S. Housing Trends: Generational Changes and the Outlook to 2050.* Analysis and Forecasting, Inc., and School of Policy, Planning, and Development, University of Southern California.

Note: To access the commissioned papers online, go to http://onlinepubs.trb.org/Onlinepubs/sr/sr298appendixb.pdf.

Appendix C

Analysis of Density Assumptions and Feasibility of Committee Scenarios

In this appendix, the plausibility of the committee's scenarios of increasing compact development by 2050 is analyzed through a comparison of the scenarios with trends in residential development. The purpose of this exercise is to understand how substantial the changes from the trends would have to be to achieve a doubling of density of either 25 percent (Scenario 1) or 75 percent (Scenario 2) of new residential development. Two different data sources are available with which to measure trends in development patterns, and there are different ways of measuring the density of residential development. The committee used both of the main data sources and two different ways of measuring density to test the assumptions behind its scenarios. The plausibility of the scenarios is tested by simply calculating how much change would be required from the trends to achieve the projected level of compact development by 2050 and then asking whether such change appears achievable. Conducting this analysis requires first a review of data sources and density measures. The second section uses the data sources and density measures to provide a summary of development trends. The third section presents the comparison between the trends and the scenarios, examines various ways in which the scenario target densities could be achieved, and provides a summary of the committee's conclusions.

DATA SOURCES AND DENSITY MEASURES

As discussed in Chapters 1 and 2, residential density is typically calculated as the number of persons, households, or dwelling units (DUs) divided by some unit of land area [e.g., acre, square mile (mi^2)].

Ideally, the denominator should be a measure of net residential acreage to closely match the land use, but such data are not readily available.[1]

Data Sources

The principal data source for the numerator of the density calculation is the decennial U.S. Census of Population and Housing. As discussed in Chapter 2, two national sources of data can be used to track changes in land use—the denominator—over time, each with its pros and cons. The first is the National Resources Inventory (NRI), collected by the Natural Resources Conservation Service of the U.S. Department of Agriculture. The NRI surveys hundreds and sometimes thousands of sample points in each U.S. county and reports, among other data, the acres of land in each of a series of land-cover categories. The NRI combines two of these categories, *urban and built-up areas* and *rural transportation land,* to derive an estimate of *developed land* (see Box C-1 for detailed definitions). For the purposes of this study, the NRI's land-cover data were aggregated to correspond to U.S. census designations for metropolitan areas as defined in 1999.[2] For the density calculation, the NRI's urban and built-up land category was used as the denominator—referred to in this appendix as urban acres—and intercensal estimates of housing units at the metropolitan level as the numerator.

The advantage of using the NRI data is that they provide true land-cover-based estimates of aggregate density, excluding land—even that within city limits—upon which development has not occurred. The NRI data also include urban and built-up land beyond census-defined "urbanized areas" where a very large share of recent development has

[1] Net residential acres include only residential land. Nonresidential land uses are excluded, as are local streets and parks (Downs 2004). Gross residential acres, by comparison, include all land within a geographic area, regardless of its uses. Unfortunately, there is no simple or well-established way to relate these two density measures because conditions vary widely from one location to another.

[2] The most recent year for which detailed inventory data from the NRI are available is 1997.

Box C-1

DEFINITION OF DEVELOPED LAND

Developed land: A combination of land cover/use categories, including urban and built-up areas and rural transportation land. *Urban and built-up areas* consist of residential, industrial, commercial, and institutional land; construction sites; public administrative sites; railroad yards; cemeteries; airports; golf courses; sanitary landfills; sewage treatment plants; water control structures and spillways; other land used for such purposes; small parks (less than 10 acres) within urban and built-up areas; and highways, railroads, and other transportation facilities if they are surrounded by urban areas. Included are tracts of less than 10 acres that do not meet the above definition but are completely surrounded by urban and built-up land. Two size categories are recognized in the NRI: (*a*) small built-up areas of 0.25 acre to 10 acres and (*b*) large urban and built-up areas of at least 10 acres. In 1997, both size categories accounted for 78 percent of total developed land.

Rural transportation land consists of all highways, roads, railroads, and associated rights-of-way outside urban and built-up areas, including private roads to farmsteads or ranch headquarters, logging roads, and other private roads, except field lanes. In 1997, this category accounted for the remaining 22 percent of total developed land.

Sources: NRCS 2002; NRCS 2003.

occurred, but at densities below the census's threshold for identifying urbanized blocks (Downs 2004). The main disadvantage of the NRI is that it does not provide accurate estimates of land cover below the county level. It therefore cannot be used either to describe the pattern of development within regions (e.g., the continuity of development) or to provide a fine-grained breakdown of development density within a metropolitan area (e.g., the share of housing built above 8 DUs per acre).

The alternative data source is the decennial U.S. Census of Population and Housing, which reports (among many other variables) the number of housing units and the amount of land area for the entire United States. The advantage of these data is that they have greater spatial accuracy than the NRI can provide for small areas, with reports available down to small blocks based on the 100 percent enumeration of housing units. They can therefore be used to classify small areas—including census tracts, as is done here—into a range of density categories for core-based statistical areas (CBSAs).[3,4] By doing so, it is possible to estimate the amount of housing in each metropolitan and micropolitan area that is built at what are presumably the lowest density levels, as

[3] Data on housing, measured at the census tract level, are drawn from the National Neighborhood Change Database, a special tabulation of data from the 1970 through 2000 censuses that allocates population and housing to the boundaries of the 2000 census. The 2000 census Geocorr application from the University of Missouri was used to collect data on the land area of all U.S. census tracts. Then, for each census tract, the number of housing units was divided by the total land area to yield an average (gross) density figure. Each tract in 1990 and 2000 was allocated to a density category (e.g., <1 acre, 1 to 1.9 acres), summing the number of housing units and land area in tracts in each density range.

[4] A CBSA is defined as a geographic entity consisting of a county or counties associated with at least one core (urbanized area or urban cluster) of at least 10,000 in population, plus adjacent counties having a high degree of social and economic integration with the core as measured through commuting ties with the counties containing the core (OMB 2000). Metropolitan and micropolitan statistical areas are the two categories of CBSAs. A metropolitan statistical area is a CBSA associated with at least one urbanized area that has a population of at least 50,000. A micropolitan statistical area is a CBSA associated with at least one urban cluster that has a population of at least 10,000 but less than 50,000. Both metropolitan and micropolitan statistical areas make up the central county or counties containing the core, plus adjacent outlying counties having a high degree of social and economic integration with the central county as measured through commuting.

well as at higher density levels.[5] The disadvantage of census tract–level data, however, is that such data are a gross measure of available land within census tracts (i.e., do not net out land uses for purposes other than residential development), thus in all likelihood underestimating the density of development in the most extensive tracts. For this reason the census data are referred to as gross acres in this appendix. Because of these pros and cons, both data sources are used here to examine density levels in light of recent development trends and how much change from current trends the committee's scenarios imply.

Density Measures

One other distinction should be made. Two methods of defining densities are possible. The conventional method (A) simply divides total DUs (or persons) by total land area to get the density of the average acre of land. The alternative method (B) is to weight developments of different densities by the number of DUs they contain to get the density of the average DU (see Box C-2 for an example). The differences and similarities between the two sources of land data and the two methods of calculating density are illustrated in Tables C-1 through C-3. Table C-1 provides a summary of changes in density patterns from 1987 to 1997 and 1990 to 2000 on the basis of density figures from the NRI and the census, respectively. Tables C-2 and C-3 provide more detail on each. Method A for calculating density can be used with both the NRI and the census measures of land area, but Method B is possible only with the more spatially detailed census data.

Densities are higher when calculated with land use data from the NRI than with those from the census, presumably because the urban acres reported by the NRI include less undeveloped land than do the gross acres reported by the census. For example, the average density

[5] It should be noted, however, that census tracts vary in size, becoming larger at metropolitan area boundaries.

Box C-2

TWO METHODS OF DEFINING DENSITIES: AN EXAMPLE

Two methods of defining densities are used in this study—one weights by population, the other by acres. A simple example illustrates the difference. Assume a hypothetical metropolitan area of 10 acres in which 5 people live. But 1 person lives on the periphery on a 9-acre lot, while the other 4 people live in the metropolitan center on ¼-acre lots.

The density to which the average acre is developed is 5 people/10 acres = 0.5 person per acre. However, the average person in the metropolitan area does not experience a density of 0.5 person per acre but something much higher. That average is (⅘ person × 4 persons per acre) + (⅕ person × 1 person/9 acres) = 3.20 + 0.02 = 3.22 persons per acre.

The two measures differ because the lot sizes vary within the metropolitan area and because the former measure weights the density by acres, while the latter weights the density by persons. If everyone in the hypothetical metropolitan area lived on a 2-acre lot, for example, the average density would be 0.5 person per acre under either approach.

Both approaches are legitimate. The population-weighted density measure provides a better sense of the density to which the average metropolitan resident is exposed rather than the density to which the average acre in the metropolitan area is developed. The former is more likely to reflect the local circumstances in which the typical person lives. In the hypothetical metropolitan area, for example, it would be misleading to say that the typical resident behaved as if he or she lived in a neighborhood of 0.5 person per acre when four-fifths of the population lives at 4 persons per acre.

TABLE C-1 **Summary of Recent Trends in the Density of Development Patterns Based on the NRI and the U.S. Census**

Based on NRI data, 1987–1997 (urban acres)	
Density of average acre (Method A)	
Density of average acre: 1987	1.86 DUs/acre
Density of average acre: 1997	1.66 DUs/acre
Density of average new acre developed: 1987–1997	0.99 DUs/acre
New development as a share of 1997 average	60 percent as dense as the average
Based on census data, 1990–2000 (gross acres)	
Density of average acre (Method A)	
Density of average acre: 1990	1.13 DUs/acre
Density of average acre: 2000	1.11 DUs/acre
Density of average new acre developed: 1990–2000	0.96 DUs/acre
New development as a share of 2000 average	86 percent as dense as the average
Density of average DU (Method B)	
Density of average DU: 1990	3.02 DUs/acre
Density of average DU: 2000	2.89 DUs/acre
Density of average new DU developed: 1900–2000	1.93 DUs/acre
New development as a share of 2000 average	67 percent as dense as the average

Note: See Tables C-2 and C-3 for details.

TABLE C-2 **Change in Dwelling Units by Urban Acre, 1987–1997, Based on NRI**

Year	Number of Dwelling Units (DUs)	Urban Acres[a]	DUs/Urban Acre
1987	75,307,500	40,543,000	1.86
1997	87,412,760	52,776,100	1.66

Density of average acre, new and existing development, 1997: 1.66
Density of average new acre developed, 1987–1997: 0.99[b]
Density of average new acre developed as a share of new and existing development in 2000: 60 percent[c]

[a]Note that urban acres correspond to counties within metropolitan statistical areas and consolidated metropolitan statistical areas as defined by the U.S. census prior to 2000. Thus, they are consistently defined for the 1987–1997 time frame used here.

[b]$0.99 = (87{,}412{,}760 - 75{,}307{,}500)/(52{,}776{,}100 - 40{,}543{,}000)$.

[c]$(0.99/1.66) \times 100 = 60$ percent.

TABLE C-3 **Change in Dwelling Units by Gross Density of Census Tract, 1990–2000, U.S. Census Data for Metropolitan and Micropolitan Areas**

Density of Average New Acre Developed (Method A)

Range—DU/gross acre	Average DU/gross acre	Average Number Persons/acre	Persons/square mile	Total Acres[a]			Percent of Total		Change 1990–2000
				1990	2000	Change: 1990–2000	1990	2000	Percentage
<1	0.6	1.50	960	62,779,845	72,862,155	10,082,310	75.5	75.7	76.5
1–1.9	1.4	3.50	2,240	10,050,874	11,914,815	1,863,941	12.1	12.4	14.1
2–2.9	2.4	6.00	3,840	4,713,174	5,494,329	781,155	5.7	5.7	5.9
3–3.9	3.5	8.75	5,600	2,460,770	2,739,475	278,705	3.0	2.8	2.1
4–7.9	5.5	13.75	8,800	2,296,743	2,443,374	146,631	2.8	2.5	1.1
8+	12.0	30.00	19,200	798,832	832,758	33,926	1.0	0.9	0.3
Total				83,100,239	96,286,906	13,186,668	100.0	100.0	100.0

Density of average acre, new and existing development, 2000
DU/gross acre: 1.11[b]
Persons/square mile: 1,776[c]

Density of average new acre developed: 1990–2000
DU/gross acre: 0.96[b]
Persons/square mile: 1,536[c]

Density of average new acre developed as a share of new and existing development in 2000: 86 percent

Density of Average New Dwelling Unit Developed (Method B)

Range—DU/gross acre	Average DU/gross acre	Persons/square mile[d]	Total Number of Dwelling Units			Percent of Total		Change 1990–2000
			1990	2000	Change: 1990–2000	1990	2000	Percentage
<1	0.6	960	37,667,907	43,717,293	6,049,386	40.1	41.0	47.5
1–1.9	1.4	2,240	14,071,224	15,680,741	2,609,517	15.0	15.6	20.5
2–2.9	2.4	3,840	11,311,617	13,186,390	1,874,773	12.0	12.4	14.7
3–3.9	3.5	5,600	8,612,696	9,588,164	975,468	9.2	9.0	7.7
4–7.9	5.5	8,800	12,632,087	13,438,555	806,468	13.5	12.6	6.3
8+	12.0	19,200	9,585,988	9,993,097	407,109	10.2	9.4	3.2
Total			93,881,519	106,604,240	12,722,721	100.0	100.0	100.0

Density of average DU, new and existing development, 2000
DU/gross acre: 2.89[e]
Persons/square mile: 4,624[f]

Density of average new DU developed: 1990–2000
DU/gross acre: 1.93[e]
Persons/square mile: 3,083[f]

Density of average new DU developed as a share of new and existing development in 2000: 67 percent[g]

[a]The number of acres is estimated by dividing the number of DUs in each density category (see above) by the aggregate density of that category. For example, in 2000, the average number of dwelling units <1 DU/acre was 43,717,293, and the aggregate density for that category was 0.6. Thus, the DUs in that category required a total of 72,862,155 gross acres.

[b]DU/average acre is calculated by dividing the total number of DUs in 2000 (see above) by the total number of acres in 2000.

[c]Persons/square mile is calculated by multiplying the average DU/gross acre by 2.5 persons/household by 640.

[d]Assumes 2.5 persons/household. There are 640 acres in 1 square mile.

[e]The average DU/gross acre is calculated by multiplying the percentage of DUs by the average DU/gross acre for each category and dividing the total by 100.

[f]The average number of persons/square mile is calculated by multiplying the average DU/gross acre by 2.5 persons/household by 640.

[g]$(1.93/2.89) \times 100 = 67$ percent.

(calculated by using Method A) was 1.66 DUs per urban acre in 1997 (when NRI data are used) but only 1.11 DUs per gross acre in 2000 (when census data are used). Densities are lower when calculated with Method A than with Method B because dense developments account for a smaller proportion of developed acres than of DUs. On the basis of the 2000 census data, for example, the average acre in a metropolitan or micropolitan area was developed to a density of 1.1 DUs per acre (Method A), while the average DU was located in a tract with a density of 2.89 DUs per acre (Method B). Densities are lower using Method A because in 2000 only 24 percent of the acres were in census tracts that were developed to densities of at least 1 DU per acre, while 59 percent of the DUs were in tracts with at least 1 DU per acre.

DEVELOPMENT TRENDS

The trends in density are similar regardless of which data source or method of calculating density one uses. Over the decade of the 1990s, average densities declined because the average density of new development was lower than the average density of the existing development.[6] On the basis of the NRI data, the density of the average acre (Method A) fell from 1.86 DUs per acre in 1987 to 1.66 DUs per acre in 1997 because the new development between 1987 and 1997 was built to a density of only 0.99 DUs per acre. On the basis of the census data, the density of the average acre fell less sharply, from 1.13 DUs per acre in 1990 to 1.11 in 2000 because the density of new development was 0.96 DUs per acre, only slightly less than the density of the existing development in 1990. The more detailed census data reveal some of the patterns behind these averages. The density of the average acre (Method A) declined between 1990 and 2000 because more than three-quarters (76.5 percent) of acres developed in this period were in tracts with

[6] The NRI data measure changes from 1987 to 1997, the most recent year for which such detailed data are available.

below 1 DU per gross acre (see Table C-3). The density of the average DU (Method B) declined slightly less sharply because only 47.5 percent of the new DUs developed during this period were built in census tracts with below 1 DU per gross acre and another 20 percent in tracts with between 1 and 2 DUs per gross acre. Less than one-third (31.9 percent) of new DUs were built in tracts having 2 or more DUs per gross acre (see Table C-3). In short, under either method, the majority of new development occurred in the lowest density categories.

COMPARISON OF TRENDS AND SCENARIOS

The committee's two scenarios assume that densities are doubled for 25 percent (Scenario 1) and 75 percent (Scenario 2) of all new residential housing built and replaced from 2000 to 2030 and to 2050. How difficult would it be to achieve these densities? The committee addressed this question by using the density data described previously to project current trends toward low-density development forward to 2050 and then comparing the higher densities assumed in the two scenarios with the baseline. Although the same calculations were conducted for 2030 as well, only the 2050 projections are presented here because the durability of the housing stock means that decades are required for the projected changes in development patterns to take hold.

The committee recognizes that the location of more compact development within a metropolitan area is likely to affect the reduction in vehicle miles traveled (VMT). In the committee's simple projections reported in Chapter 5, however, the VMT estimates are sensitive only to the average density of urban areas, not the spatial distribution of that density within urban areas. Thus while the committee uses the doubling of density in 25 or 75 percent of new development as a shorthand for describing its two scenarios, there are many ways in which an equivalent change in average urban density could be achieved. The committee assumed that much of the new development would occur at the urban fringe where developable land is available. But

some amount of infill is also likely, particularly in Scenario 2, which assumes that a large share (75 percent) of new development is at higher densities.

Calculations Using NRI Data

On the basis of the data from the NRI, which pick up lower densities at the urban fringe and leapfrogged development, if all new and replacement housing were to be built at the current average density of new development (the base case scenario)—0.99 DUs per urban acre—the average density of the housing stock would fall from 1.66 DUs per urban acre in 2000 to 1.29 to 1.39 DUs per urban acre by 2050 (see Table C-4). If 25 percent were developed at double the density (1.98 DUs per urban acre) (Scenario 1), average densities would decline from 1.66 to only between 1.43 and 1.49 DUs per urban acre, a 7 to 11 percent increase from the 2050 baseline. Average densities still decline in this scenario because even with the doubling of density for 25 percent of new development, the average density of new development from 2000 to 2050 (1.24 DUs per urban acre)[7] is still below the average density of existing development in 2000 (1.66 DUs per urban acre).

In the upper-bound scenario (Scenario 2), which assumes 75 percent of new and replacement housing is built at these higher densities, the average density in 2050 would actually increase from the 2000 average of 1.66 DUs per urban acre to between 1.69 and 1.7 DUs per urban acre, a 22 to 32 percent increase from the 2050 baseline (see Table C-4). Average densities would be higher in 2050 than they were in 2000 because the doubling of density for 75 percent of new development would increase the average density of new development (1.73 DUs per urban acre)[8] above the average density of existing development in 2000 (1.66 DUs per urban acre).

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[7] $(1.98 \times 0.25) + (0.99 \times 0.75) = 1.24$.
[8] $(1.98 \times 0.75) + (0.99 \times 0.25) = 1.73$.

TABLE C-4 **Changes in Density to Meet Targets of Committee Scenarios by 2050**

	NRI Data				Census Data (Method B Only)[a]		
	Number of Units (millions)	Density Level (DU/urban acre)	Percent Change from Base Case		Number of Units (millions)	Density Level (DU/gross acre)	Percent Change from Base Case
Base case				**Base case**			
Original housing stock in 2050	86.64–90.35	1.66		Original housing stock in 2050	86.64–90.35	2.9	
New and replacement units	62.44–105.37	0.99		New and replacement units	62.44–105.37	1.9	
Total in 2050	152.79–192.01[b]	1.29–1.39	—	Total in 2050	152.79–192.01[b]	2.35–2.49	—
Scenario 1 (25 percent)				**Scenario 1 (25 percent)**			
Original housing stock in 2050	86.64–90.35	1.66		Original housing stock in 2050	86.64–90.35	2.9	
New, more compact	15.61–26.34	1.98[c]		New, more compact	15.61–26.34	3.8[c]	
New, not more compact	46.83–79.02	0.99		New, not more compact	46.83–79.02	1.9	
Total in 2050	152.79–192.01	1.43–1.49	7.2–10.8	Total in 2050	152.79–192.01	2.61–2.69	8–11.1

(continued on next page)

TABLE C-4 *(continued)* **Changes in Density to Meet Targets of Committee Scenarios by 2050**

	NRI Data				Census Data (Method B Only)[a]		
	Number of Units (millions)	Density Level (DU/urban acre)	Percent Change from Base Case		Number of Units (millions)	Density Level (DU/gross acre)	Percent Change from Base Case
Scenario 2 (75 percent)				**Scenario 2 (75 percent)**			
Original housing stock in 2050	86.64–90.35	1.66		Original housing stock in 2050	86.64–90.35	2.9	
New, more compact	46.83–79.02	1.98[c]		New, more compact	46.83–79.02	3.8[c]	
New, not more compact	15.61–26.34	0.99		New, not more compact	15.61–26.34	1.9	
Total in 2050	152.79–192.01	1.69–1.70	21.6–31.8	Total in 2050	152.79–192.01	3.07–3.13	23.3–33.2

Note: Scenario 1 assumes 25 percent of all new and replacement housing is built more compactly. Scenario 2 assumes 75 percent of all new and replacement housing is built more compactly.

[a]Only Method B was selected to illustrate the scenario results using census data because the population-weighted density measure better reflects how the average resident experiences density (see Box C-2).

[b]Assumes the same range of housing units projected in Chapter 4, Table 4-3.

[c]Assumes density of new development is doubled ($0.99 \times 2 = 1.98$ for NRI data; $1.9 \times 2 = 3.8$ for census data).

Calculations Using Census Data

According to the census data, if all new and replacement housing were to be built at the current average density of new development (the base case scenario)—1.9 DUs per gross acre—the average density of the housing stock would fall from 2.9 DUs per gross acre in 2000 to 2.35 to 2.49 DUs per gross acre by 2050 (see Table C-4). If 25 percent were developed at double the density (3.8 DUs per gross acre) (Scenario 1), the average density of new development (2.38 DUs per gross acre)[9] would still be slightly below the density of the development that existed in 2000. As a result, average densities would fall slightly from 2.9 DUs per gross acre in 2000 to between 2.61 and 2.69 DUs per gross acre in 2050, an 8 to 11 percent increase from the 2050 baseline.

In the upper-bound scenario (Scenario 2), which assumes 75 percent of new and replacement housing is built at these higher densities, new development is denser (3.33 DUs per acre)[10] than existing development, so average density increases from 2.9 DUs per gross acre in 2000 to between 3.07 and 3.13 DUs per gross acre, a 23 to 33 percent increase from the 2050 baseline. As with the NRI data, the census data show that doubling density in 25 percent of new development is equivalent to assuming that the average new development is slightly less dense than the average existing development. In contrast, doubling density in 75 percent of new development is comparable with assuming that the average new development is moderately more dense than the average existing development.

Seen in this way, both scenarios are substantial departures from existing patterns in that new development has historically been significantly less dense than existing development. In some metropolitan areas, however, even a growing area such as Phoenix, densities for new development are similar to or slightly higher than densities for existing development, so the 25 percent doubling scenario is possible. But as

[9] $(3.8 \times 0.25) + (1.9 \times 0.75) = 2.38$.
[10] $(3.8 \times 0.75) + (1.9 \times 0.25) = 3.33$.

discussed in Chapter 5, Phoenix has unusual characteristics (e.g., bounded by desert, limits on development), so that the 25 percent doubling scenario for all metropolitan areas would require substantial policy intervention. A 75 percent doubling scenario would require even greater policy intervention and public acceptance because it assumes that new developments are denser than existing developments, and, if compared with a continuing trend of new, low-density development to 2050, significantly more dense than the 2050 baseline.

The more detailed census data allow a test of the plausibility of the two scenarios by showing how much the different density categories would have to change to reach the target densities implicit in the scenarios. Meeting the target of Scenario 1—doubling density in 25 percent of new development—could be achieved (or nearly so) in a variety of ways. For example, one way would be to eliminate half of all new development in tracts in the lowest density category (less than 1 DU per gross acre), substantially reducing development in many urban fringe areas where lots are very large (see Strategy B in Table C-5). Alternatively, one could follow an infill strategy and double the densities in tracts with an average of 4 or more DUs per acre (see Strategy C in Table C-5).

Reaching the target of Scenario 2—doubling density in 75 percent of new development—would require much more drastic measures, for example, eliminating all new DUs in tracts where development currently averages less than 1 DU per acre (see Strategy A in Table C-5) or doubling the density of tracts with an average of 3 or more DUs per acre, which would be a much more aggressive infill scenario (see Strategy D in Table C-5). Note that the comparisons made here are based on measures of the density of the average DU (Method B).

Using an alternative way of measuring density (Method A)—by the density of the average developed acre rather than the density of the average DU—changes somewhat the ease (or difficulty) of the various ways of achieving the target densities. For example, infill scenarios are less effective. Even the aggressive infill scenario—doubling the density of tracts with 3 or more DUs per acre—does not achieve either the

TABLE C-5 **Alternative Strategies for Achieving Higher Densities for New Development Implied in Committee Scenario Targets**

Baseline

DUs/Acre (range)	Average DU/Acre	Change in DUs, 1990–2000	Percent of Total	Change in Acres, 1990–2000	Percent of Total
<1	0.6	6,049,386	47.5	10,082,310	76.5
1–1.9	1.4	2,609,517	20.5	1,863,941	14.1
2–2.9	2.4	1,874,773	14.7	781,155	5.9
3–3.9	3.5	975,468	7.7	278,705	2.1
4–7.9	5.5	806,468	6.3	146,631	1.1
8+	12.0	407,109	3.2	33,926	0.3
Total		12,722,721	100.0	13,186,668	100.0

Strategy A: Eliminate All New DUs in Lowest-Density Tracts, Redistribute Proportionately

DUs/Acre (range)	Change in DUs	Percent of Total	Change in Acres	Percent of Total
<1	0	0	0	0
1–1.9	4,975,047	39	3,553,605	60
2–2.9	3,574,257	28	1,489,274	25
3–3.9	1,859,731	15	531,352	9
4–7.9	1,537,532	12	279,551	5
8+	776,154	6	64,679	1
Total	12,722,721	100	5,918,461	100

	DUs/Acre	Persons/Acre[a]	Persons/Square Mile[b]
Density of average acre (Method A)			
Baseline	0.96	2.40	1,536
Strategy A	2.15	5.37	3,440
Percent change	129	129	129
25 percent higher density target	1.2	3.0	1,920
75 percent higher density target	1.68	4.2	2,688
Density of average DU (Method B)			
Baseline	1.93	4.82	3,085
Strategy A	3.13	7.82	5,008
Percent change	62	62	62
25 percent higher density target	2.41	6.02	3,856
75 percent higher density target	3.38	8.43	5,399

(continued on next page)

TABLE C-5 *(continued)* **Alternative Strategies for Achieving Higher Densities for New Development Implied in Committee Scenario Targets**

Strategy B: Reduce by One-Half New DUs in Lowest-Density Tracts, Redistribute Proportionately

DUs/Acre (range)	Change in DUs	Percent of Total	Change in Acres	Percent of Total
<1	3,024,693	24	5,042,155	53
1–1.9	3,792,282	30	2,708,773	28
2–2.9	2,724,515	21	1,135,215	12
3–3.9	1,417,599	11	405,028	4
4–7.9	1,172,000	9	213,091	2
8+	591,631	5	49,303	1
Total	12,722,721	100	9,552,564	100

	DUs/Acre	Persons/Acre[a]	Persons/Square Mile[b]
Density of average acre (Method A)			
Baseline	0.96	2.40	1,536
Strategy B	1.33	3.33	2,128
Percent change	38	38	38
25 percent higher density target	1.2	3.0	1,920
75 percent higher density target	1.68	4.2	2,688
Density of average DU (Method B)			
Baseline	1.93	4.82	3,085
Strategy B	2.39	5.97	3,721
Percent change	24	24	24
25 percent higher density target	2.41	6.02	3,856
75 percent higher density target	3.38	8.43	5,399

Strategy C: Double New DUs in Highest-Density Tracts (>4 DU/Acre), Redistribute Proportionately

DUs/Acre (range)	Change in DUs	Percent of Total	Change in Acres	Percent of Total
<1	5,411,511	43	9,019,185	75
1–1.9	2,334,358	18	1,667,398	14
2–2.9	1,667,088	13	698,787	6
3–3.9	872,610	7	249,317	2
4–7.9	1,612,936	13	293,261	2
8+	814,218	6	67,852	1
Total	12,722,721	100	11,995,800	100

	DUs/Acre	Persons/Acre[a]	Persons/Square Mile[b]
Density of average acre (Method A)			
Baseline	0.96	2.40	1,536
Strategy C	1.06	2.65	1,696
Percent change	10	10	10
25 percent higher density target	1.2	3.0	1,920
75 percent higher density target	1.68	4.2	2,688
Density of average DU (Method B)			
Baseline	1.93	4.82	3,085
Strategy C	2.28	5.70	3,648
Percent change	18	18	18
25 percent higher density target	2.41	6.02	3,856
75 percent higher density target	3.38	8.43	5,399

Strategy D: Double DUs in Tracts Averaging >3 DUs/Acre, Redistribute Proportionately

DUs/Acre (range)	Change in DUs	Percent of Total	Change in Acres	Percent of Total
<1	4,792,239	38	7,987,065	73
1–1.9	2,067,223	16	1,476,588	13
2–2.9	1,485,169	12	618,820	6
3–3.9	1,950,936	15	557,410	5
4–7.9	1,612,936	13	293,261	3
8+	814,218	6	67,852	1
Total	12,722,721	100	11, 000,996	100

	DUs/Acre	Persons/Acre[a]	Persons/Square Mile[b]
Density of average acre (Method A)			
Baseline	0.96	2.40	1,536
Strategy D	1.16	2.90	1,856
Percent change	21	21	21
25 percent higher density target	1.2	3.0	1,920
75 percent higher density target	1.68	4.2	2,688
Density of average DU (Method B)			
Baseline	1.93	4.82	3,085
Strategy D	2.51	6.27	4,016
Percent change	30	30	30
25 percent higher density target	2.41	6.02	3,856
75 percent higher density target	3.38	8.43	5,399

[a]Persons/acre equals number of DUs/acre times 2.5 persons/household.

[b]Persons/square mile equals persons/acre multiplied by 640 acres.

25 percent or the 75 percent target because doing so prevents much less land from being used for development than curtailing development in the lowest-density tracts where the average acres per DU are largest. Pursuing the latter strategy—eliminating all new development in tracts with densities below 1 DU per acre—results in achieving not only the 25 percent but also the 75 percent target. The reason is the large amount of acreage in the below-1-acre category (see the baseline in Table C-5). Because such large lots represented approximately 75 percent of the residential land developed between 1990 and 2000, this strategy would require an almost complete reversal of recent development patterns. Given the large amount of land available for development and lax land use policies in more rural counties, achieving such a goal would require extraordinary changes in land use policy and market trends.

The analyses provided here suggest that both the 25 and the 75 percent targets represent a significant departure from recent trends, which have involved lower densities than the average for new development over the decade of the 1990s and for decades before that. Doubling the density of 25 percent of new development by 2050 will not raise densities above the current average and will raise them only about 7 to 11 percent above the 2050 baseline. In addition, precedents for such changes in density can be found even in growing areas such as Phoenix. Nevertheless, Phoenix is not typical of many growing metropolitan areas, and meeting the 25 percent target will require a trend change. Doubling the density of 75 percent of new development by 2050 will require densities above those of existing developments, significantly above (approximately 20 to 33 percent) the 2050 baseline.

The committee disagreed about the feasibility of doubling the density of 75 percent of new development, even by 2050. Those members who thought it was possible questioned whether densities will keep declining. The combination of macroeconomic trends—likely higher energy prices and carbon taxes—in combination with growing public support for strategic infill, investments in transit, and higher densities

along rail corridors, could result in considerably higher densities by 2050. Other members believed that the substantial infill or curbing of large-lot development at the urban fringe, or both, implied in achieving the targets in Scenario 2 would require such a significant departure from current housing trends, land use policies of jurisdictions on the urban fringe, and public preferences that they would be unrealistic absent a strong state or regional role in growth management.

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Abbreviations

NRCS	Natural Resources Conservation Service
OMB	Office of Management and Budget

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Study Committee Biographical Information

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Dianne R. Brake is President of PlanSmart NJ in Trenton, New Jersey. With degrees in sociology and planning, she was hired in 1985 to run the Regional Forum, a multidisciplinary public–private partnership that developed a 10-point action plan for central New Jersey. In 1990 she was made President of PlanSmart NJ, and with the board, she has presided over many organizational changes, such as the growth from a regional to a statewide organization and the creation of many innovative planning tools and strategies designed to improve the results of land use plans, regulations, and infrastructure investments. Ms. Brake has developed in-depth knowledge of land use planning in central New Jersey, as well as in statewide transportation, housing, and state plan

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