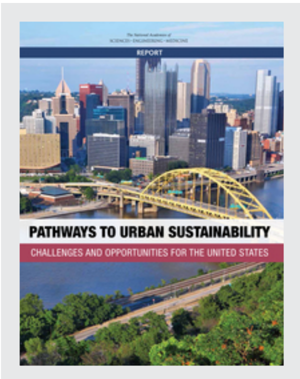

Pathways to Urban Sustainability: Challenges and Opportunities for the United States

DETAILS

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PATHWAYS TO URBAN SUSTAINABILITY

CHALLENGES AND OPPORTUNITIES FOR THE UNITED STATES

Committee on Pathways to Urban Sustainability: Challenges and Opportunities

Science and Technology for Sustainability Program

Policy and Global Affairs

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Preface

More than 80 percent of the U.S. population now resides in urban areas, a number that is projected to continue to increase. Cities and their suburbs account for a proportion of the U.S. economy far higher than their share of population. Urban areas have been associated with several environmental and social inequities, such as disproportionate levels of air and water pollution, loss of biodiversity, increased rates of poverty, and high rates of wealth inequity. Despite these problems, urban centers may have the potential to be more sustainable than suburban or rural areas. Through smart land-use planning, they can locally greatly reduce environmental impacts with lower per capita energy and water use. While there is no "cookie-cutter" approach to urban sustainability, the innovative methods now being developed in some cities may be transferable to others. Thus, it is valuable to assess some of the most innovative practices being implemented in specific metropolitan regions to determine whether and how they might be adapted and applied in other regions. Significant opportunities exist to strengthen collaborative learning across metropolitan regions. However, it must be realized that, from a whole system perspective that includes the biosphere with humans as part of it, this may not be the case. There are constraints that will strongly impact how urban areas can be in striving for sustainability.

This report builds on previous work by the National Academies of Sciences, Engineering, and Medicine's Science and Technology for Sustainability (STS) Program in this quickly growing field. In 2009, STS hosted a public meeting to engage federal, academic, and private researchers focusing on emerging research on urban systems, and on how human and environment interactions and the interplay among energy, water, transportation, and other systems could help decision makers address complex challenges. Following the 2009 meeting, STS convened three place-based urban sustainability workshops—in Atlanta, Georgia; Houston, Texas; and Portland, Oregon. These public workshops gathered local, state, and federal officials, academics, and key stakeholders to examine how challenges due to continued growth in each region can be addressed within the context of sustainability.

The regional workshops highlighted the complex challenges American cities face in trying to maximize environmental, social, and economic benefits and emphasized the need for providing a collective guide to inform how cities and regions can become more successful in implementing sustainable strategies. To address this need, an ad hoc committee from government, academia, and the philanthropic community was convened in December 2014. Brief biographies of the individual committee members are provided in Appendix A. The committee was charged to produce a paradigm that incorporates the social, economic, and environmental systems that exist in metropolitan regions in the United States, which are critical in the transition to sustainable metropolitan regions.

This paradigm could then serve as a blueprint for other regions with similar barriers to and opportunities for sustainable development and redevelopment.

In this report, Chapter 1 describes the challenge that the committee addressed. Chapter 2 discusses detailed urban sustainability indicators and metrics, Chapter 3 examines principles of urban sustainability and offers a roadmap for decision making, Chapter 4 explores the city profiles and the lessons they provide, and Chapter 5 provides a vision for improved responses to urban sustainability.

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Academies of Sciences, Engineering, and Medicine's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its 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 review comments and draft manuscript remain confidential to protect the integrity of the process. We wish to thank the following individuals for their review of this report: David Allen, University of Texas, Austin; John Crittenden, Georgia Institute of Technology; Christopher Crockett, Philadelphia Water Department; Ruth DeFries, Columbia University; Janet Hering, Swiss Federal Institute of Aquatic Science & Technology; Andrew Hutson; Environmental Defense Fund; Danya Keene, Yale University; Kevin Krizek, University of Colorado, Boulder; Matt Petersen, City of Los Angeles, California; Kenneth Reifsnider, University of Texas, Arlington; Jerry Schubel, Aquarium of the Pacific; William Solecki, Hunter College of the City University of New York; and Alison Taylor, Siemens Corporation.

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations, nor did they see the final draft of the report before its release. The review of this report was overseen by Richard Wright (Retired), National Institute of Standards and Technology, and Michael Kavanaugh, Geosyntec Consultants. Appointed by the National Academies, they were responsible for making certain that an independent examination of this 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.

The report would not have been possible without the sponsors of this study, including the U.S. Environmental Protection Agency, the John D. and Catherine T. MacArthur Foundation, and the National Aeronautics and Space Administration.

The committee gratefully acknowledges the following individuals for making presentations to the committee: Alan Hecht, U.S. Environmental Protection Agency; Mijo Vodopic, John D. and Catherine T. MacArthur Foundation; Elisabeth Larson, National Aeronautics and Space Administration; Matt Petersen, City of Los Angeles; Nancy Sutley, Los Angeles Department of Water and Power; Martin Wachs, University of California, Los Angeles; Jonathan Parfrey, Climate Resolve; Ted Bardacke, City of Los Angeles; Christine Margiotta, United Way of Greater Los Angeles; Mark Gold, University of California, Los Angeles; Jerry R. Schubel, Aquarium of the Pacific; Kevin Wattier, Long Beach Water Department; Heather Tomley, Port of Long Beach; Brian Ulaszewski, City Fabrick; Mayor Robert Garcia, City of Long Beach; Dan Sperling, University of California, Davis; John Mahoney, OpTerra Energy Services; James Brown, University of New Mexico; Erik Schmidt, City of Chattanooga; Harold DePriest, Electric Power Board; Blythe Bailey, Chattanooga Department of Transportation; David Crockett, formerly City of Chattanooga; Michael Walton, Green Spaces; Charlie Catlett, Argonne National Laboratory; Donna Williams, Chattanooga Office of Economic and Community Development; Benic Clark, Lyndhurst Foundation; Rick Wood, The Trust for Public Land; Lisa Darger, University of Tennessee; Stephen A. Hammer, The World Bank Group; Philip Enquist, Oak Ridge National Laboratory; and Garrett Fitzgerald, Urban Sustainability Directors Network. The information provided during the meetings is used throughout this report and provided important perspectives that were utilized in this report's findings and conclusions. The committee would also like to recognize Lee Huang, Econsult Solutions, Inc.; Robert A. Joseph, graduate student researcher at New York University; Lindsay Alexis Voirin, graduate student researcher at New York University; Daniel D'Arcy, graduate student researcher at Georgia Institute of Technology; Lu Wang, graduate student researcher at Georgia Institute of Technology; Melissa Kopf, City of Cedar Rapids; Debora Loader, City of Flint; and Brent Heard, University of Michigan, who provided valuable assistance that informed committee deliberations.

On behalf of the committee, I want to express our thanks and appreciation to Jerry Miller, director of the Science and Technology for Sustainability Program; Michael Dorsey, senior program officer; Dominic Brose, program officer; Yasmin Romitti, research assistant; Emi Kameyama, program associate; Jennifer Saunders, senior program officer (through October 2015); Mark Lange, program officer (through January 2016); and Ryan Anderson, Christine Mirzayan Science and Technology Policy Graduate Fellow (January to April 2016) for the time and effort they put into assembling the committee, planning the meetings, and organizing the report. I also thank the Academies staff, including Adriana Courembis, financial officer; Marilyn Baker, director for report and communication; Rita Johnson, senior editor; Karen Autrey, report review associate; Kara Laney, senior program officer; and Richard Bissell, executive director of Policy and Global Affairs, for their support and assistance with study activities.

Finally, I thank especially the members of the committee for their tireless efforts throughout the development of this report.

Linda Katehi, Chair
Committee on Pathways to Urban Sustainability:
Challenges and Opportunities

Contents

Abbreviations and Acronyms

ACS	American Community Survey
APTA	American Public Transportation Association
AQI	Air Quality Index
CAA	Clean Air Act
CARB	California Air Resources Board
CBSA	Core Based Statistical Area
COP	United Nations Conference of Parties
CSP	Grand Rapids Area Community Sustainability Partnership
CUSP	Center for Urban Science and Progress
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
DSM	Demand Side Management
EAC	Chattanooga Early Action Compact
EIA	Energy Information Administration
EIU	Economic Intelligence Unit
EPA	U.S. Environmental Protection Agency
EPB	Chattanooga Electric Power Board
EPD	Chattanooga Environmental Protection Division
EPR	Extended Producer Responsibility
FARS	Fatality Analysis Reporting System
FEMA	Federal Emergency Management Agency
FHWA	Federal Highway Administration
F.I.R.E.	Financial, Insurance and Real Estate
GCP	Gross city product

GDP	Gross domestic product
GFN	Global Footprint Network
GHG	Greenhouse gas
GSI	Green Stormwater Infrastructure
HAP	Hazardous air pollutant
HOT	High Occupancy/Toll
ICT	Information and communication technologies
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
LACMTA	Los Angeles County Metropolitan Transportation Authority
LADWP	Los Angeles Department of Water and Power
LED	Light-emitting diode
LEED	Leadership in Energy & Environmental Design
MAC	New York State Municipal Assistance Corporation
MIT	Massachusetts Institute of Technology
MMR	Mayor's Management Report
MSA	Metropolitan Statistical Area
MTA	New York Metropolitan Transportation Authority
MTCO2e	Metric tonnes of carbon dioxide equivalent
NAACP	National Association for the Advancement of Colored People
NAAQS	National Ambient Air Quality Standards
NASA	National Aeronautics and Space Administration
NCA	National Climate Assessment
NCDC	National Climatic Data Center
NGO	Nongovernmental organization
NHTSA	National Highway Traffic Safety Administration
NOAA	National Oceanic and Atmospheric Administration
NRC	National Research Council
NYCCAS	New York City Community Air Survey
NYC DEP	New York City Department of Environmental Protection
NYMTC	New York Metropolitan Transportation Council
NYS DEC	New York State Department of Environmental Conservation
NYS ISO	New York State Independent System Operator
PANYNJ	Port Authority of New York and New Jersey
PEV	Plug-in electric vehicle
PM	Particulate matter
RPS	Renewable Portfolio Standard
SAIDI	System Average Interruption Duration Index
SCADA	Supervisory control and data acquisition
SDG	Sustainable Development Goal
SEPTA	Southeastern Pennsylvania Transportation Authority
SLR	Sea-level rise

SO_2	Sulfur dioxide
S&P	Standard & Poor's
STAR	Sustainability Tools for Assessing and Rating Communities
TDM	Transportation demand management
TEU	Twenty-foot Equivalent Units
TMDL	Total maximum daily load
TSM	Transportation system management
TVA	Tennessee Valley Authority
UN	United Nations
UN-Habitat	United Nations Human Settlements Programme
USDN	Urban Sustainability Directors Network
USGCRP	U.S. Global Change Research Program
USGS	U.S. Geological Survey
VMT	Vehicle miles of travel

Summary

Cities have experienced an unprecedented rate of growth in the past decade. More than 50 percent of the world's population lives in urban areas, with the U.S. percentage at 80 percent. Cities have captured more than 80 percent of the globe's economic activity and offered social mobility and economic prosperity to millions by clustering creative, innovative, and educated individuals and organizations. Clustering populations, however, can compound both positive and negative conditions, with many modern urban areas experiencing growing inequality, debility, and environmental degradation.

The spread and continued growth of urban areas presents a number of concerns for a sustainable future, particularly if cities cannot adequately address the rise of poverty, hunger, resource consumption, and biodiversity loss in their borders. Cities already place a large stress on the planet's resources by emitting more than 75 percent of the world's greenhouse gas (GHG) emissions, though on a per capita basis the emissions on cities tend to be lower (Dodman, 2009). In addition, a large proportion of the world's population with unmet needs lives in urban areas. Thus, any discussion of sustainable development should center on cities and how to capitalize on their positive energy and innate diversity in forging new pathways toward urban sustainability.

Urban sustainability practitioners and scholars regularly develop and apply a variety of innovative methods. Assessing the spectrum of new practices that have been implemented in specific metropolitan regions provides insight into whether and how other urban areas might adapt and apply these methods. Applying such new methods and practices additionally calls for an understanding that cities exist within the larger contexts of the planet's finite resources; thus, achieving urban sustainability requires recognizing interconnections among places and the associated impacts of actions.

As such, this study committee was tasked with examining various areas within metropolitan regions to understand how sustainability practices could contribute to the development, growth, and regeneration of major metropolitan regions in the United States. The committee was also tasked with the aim of providing a paradigm incorporating the social, economic, and environmental systems within the urban context that are critical in the transition to sustainable metropolitan regions which could then serve as a blueprint for other regions with similar sustainability challenges and opportunities. In addition to the development of a paradigm incorporating the critical systems needed for sustainable development in metropolitan regions, the committee's task included a focus on

- How national, regional, and local actors are approaching sustainability;
- How stakeholders can better integrate science, technology, and research into catalyzing and supporting sustainability initiatives; and

- The commonalities, strengths, and gaps in knowledge among rating systems that assess the sustainability of metropolitan regions.

Finally, the committee's task included the organization of a series of public data-gathering meetings to examine issues relating to urban sustainability, culminating in findings and recommendations that describe and assess

- The linkages among research and development, hard and soft infrastructure, and innovative technology for sustainability in metropolitan regions;
- The countervailing factors that inhibit or reduce regional sustainability and resilience;
- Future economic drivers, as well as the assets and barriers to sustainable development and redevelopment; and
- How federal, state, and local agency and private-sector efforts and partnerships can complement and/or leverage the efforts of key stakeholders.

Intended as a comparative illustration of the types of urban sustainability pathways and subsequent lessons learned existing in urban areas, this study examines specific examples that cut across geographies and scales and that feature a range of urban sustainability challenges and opportunities for collaborative learning across metropolitan regions. The study committee chose nine cities: Los Angeles, California; New York City, New York; Philadelphia, Pennsylvania; Pittsburgh, Pennsylvania; Grand Rapids, Michigan; Flint, Michigan; Cedar Rapids, Iowa; Chattanooga, Tennessee; and Vancouver, Canada. These cities were selected to represent a variety of metropolitan regions, with consideration given to city size, proximity to coastal or other waterways, susceptibility to hazards, primary industry, water scarcity, energy intensity and reliability, vertical density, transportation system performance, and social equity issues. The committee chose two cities, Los Angeles and Chattanooga, as the sites for its public data-gathering meetings due to their diverse characteristics in terms of size, geography, and varied sustainability challenges, such as water and air quality.

THE CHALLENGE OF URBAN SUSTAINABILITY

This report first describes the concept and challenges of the pathways to becoming a "sustainable city." Cities concentrate people, investment, and resources, which, despite the potential for positive consequences in the form of creativity, economic development, and social and community well-being, also can be associated with negative consequences for air and water quality, ecosystem viability, poverty rates, and high rates of wealth inequity. Sustainability of urban areas therefore encompasses a range of interconnected environmental, economic, and social issues. Additionally, sustainability of urban areas also requires the adoption of a geographic scope that incorporates those ecosystems and people existing outside of immediate urban areas, such as hinterlands and rural regions, which are affected by urban consumption and demands.

The committee defines urban sustainability as the process by which the measurable improvement of near- and long-term human well-being can be achieved through actions across environmental (resource consumption with environmental impact), economic (resource use efficiency and economic return), and social (social well-being and health) dimensions. Measuring the dimensions of urban sustainability has proven as challenging as defining the concept. This report provides a meta-review of a set of indicators and metrics that the committee selected from a large pool of publicly available data. The goal is to select a subset of urban sustainability indicators that help identify problems and pressures to provide useful information for policy intervention by urban communities. The selected indicators represent urban sustainability's three dimensions of environment, economy, and society (see Figure 2-1), including air quality, water quality, ecological footprints, financial health, infrastructure, education, and community health. These indicators do not operate in isolation; rather, they operate synergistically. Additionally, a fourth dimension of metrics is put forward to consider institutional capacities and governance issues as an important area for future research.

A ROADMAP TO URBAN SUSTAINABILITY

With their convergence of people and resources, cities are not sustainable without the support of ecosystem services and products from nonurban areas, including those long distances away. Because each city is also linked into the global system of cities, actions taken in one place will likely have effects in other places. The sustainability of a city cannot be considered in isolation from the planet's finite resources or from the city's interconnections with other places. As such, pathways toward urban sustainability must adopt a multiscale approach that highlights resource dependencies and cities' interlinkages. Within this context, this study presents four main principles, as heuristics, to promote urban sustainability:

- **Principle 1 – The planet has biophysical limits**
  Urban activities use resources and produce byproducts such as waste and GHG emissions which drive multiple types of global change, such as resource depletion, land-use change, habitat and biodiversity loss, and global climate change. What may appear to be sustainable locally, at the metropolitan scale, belies the total planetary-level environmental or social consequences of local actions. Thus, strategies aimed at urban sustainability must pay heed to biophysical limits at the planetary scale. One way to do this is to try to reduce the city's metabolism, which is constituted by the material and energy that flows in and out of cities. A city cannot reduce its footprint by exporting carbon-intensive activities to other areas.
- **Principle 2 – Human and natural systems are tightly intertwined and come together in cities**
  Healthy people, healthy biophysical environments, and healthy human-environment interactions are synergistic relationships that underpin the sustainability of cities. Incorporating diverse community interests into sustainability planning and decision making is required in order to facilitate both healthy human and natural ecosystems. Cities, especially large ones, are connected to natural systems, not just locally but globally.
- **Principle 3 – Urban inequality undermines sustainability efforts**
  Reducing severe economic, political, class, and social inequalities is pivotal to achieving urban sustainability. Efforts to reduce these inequalities and make cities more inclusive help cities realize their full potential, making them appealing places to live, work, and improve prospects for economic development. Long-term policies and institutionalized activities can promote greater equity and contribute to the future of sustainable cities.
- **Principle 4 – Cities are highly interconnected**
  Cities are not islands. They are complex networks of interdependent subsystems that are affected by decisions and institutions across different spatial scales and in other localities. Cities require resources that come from other places and are affected by decisions and stakeholders in these places. Making cities livable, economically competitive, and sustainable demands new models of governance, institutions, and innovative partnerships that can address multiple dimensions of a city's connections with other places, stakeholders, and decision making. A multiscale governance system that explicitly focuses on interconnected resource chains and places is essential to transition toward urban sustainability.

This study constructed a comprehensive strategy in the form of a roadmap that incorporates these principles while focusing on the interactions among urban and global systems; the roadmap can provide a blueprint for all stakeholders engaged in metropolitan areas to facilitate meaningful pathways to urban sustainability. The roadmap is organized in three phases: **(1) creating the basis for a sustainability roadmap, (2) design and implementation, and (3) outcomes and reassessment** (Figure S-1).

In the first phase, adopting urban sustainability principles, identifying opportunities and constraints, and prioritizing co-net benefits—activities that offer co-occurring, reasonably sized benefits while managing tradeoffs across the environmental, economic, and social dimensions of sustainability—form the basis for a sustainability roadmap. The second phase describes multiple and interchangeable steps for design and implementation of urban sustainability programs. These steps include engaging partnerships with major stakeholders and the public; establishing goals, targets, and indicators for traditional metropolitan concerns; developing strategies aimed at facilitating

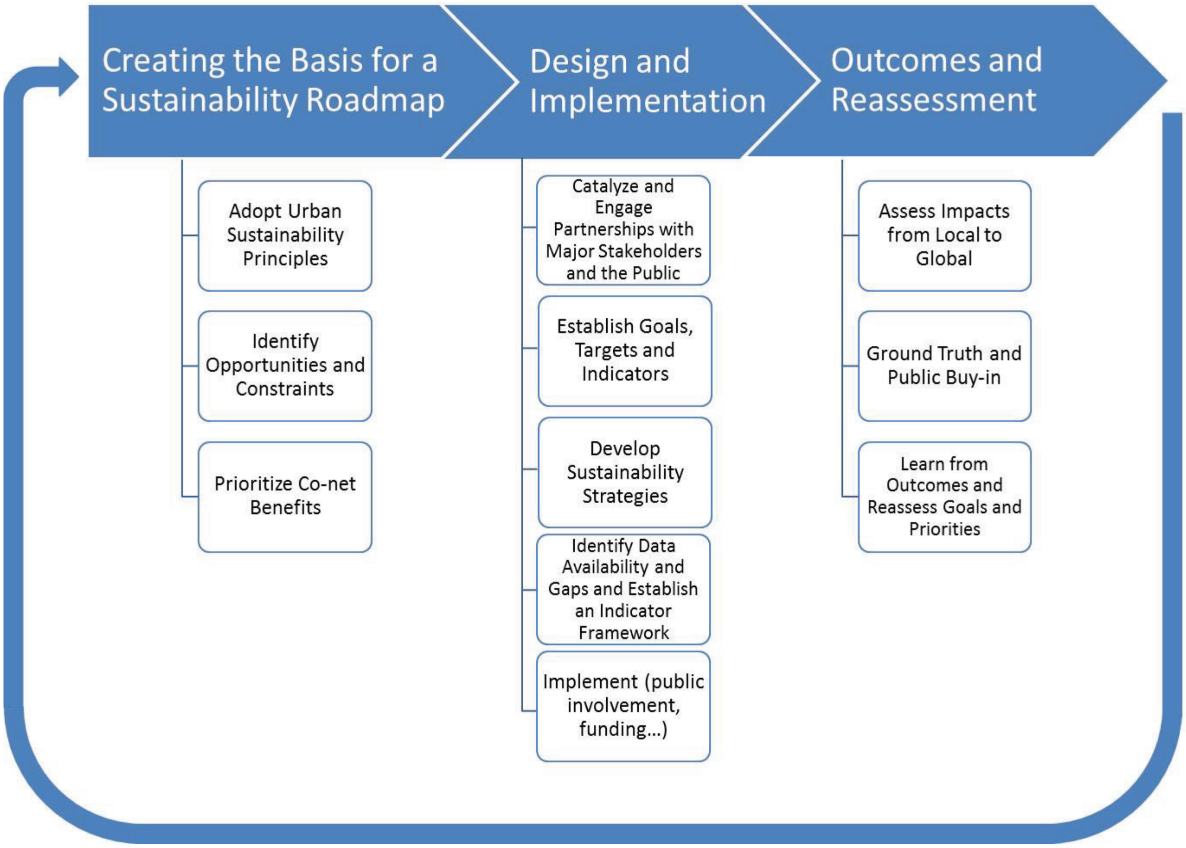

FIGURE S-1 The committee's proposed urban sustainability roadmap. SOURCE: Committee generated.

greater urban sustainability; identifying data gaps to better analyze the dynamics and benchmarks of indicator frameworks; and implementation—focusing on the institutional scale(s) at which each issue can be addressed. The committee suggests that every indicator should be connected to both an implementation and impact statement to garner more support, to engage the public in the process, and to ensure the efficiency and impact of the indicator once realized. Outcomes and reassessment constitute the third phase of this roadmap, including assessing impacts from the local to the global scales, developing ground truthing and securing public buy-in, continuing the reassessment of priorities, and learning from outcomes.

Research needs on new frontiers in science and development that can further contribute to the pathways to urban sustainability include deeper understandings of urban metabolism, critical thresholds for indicators, different types of data, and decision-making processes linked across scales.

LESSONS FROM CITY PROFILES

In examining the various challenges and sustainability strategies in the nine profile cities, the study explored a wide range of issues and questions encompassing science, organization, communication, and governance. This set of cities illustrates challenges involving energy, natural resource management, climate adaptation, economic development, public health, social equity, community engagement, and land-use considerations. The individual context and situation of each city played a key role in the sustainability challenges and opportunity solutions each faced. For example, New York and Los Angeles, the cities with the largest and most diverse populations, illustrated the longest history of implementing sustainability measures in addition to the largest reliance on imported resources and greatest challenges in reducing social inequities and eradicating poverty. Philadelphia and Pittsburgh provided examples of cities that actively pursued diversification of their economies with varied success and outcomes. Both implemented innovative collaborations with municipalities, nonprofits, and various public-private partnerships. Although Philadelphia and Pittsburgh capitalize on their economic assets, barriers in the form of policies at the state and national levels continue to hinder sustainable growth for these metropolitan regions. Chattanooga, Grand Rapids, Cedar Rapids, and Flint—all smaller in population size and density—have each pursued a different path to sustainability and met their intended goals with varying degrees of success. To provide a comparative snapshot of the nine cities assessed in the study, the spider charts (Figure 4-22) were created using the metrics data supplied in Tables 4-1, 4-3, 4-5, 4-7, 4-9, 4-11, 4-13, 4-15, and 4-17, with the convention being the larger the spider web, the more sustainable the city. These charts are not meant to provide a definitive determination as to whether a city qualifies as sustainable, but rather to provide an illustration as to how metropolitan areas varied as compared to the national average.

FINDINGS AND RECOMMENDATIONS

Based on the review and synthesis of the information gathered during the course of this study, the committee has 10 recommendations for moving toward sustainable metropolitan regions. This set of recommendations targets the need for urban sustainability strategies to be multi-issue, multidimensional, integrative, and collaborative, acknowledging both the urgency and need to prioritize sustainability efforts, as well as the constraints of the global biophysical environment.

Global Constraints and Co-dependencies

First, an understanding of the extent to which local sustainability programs can contribute to global solutions is essential to putting local sustainability plans into a global context. This understanding begins with a comprehensive accounting of flows from source to city and vice versa.

- **Recommendation 1: Actions in support of sustainability in one geographic area should not be taken at the expense of the sustainability of another. Cities should implement local sustainability plans and decision making that have a larger scope than the confines of the city or region.**

Importance of Incorporating Cross-scale Processes

Sustainability planning efforts should address the multiple linkages among varying spatial scales relevant to particular sustainability processes.

- **Recommendation 2: Urban leaders and planners should integrate sustainability policies and strategies across spatial and administrative scales, from block and neighborhood to city, region, state, and nation, to ensure the effectiveness of urban sustainability actions.**

Cross-cutting Challenges, Solutions, and Co-benefits

Because the social, economic, and environmental dimensions of sustainability are interdependent and closely linked, pathways to urban sustainability must exploit synergies among the dimensions so as to yield co-benefits across the three dimensions.

- **Recommendation 3: Urban leaders and planners should implement sustainability policies and programs that identify and establish processes for promoting synergies among environmental, economic, and social policies that produce co-benefits across more than one dimension of sustainability.**

Shared Versus Unique Challenges

Each city combines uniqueness and generality in the sense that whereas no two cities are identical, many share some common traits and common problems, such as road congestion or high housing costs.

- **Recommendation 4: Urban leaders and planners should look to cities with similar economic, environmental, social, and political contexts to understand and adapt local and regional sustainability strategies that have proven to provide measurable impact.**

The Key Role of Science

Science plays a central role in illuminating pathways to urban sustainability. Sharing among cities requires building evidence of what actions have been taken in particular places and what were the associated outcomes. With this information, urban and regional planners can choose actions that have led to measurable progress toward sustainability goals in other places.

- **Recommendation 5: Urban leaders and planners should gather scientific input to the maximum extent available in the form of metrics on social, health, environmental, and economic dimensions of sustainability; data related to policies, programs, and implementation processes; and measures of community involvement.**

Partnerships for Sustainability

Partnerships and community engagement are essential to the success of sustainability efforts. In the cities examined, no sustainability initiative was undertaken without some form of collaboration or partnership, such as that between business leadership and local government or the extensive involvement of diverse groups of citizens.

- **Recommendation 6: Cities should ensure broad stakeholder engagement in developing and implementing sustainability actions with all relevant constituencies, including nontraditional partners.**

Durable and Dynamic Sustainability Planning

Moreover, the committee found that the durability of leadership and of sustainability planning is essential in facilitating the transition to greater sustainability. Enduring leadership structures will need to be written into cities' operating budgets and sustainability plans and, where possible, voted into perpetuity by their citizens to ensure the ongoing success of sustainability efforts.

- **Recommendation 7: Every city should develop a cohesive sustainability plan that acknowledges the unique characteristics of the city and its connections to global processes while supporting mechanisms for periodic updates to take account of significant changes in prevailing environmental, social, and economic conditions. Sustainability plans should strive to have measureable characteristics that enable tracking and assessment of progress, minimally along environmental, social, and economic lines.**

Improving Opportunities, Outcomes, and Quality of Life for All

The committee also found that reducing inequality is an important yet often overlooked aspect of sustainability planning. Strategies aimed at reducing inequality are essential to improve quality of life not only for those with the fewest resources and opportunities, but also for the city's entire population.

- **Recommendation 8: Sustainability plans and actions should include policies to reduce inequality. It is critical that community members from across the economic, social, and institutional spectrum be included in identifying, designing, and implementing urban sustainability actions.**

The Importance of Benchmarks and Thresholds

In addition, to measure progress toward sustainability, accurate data are essential to create sustainability metrics and indicators with benchmark targets and outcomes. Multiple rating systems exist for urban sustainability, but they are not common, cannot be shared, and differ in scale. Furthermore, many of these metrics and indicators have weak scientific underpinnings; additional research is needed to assess their relevance and applicability. Given these challenges, achieving a scientific consensus on effective metrics and indicators presents a grand challenge for future urban sustainability work.

- **Recommendation 9: Cities should adopt comprehensive sustainability metrics that are firmly underpinned by research. These metrics should be connected to implementation, impact, and cost analyses to ensure efficiency, impact, and stakeholder engagement.**

The Urgency in Sustainability

Finally, all three dimensions of sustainability hold serious challenges for urban, regional, and global sustainability, necessitating a call to action. Infrastructure replacement needs throughout the United States provide a window of opportunity for action by targeting designed strategies to address existing problems that have limited progress toward sustainability.

- **Recommendation 10: Urban leaders and planners should be cognizant of the rapid pace of factors working against sustainability and should prioritize sustainability initiatives with an appropriate sense of urgency to yield significant progress toward urban sustainability.**

As an increasing percentage of the world's population and economic activities concentrate in urban areas, cities have become pivotal to discussions of sustainable development. While no single approach guarantees urban sustainability, it is valuable to assess the diversity of practices being implemented in urban and metropolitan regions to determine their transferability to other urban areas. Managing tradeoffs among the environmental, economic, and social dimensions of sustainability—while aiming to maximize total net benefits relative to costs—is an important part of the sustainability process. Because of the specificities of place and the particular problems being addressed, solutions are likely to be situation specific. Cross-place learning about how to manage such multidimensional problems will depend on developing and analyzing a data base that captures these specifics in many places and situations. Simultaneous action across multiple sectors and interconnected dimensions can facilitate cities' transitions to sustainability. The sustainability principles and the roadmap described in this report can serve as a blueprint for academics, practitioners, policy makers, civil society, and other stakeholders seeking pathways to greater sustainability for metropolitan regions across the United States and globally.

1

Introduction

In the United States and globally, urban areas are experiencing an unprecedented rate of population growth. More than 80 percent of the U.S. population now lives in urban areas, a number that is expected to continue to increase for the foreseeable future. Globally, since 2007, more than half of the world's population has been living in urban areas and the figure is estimated to exceed 70 percent by 2050 (UN, 2013). During 2000-2050, developing regions could add 3.2 billion new urban residents, a figure larger than the world's population in 1950 and double the urban population added during 1950-2000. By 2050, the world urban population could reach a total of 6.25 billion, 80 percent of whom may be living in developing regions, and concentrated in cities of Africa and Asia (UN, 2013).

The concentration of people, investment, and resources in cities has the potential for both positive and negative consequences. Despite the synergy for creativity, innovation, economic development, and social and community well-being, cities also can experience disproportionate levels of air and water pollution, loss of biodiversity, and increased rates of concentrated poverty. Cities also face challenges that can overwhelm their efforts to achieve sustainability. For example, sustainable[1] urban areas require improved access to public services, renewable as well as conventional sources of energy, adequate employment for their residents, equity both economically and culturally, as well as increasing resilience against the growing impact of natural hazards. In addition, growing urban populations place increasing stress on existing infrastructure and demand for new infrastructure, while aging and deteriorating infrastructure creates further waste and inefficiencies within cities; however, addressing such challenges is hindered by financial stresses and competition for monetary resources that pressure many government budgets (Global Cities Institute, 2015). Sustainability must also consider the enormous flows of materials, energy, financial resources, and wastes into and out of cities. Despite these challenges, urban centers have the potential to capitalize on their growth and innate diversity in becoming the world's leading lights in terms of sustainability.

The definition of a city, let alone a "sustainable city," is controversial. Cities are extremely diverse in terms of their size, spatial structure, employment patterns, level of economic development, natural resource availability, and social fabric. In addition, each country defines a city according to its own criteria, including a combination of administrative, population size or density, economic, and urban characteristics (e.g., paved streets, water-supply

[1] In the United States, sustainability is commonly defined as follows: "to create and maintain conditions, under which humans and nature can exist in productive harmony, that permit fulfilling the social, economic, and other requirements of present and future generations" (National Environmental Policy Act of 1969 [NEPA, 2000]; Executive Order 13514 [White House, 2009]).

systems, sewerage systems, and electric lighting), while temporal and spatial data gaps make accurate prediction of urbanization and size of city populations difficult (UN, 2013). In the United States, it has become increasingly challenging to delineate urban versus nonurban areas, further complicating how to clearly define sustainability issues and boundaries. As was discussed in a recent National Research Council (NRC) workshop on urban sustainability, the American landscape has become, in a crucial and enduring sense, a single entity: it is borderless, though often a separated amalgam of people and places (NRC, 2010). And in many senses, the country itself is borderless given the enormous flows across its international boundaries.

Several definitions of urban sustainability have been discussed over the years. For example, concepts of a sustainable city were reflected in the 1992 Rio de Janeiro Conference on Environment and Development (UN, 1993). The 1992 Rio Declaration integrated the economic, social, environmental, and governability dimensions of sustainability and argued for the eradication of unsustainable patterns of production and consumption, the eradication of poverty, and the role of the state, civil society, and international community in protecting the environment. Furthermore, in 1997, the Habitat Agenda (UN, 1997), adopted by the United Nations (UN) Conference on Human Settlements, noted similar concerns expressed in Agenda 21 with respect to the multiple dimensions of development, and discussed urban sustainability as requiring a harmonious integration of economic, social, and environmental issues (UN, 2013). In 2002, the World Urban Forum also affirmed that addressing economic, social, environmental, and governance issues was integral to the creation of sustainable cities and noted that the inability to address the integration of these issues would prevent the achievement of sustainable development (UN-Habitat, 2002).

In discussing sustainable development, Satterthwaite (1992) stated, “sustainable cities should meet their inhabitants’ development needs without imposing unsustainable demands on local or global natural resources and systems.” Burger et al. (2012) stressed biophysical constraints at the global level when considering sustainability. In this view urban sustainability is a fluid concept with the goal of devising policies that will improve living and working conditions for present and future generations (NRC, 2010). In the most general terms then, urban sustainability can be thought of as the measureable improvement of near- and long-term human well-being achieved through actions across environmental (resource consumption and environmental impact), economic (resource use efficiency and economic return), and social (social well-being and health) dimensions (Box 1-1).

Although cities concentrate a diverse mix of people and resources, it is also clear that cities themselves are not sustainable without water, energy, raw materials, food, and other resources from nonurban areas, and likewise the regions in which they are located depend on cities for resources. The resources needed to support urban life often originate at great distances from their final points of consumption, thereby extending the spatial reach of their impacts on global climate change. Cities that develop an island or walled-city perspective, where sustainability is defined as only activities within the city’s boundaries, are by definition not sustainable.

Whatever the precise definition, cities across the world are embracing the concept of urban sustainability, including addressing the challenges of rapid population growth and its impacts on limited natural resources. An

BOX 1-1
Defining Urban Sustainability

In the process of researching, discussing, and drafting this report, the committee adopted the following general definition:

> Urban sustainability is the process by which measureable improvement of near- and long-term human well-being can be achieved through actions across environmental (resource consumption with environmental impact), economic (resource use efficiency and economic return), and social (social well-being and health) dimensions.

impressive number of urban sustainability initiatives are currently under way or planned by local, regional, state, and federal governments; academia; the private sector; and nongovernmental entities.

While there is no single approach to urban sustainability, innovative methods now being developed in some cities may be transferable to others. It is valuable to assess practices being implemented in specific urban and metropolitan regions to determine whether and how they might be adapted and applied in other urban areas. Significant, albeit otherwise unrecognized, opportunities may exist to strengthen collaborative learning across cities to the broader benefit of worldwide urban, and nonurban, communities.

COMMITTEE'S TASK

Recognizing the importance and timeliness of these issues, the U.S. Environmental Protection Agency, the John D. and Catherine T. MacArthur Foundation, and the National Aeronautics and Space Administration formally requested that the National Academies of Sciences, Engineering, and Medicine undertake a study that used examples from metropolitan regions to understand how sustainability practices could contribute to the development, growth, and regeneration of major metropolitan regions in the United States. An ad hoc committee was asked to provide a paradigm that incorporates the social, economic, and environmental systems that exist in metropolitan regions that are critical in the transition to sustainable metropolitan regions (see Box 1-2 for the full statement of task). This paradigm could then serve as a blueprint for other regions with similar barriers to sustainable development and redevelopment.

COMMITTEE'S APPROACH TO ITS TASK

To accomplish its task, the Committee on Pathways to Urban Sustainability held several fact-finding meetings and committee meetings. The first meeting, held in February 2015 in Washington, DC, included presentations from the study sponsors focusing on their interests and perspectives on the topic. As part of its evidence-gathering process, the committee also organized two public data-gathering meetings in different metropolitan regions to examine issues relating to urban sustainability. These meetings were held in April and July 2015. The April meeting focused on sustainability issues in the Los Angeles metropolitan region; the July meeting focused on Chattanooga, Tennessee. These two cities were chosen as the sites for the committee's public data-gathering meetings due to their diverse characteristics in terms of size, geography, and varied sustainability challenges, such as related to water and air quality. The committee developed an agenda for each meeting in consultation with regional stakeholders so that the invited presentations and discussions reflected place-based knowledge and approaches to sustainability. During these fact-finding sessions, the committee heard speakers from industry, nongovernmental organizations, academia, and local and regional governments on innovative and successful actions cities have undertaken to address their sustainability challenges, as well as approaches that did not have their intended outcome. The committee also heard presentations and received information from key individuals who met with the committee and reviewed a large body of written material on urban sustainability concerns and practices in other cities, including literature that informed the committee on how cities could further strengthen their sustainability efforts. The report is focused on the United States, as required by the statement of task, but also acknowledges global linkages and other urban sustainability efforts in other parts of the world.

STRUCTURE OF THE REPORT

After this introduction, this report begins with a chapter on indicators and metrics for urban sustainability intended to guide city profiles and based on a review of a very large literature on urban sustainability indicators. A following chapter describes a set of guiding principles that help to establish the boundaries of an urban system while recognizing the constraints on urban sustainability. The statement of principles is followed by a high-level decision framework, and an urban sustainability "roadmap" that then inspires a series of city profiles, which serve as "guideposts" to highlight the opportunities and challenges in their associated specific urban contexts. The

BOX 1-2
Committee Statement of Task

An ad hoc committee will conduct a study by using examples from metropolitan regions to understand how sustainability practices could contribute to the development, growth, and regeneration of major metropolitan regions in the United States. The study will provide a paradigm that incorporates the social, economic, and environmental systems that exist in metropolitan regions that are critical in the transition to sustainable metropolitan regions. This paradigm could then serve as a blueprint for other regions with similar barriers to and opportunities for sustainable development and redevelopment.

As part of its evidence-gathering process, the committee will organize a series of public data-gathering meetings in different metropolitan regions to examine issues relating to urban sustainability. Likely topics to be addressed include path dependencies, biophysical constraints, energy, natural resource management, climate adaptation, economic development, hazard mitigation, public health, social equity, and land-use considerations. The committee will develop an agenda for each meeting in consultation with regional stakeholders (e.g., academia, industry, and city and county governments), so that the invited presentations and discussions can reflect place-based knowledge and approaches to sustainability.

The committee will focus on

- How national, regional, and local actors are approaching sustainability, and specifically how they are maximizing benefits and managing tradeoffs among social, environmental, and economic objectives;
- How stakeholders (e.g., industry, city and county governments, universities, and public groups) can better integrate science, technology, and research into catalyzing and supporting sustainability initiatives;
- The commonalities, strengths, and gaps in knowledge among rating systems that assess the sustainability of metropolitan regions; and
- A paradigm that would incorporate the critical systems needed for sustainable development in metropolitan regions.

In carrying out this charge and preparing its report with findings and recommendations, the study committee will

- Describe and assess the linkages among research and development, hard and soft infrastructure, and innovative technology for sustainability in metropolitan regions;
- Describe the countervailing factors that inhibit or reduce regional sustainability and resilience and identify steps that can be taken to reverse or mitigate the factors;
- Describe and assess the future economic drivers, as well as the assets essential to and barriers that hinder sustainable development and redevelopment; and
- Examine how federal, state, and local agency and private-sector efforts and partnerships can complement or leverage the efforts of key stakeholders and assess the role of public and private initiatives that may serve as a model for moving forward.

committee chose to denote this conceptual structure as a framework—an urban sustainability roadmap—rather than a paradigm to better relate to decision-making processes and flows experienced by urban sustainability practitioners and stakeholders. The additional seven city profiles, New York City, New York; Vancouver, British Columbia; Philadelphia, Pennsylvania; Pittsburgh, Pennsylvania; Grand Rapids, Michigan; Cedar Rapids, Iowa; and Flint, Michigan, were selected to reflect the diversity of U.S. urban contexts along dimensions of city size and density, geographic location, primary industries, and the key challenges to sustainability such as water scarcity, air quality, and social issues. Each profile provides a brief description of an urban area including relevant metrics and then outlines two to three noteworthy sustainability efforts the city undertook along with other relevant issues discovered during the committee's research. The city descriptions end with a series of observations and recommendations based on that city. The final chapter distills these city observations and recommendations in view of the principles outlined earlier to produce a series of generalizable recommendations for a new approach to urban sustainability.

2

Urban Sustainability Indicators and Metrics

Indicators of urban sustainability typically span the three broad dimensions described and noted in Chapter 1: environmental, economic, and social. These are often referred to as the triple-bottom line (Elkington, 1999). How is this threefold typology covered in the literature on indicators for urban sustainability? How useful is it as a foundation for understanding urban sustainability challenges? Are critical indicators omitted when the scope is limited to or organized in terms of environmental, economic, and social dimensions? These are the questions addressed by the first section of this chapter, based on a detailed review of four existing sets of urban sustainability indicators (Arcadis, 2015; The Economist, 2011; Lynch et al., 2011; Mega and Pedersen, 1998).

The chapter then presents an urban sustainability indicator set that was an important resource for the committee's work, providing much of the empirical basis of the report's nine city profiles. This chapter describes and explains the set of indicators and metrics that the committee selected from publicly available data as illustrative of the three dimensions of urban sustainability. Some indicators are specific to cities and vary in their coverage, that is, the coverage may be limited to specific cities, while others span regions or are specific to states but can nonetheless be adapted to cities (Arcadis, 2015; The Economist, 2011; Lynch et al., 2011; Mega and Pedersen, 1998). In many instances indicators are contained in local climate, energy, and water plans. The goal is to identify a set of urban sustainability indicators that allow urban communities to diagnose problems and identify pressures that provide useful information to policy intervention.

Many city leaders aspiring to change sustainability policies use indicators and metrics as motivation; they are also used to document progress as a source of urban pride. These tools cannot be underestimated in terms of their importance and impact on political leaders. Every year numerous organizations run rankings for various aspects of sustainability and they are often highly publicized in the press. They are seen by political and economic leaders as bellwethers of the perception of the urban area and can impact tourism and enhance prospects for economic development. Many of the case-study cities illustrate the transformations that can occur when metrics document the decline of a city's environmental sustainability and its move toward greater sustainability.

Terminology is important: Indicators as used here are quantified by metrics. Like indicators used by the U.S Environmental Protection Agency (EPA, 2014a) and others (Wilbanks and Fernandez, 2012) in the context of climate change, the indicators used in this report are measures of "the state or trend of certain environmental or societal conditions over a given area and a specified period of time" (EPA, 2014a, p. 3). The indicators reflect both baseline conditions and impacts. Some have or imply benchmarks or standards, while others stand alone as nonnormative descriptive attributes. This work emphasizes the latter, though standards and benchmarks are occasionally referenced.

META-REVIEW OF URBAN SUSTAINABILITY INDICATOR SYSTEMS

Existing urban sustainability indicator sets from the literature are evaluated in terms of their underlying dimensions and the specific indicators and metrics they use. Those that were examined are listed below:

1. The **North America Green City Index** (EIU, 2011) assesses the environmental performance of 27 major U.S. and Canadian cities (The Economist, 2011). While it was originally one product of a research project conducted by the Economist Intelligence Unit (EIU), sponsored by Siemens, it is now part of a larger set of city studies conducted by the EIU.
2. The **Urban Sustainability Indicators** is a product of the European Foundation for the Living and Working Conditions (Mega and Pedersen, 1998). It presents the urban sustainability indicators framework in the context of the Foundation's program on socioeconomic aspects of sustainable development. The indicator set was examined for a network of medium-sized cities in Europe.
3. The **Sustainable Cities Index** by Arcadis was tested with data on 50 world cities from 31 countries (Arcadis, 2015).
4. The **Sustainability Urban Development Indicators** is a product of the University of Pennsylvania and was commissioned by the Office of Policy Development and Research, U.S. Department of Housing and Urban Development; it focuses on U.S. urban areas (Lynch et al., 2011).

Other notable literature was reviewed in detail, as well. For example, the Sustainability Tools for Assessing and Rating Communities Community Rating System is a toolbox developed for community leaders in the United States to assess the sustainability of their communities, set targets for the future, and measure progress along the way (Lynch et al., 2011). The Carbon Disclosure Project works with cities globally to measure, monitor, and manage greenhouse gas (GHG) emissions (Carbon Disclosure Project, 2014). Other related measurement protocols are the Greenhouse Gas Protocol for cities, the ICLEI Local Governments for Sustainability compact of mayors, the International Organization for Standardization's (ISO's) ISO 37120:2014: Sustainable development of communities—Indicators for city services and quality of life, and the ecological footprint protocol being piloted by the recent *European Common Indicators* report (Ambiente Italia Research Institute, 2003; Greenhouse Gas Protocol, 2015; ICLEI Local Governments for Sustainability, 2015; ISO, 2014).

The literature spans research and metrics at different spatial scales. Which of these systems and metrics are most important for a particular urban region depends on the questions being asked, but what is clear from policy research by Ostrom (2009a,b) is that simultaneous action across multiple dimensions can accelerate the pace and depth of on-the-ground transformations. No single scale alone is sufficient.

The committee's meta-review is presented in Table 2-1. It shows the predominance of three common dimensions—environmental, economic, and social—across the four sets studied, as well as across a fifth set developed by the committee. The applicability of these three dimensions appears to hold up in these studies.

In addition, the meta-review underscores the overlapping nature of the three sustainability dimensions; that is, a given indicator may cut across the three dimensions, supporting the necessity for integration across them. This is illustrated in the Venn diagram shown in Figure 2-1. This diagram was adapted in the *Science for Environment Policy 2015* report, based on prior work, in particular referencing concepts proposed by the World Commission on Environment and Development (WCED, 1987). It suggests that sustainability requires the co-occurrence of conditions that operate synergistically to achieve desired outcomes. Another observation is that indicators do not operate in isolation: their impacts depend on context including the historic evolution of the urban system.

The committee suggests, based on its review, that a fourth dimension should be considered, covering institutional arrangements and governance. Sustainability requires that political processes be inclusive, be participatory, exhibit good governance practices, be populated by organizations that offer an ease of doing business, and be linked to local, national, and global networks.

TABLE 2-1 Meta-Review of Urban Sustainability Indicator Sets

		Urban Sustainability Systems				
	Measures	I	II	III	IV	V
Environmental Indicators						
Air quality	Air Quality index[II, IV, V]; criteria pollutant nonattainment[V]; nitrogen oxides emissions[I]; sulfur dioxide emissions[I]; $PM_{2.5}$ emissions[III, V]; PM_{10} emissions[I, III, V]	3	1	2	1	4
Greenhouse gas emissions	Residential greenhouse gas (GHG) emissions[I, V]; commercial GHG emissions[I, V]; industrial GHG emissions[II, V]; total greenhouse gases (CO_2, CH_4, N_2O, and chlorofluorocarbons [CFCs]) [II, III, IV]; CO_2 emissions by the energy sector divided by the total electricity output[IV]; annual amount of carbon dioxide emissions divided by the city population[IV]	2	2	1	3	3
Water	Average annual precipitation per year[V]; example of a waterway applicable to the city[V]; number of waterways impaired[IV, V]; water leakages in water distribution system[I]; total water consumption[II]; water consumption per capita[I, IV]; drinking water quality[III]; water usage[IV, V]	2	1	1	3	4
Land	Green space[I, II, III]; existing tree canopy[IV, V]; landslide vulnerability[IV, V]; park acres per 1,000 residents[IV,V]; urban sprawl[I, III]	2	1	2	3	3
Waste	Total solid waste production[IV]; percent of municipal solid waste recycled [I, IV]; waste management indicator[II]; solid waste management[III]	1	1	1	2	—
Ecological footprint	Ecological footprint by Global Footprint Network[V]	—	—	—	—	1
Natural hazards vulnerability	Natural hazards vulnerability[IV, V]; natural catastrophe exposure[III]	—	—	1	1	1
Economic Indicators						
Income	City income[II]; gross domestic product (GDP) per capita[I, III]; median household income[V]	1	1	1	—	1
Price	Consumer Price Index[III, IV]; average residential electricity rate[V]	—	—	1	1	1
Unemployment	Unemployment[II, IV, V]; goods employment[I]; services employment[I]; employment by mix of economic sectors[V]	2	1	—	1	2
Energy	Energy consumption[II, III]; energy consumption per capita[IV]; residential energy intensity[IV, V]; commercial energy intensity[V]; industrial energy intensity[V]; electricity consumption per person[I]; electricity consumption per unit of GDP[I]; energy efficiency[III]; renewable energy consumption[IV, V]; share of renewable energy in energy mix[III]; system average interruption duration index[V]; light-emitting diode (LED) street lighting[V]	2	1	3	3	6
Financial health	G.O. Bond ratings 2014 or 2015 S&P ratings or *Moody's – AA+ is S&P equivalent to Aa1[V]; viability of the urban economy[II]; city fiscal deficit[II]; indicator tracks the performance of banks and thrifts in meeting the credit needs of the community by using Community[IV]; reinvestment Act lender ratings[IV]	—	2	—	2	1

TABLE 2-1 Continued

	Measures	Urban Sustainability Systems I	II	III	IV	V
Transportation	Transportation mode share[IV, V]; share of workers traveling by public transit, bicycle, or foot[I, II, IV]; annual vehicle miles of travel per capita[IV, V]; public transportation ridership average[IV, V]; mean travel time to work in minutes[I, III, IV, V]; Walkscore.com[IV, V]; length of transport infrastructure[I, III]; congestion[V]; yearly delay[V]; excess fuel[V]; cost[V]; licensed drivers per 1,000 driving age population[V]	3	1	2	6	10
Social Indicators						
Demographics	Population[I, V]; population density[I, V]; race, ethnicity, age, and gender[V]	2	—	—	—	3
Education	High school, college, and bachelor's degrees[IV, V]; university rankings[III]; literacy[III]	—	—	2	1	1
Public health	Poor or fair health[V]; adult obesity[V]; premature age-adjusted mortality[V]; under age 5 mortality per 1,000 live births[IV]; life expectancy at birth[III]; percent of population with health insurance[IV]; total percentage of the population affected seriously by crime or traffic accidents[II, IV]; rate of violent crimes[IV, V]; roadway fatalities per hundred million annual vehicle miles of travel (VMT)[V]	—	1	1	4	5
Equity	Ratio of household income at the 80th% to income 20th%[V]; Gini coefficient[III, IV]; percentage of city population living in poverty[IV, V]; percentage of people affected by poverty, unemployment, lack of access to education, information, training, and leisure[III]; percentage of low-income households within 1/4 mile of a neighborhood center and a transit stop[II]; ratio of economically active population to economically inactive population[III]; children in poverty[IV, V]	—	1	3	3	3
Housing and buildings	Housing affordability[IV]; home ownership[V]; percentage of the homeless population[II]; percentage of the population affected by poor housing conditions[II, IV]; numbers of Leadership in Energy & Environmental Design (LEED)-certified buildings[I]; number of houses certified as energy efficient by certification organizations[IV]; median house size of new construction[IV]	1	2	—	4	1
Citizen participation	Percentage of people participating in local election or as active members in associations for urban improvement and quality of life[II, IV]; voter participation as a percentage of the population[IV]	—	1	—	2	—

NOTE: Superscripts indicate the urban sustainability system that uses each measure indicated in the right-hand columns: I = America Green City Index; II = Urban Sustainability Indicators; III = Sustainable Cities Index; IV = Sustainability Urban Development Indicators; V = The Academies' Pathways to Urban Sustainability Committee. The number in each cell represents the number of measures represented in each urban sustainability indicator set.

Future research could help to make available indicators more useful to decision makers by ensuring that indicators address actionable issues, target sustainability goals and objectives, incorporate risk levels, and cover institutional and governance issues. It could also provide directions for spatial and temporal adaptations of the indicators to reflect, for example, lifetime of service facilities, equity, and anticipated population shifts, and cover institutional and governance issues.

FIGURE 2-1 Overlapping sustainability dimensions. SOURCE: Science for Environment Policy (2015) Indicators for sustainable cities. In-depth Report 12. SCU, UWE: Bristol. Available at http://ec.europa.eu/environment/integration/research/newsalert/index_en.htm. Reprinted with permission from the Science for Environment Policy.

URBAN SUSTAINABILITY INDICATORS AND METRICS

The indicator dimensions and individual indicator descriptions that follow were used to construct Appendix B and provide the basis for applying the specific indicators to the case-study cities. They are also intended to be more broadly applicable to other communities. Indicators in this chapter, where possible, are defined at the city or metropolitan area scale. Counties were used where city data were not available, and the county list is contained in Table 2-2. These broader geographic areas, i.e., metropolitan areas, are referred to in different ways by the U.S. Census. Indicator values are generally not reported for the states in this chapter and in Appendix B, unless city-based or county-based references were not available or for comparison purposes. Nationwide U.S. values are reported for the purpose of comparison, where they are available or applicable. Indicators generally fall within the following generic typology: characteristics and trends in state or condition measures, users and usage (including equity), and stresses and response to and resilience in the face of stresses. These cut across the three dimensions.

An important consideration is that the indicators covered in this report are specifically adapted to urban areas and are illustrative of a very wide range of sustainability-related indicators covering environmental, social, and

TABLE 2-2 County List: List of Principal Counties Representing Case-Study Cities (where data for the individual cities were not available)

City of New York: Bronx County (Bronx) Kings County (Brooklyn) New York County (Manhattan) Queens County (Queens) Richmond County (Staten Island)	City of Pittsburgh: Allegheny County City of Grand Rapids: Kent County City of Chattanooga: Hamilton County
City of Los Angeles: Los Angeles County	City of Cedar Rapids: Linn County
City and County of Philadelphia (single legal entity)	City of Flint: Genesee County

economic dimensions, many of which are not necessarily directly adapted to urban areas. Examples from this literature are The Heinz Center (2008), Janetos et al. (2012), EPA (2014), the World Bank (ongoing, web site), and Yale University (2016).

ENVIRONMENTAL INDICATORS

Air Quality

One key way of framing air quality indicators is in terms of the regulatory requirements that have evolved over many decades. Two aspects of these requirements are (1) measures of the attainment or compliance with federal Clean Air Act air quality standards and (2) indexes that combine a number of air quality parameters and their standards.

Criteria Pollutant Nonattainment. The federal Clean Air Act and its amendments set forth National Ambient Air Quality Standards (NAAQS) for the six "criteria" pollutants carbon monoxide, lead, nitrogen oxide, ozone, particulate matter, and sulfur oxide.[1] Comparisons between the standards and monitored values for each pollutant are made according to a defined process that specifies the procedures for the monitoring and the applicable, defined geographic areas embodied in State Implementation Plans (SIPs) (EPA, 2015e). Since areas defined in SIPs do not contiguously cover the entire United States, a U.S. average is difficult to obtain. "Nonattainment" areas are those that do not conform to the standards, a determination that is made for each pollutant and for the time period specified in the monitoring requirements. The listing of counties that are in nonattainment status and the pollutants which the nonattainment status refers to are available from the EPA (2015b). Particulate matter of 2.5 microns in diameter ($PM_{2.5}$) is singled out here as an example of one of the NAAQS for its relationship to specific urban area health impacts. It is one that is commonly singled out as an indicator in global indicators and for urban areas (see, for example, City of New York, 2015, p. 18).

Air Quality Index (AQI). EPA has developed an air quality index that combines the values for each of the NAAQS pollutants. The index is measured on a scale that reflects the number of days for each index category, ranging from 0 (the best air quality or "good") to 201 or higher (the worst air quality or "very unhealthy"), and is given for cities as well as other geographic areas. Below is the EPA interpretation of each of the characteristics it covers (EPA, 2015a):

> "# Days with AQI. Number of days in the year having an Air Quality Index value. This is the number of days on which measurements from any monitoring site in the county or MSA were reported to the AQS database.

[1] See EPA's ongoing web page: https://www.epa.gov/criteria-air-pollutants/naaqs-table.

Days Good. Number of days in the year having an AQI value 0 through 50.
Days Moderate. Number of days in the year having an AQI value 51 through 100.
Days USG - Unhealthy for Sensitive Groups. Number of days in the year having an AQI value 101 through 150.
Days Unhealthy. Number of days in the year having an AQI value 151 through 200.
Days Very Unhealthy. Number of days in the year having an AQI value 201 or higher. This includes the AQI categories very unhealthy and hazardous. The EPA indicates that very few locations (about 0.3 percent of counties) have any days in the very unhealthy or hazardous categories.

Other characteristics based on the AQI are:

AQI Maximum. The highest daily AQI value in the year.
AQI 90th percentile. 90 percent of daily AQI values during the year were less than or equal to the 90th percentile value.
AQI Median. Half of daily AQI values during the year were less than or equal to the median value, and half equaled or exceeded it."

Index values have been linked to qualitative health status.

Climate-Related Variables

Detailed variables to reflect climate change are set forth by the Intergovernmental Panel on Climate Change, the EPA, the National Climate Assessment of the U.S. Global Change Research Program (USGCRP), and numerous research studies that provide details and variations for each of these variables (EPA, 2014a; USGCRP, 2015). This section focuses on GHG emissions data that are specific to cities and generally more controllable by them. GHGs can be described directly in terms of carbon dioxide or as carbon dioxide equivalents. The former measure is used here, that is, carbon dioxide alone (Cox, 2014). The equivalents acknowledge that each of the many kinds of greenhouse gases absorbs radiation differently. For that reason, emissions are often translated into equivalent carbon dioxide mass units for standardization for some particular planning horizon (EPA, 2015d). CO_2 equivalents are traditionally expressed in different units by economic sectors; for example, for the residential sector it is per capita, for the commercial sector per gross domestic product (GDP) and per square foot of buildings, and for the industrial sector per dollar value of products. GHGs are often provided by states in terms of such measures as CO_2 emissions per capita or per million dollars of GDP. However, it must be remembered and taken into consideration that state-level data yield high values for states that have high levels of energy production and certain types of industry such as petrochemicals. In order to accurately assess the per capita emissions, they must be applied to the balance sheet of end users.

Water Quality

Indicators for water quality are provided separately for waterways and drinking water. The former is covered under the federal Clean Water Act and the latter under the Safe Drinking Water Act (SDWA).[2] The federal Clean Water Act and its amendments require that impaired waterways, that is, those that violate federally approved state water quality standards, appear on a list under section 303(d) of the Act. The EPA provides access to the data organized by state with smaller geographic units available also on its website. Indicators are defined by waterway segment, designated usages for each segment, and type of pollutant. Impaired waters are listed by the EPA under section 303(d) of the Clean Water Act. Although this is difficult to operationalize as an indicator, given the level of detail it provides, it is useful to describe it: The federal Clean Water Act's section 303(d) requires that a list of waterways not meeting water quality standards for individual pollutants be developed and prioritized by the states. Total Maximum Daily Loads (TMDLs) are developed for these waterways, determined as follows: "A TMDL is a calculation of the maximum amount of a pollutant that a water body can receive and still safely meet water quality standards" (EPA, 2015c).

[2] The Clean Water Act actually has a category for drinkable water, but this is distinct from SDWA coverage, which is for community water supply systems.

One indicator based on the impaired waterways concept that reflects overall water quality in a state is the statewide number of impaired waterways, the values of which vary by year, for each state and each pollutant. The status and characteristics of water quality segments for smaller geographic units can be obtained by knowing the waterways within those geographic units and extracting the data for each waterway. The metrics include types of pollutants, sources of the impairment, nature of the impairment, and the length or size of waterways affected. Other potential water quality indicators are the number of exceedances of standards over a given time period and waterway.

Hydrology

The water budget of an area reflects what an area uses versus the capacity it has. Precipitation is one aspect of the water budget of a given area. Other factors are evaporation rate, percolation rate into the ground, and runoff over land. Precipitation as rainfall by city is available in a number of different forms and average annual precipitation in inches per year is given based on National Oceanic and Atmospheric Administration (NOAA) 1981-2010 averages (Current Results, 2015).

Tree Canopy

Tree coverage is one component of land cover along with vegetation in general that pertains to supporting sustainability aimed at water retention, air quality improvements, temperature control, provision of species habitats, aesthetics, and numerous other social and environmental purposes. Tree canopies are measured in terms of the acreage of tree components, for example, leaves, branches, and stems (City of New York, 2012a). Tree canopy assessments are carried out in many areas and the protocol is generally consistent.

Landslide Vulnerability

Landslides are just one example of land-related vulnerabilities. They have occurred in a number of areas throughout the United States for different reasons. The U.S. Geological Survey (USGS) maps landslide vulnerability, and values for a particular location can be estimated from the maps (USGS, 2014b). The USGS scoring system is qualitative based on the following levels:

L, Low (less than 1.5 percent of area involved);
M, Moderate (1.5 to 15 percent of area involved); and
H, High (greater than 15 percent of area involved).

Natural Hazards Vulnerability

The NOAA National Climatic Data Center Storm Events Database enables information to be extracted at the city level (by means of a county identifier) in terms of numbers and types of events, fatalities, injuries, and other factors. State and city Hazard Mitigation Plans also typically provide data on natural hazard events and frequencies. This indicator reflects vulnerability but not risk in terms of likelihood of occurrence or magnitude of the consequences, such as a comprehensive value of damage. The period January 2005 through June 1, 2015, was selected to identify the number of events for each of the cities in Appendix B. Where the number of events exceeded 500 events in that time period, the number entered was 500+. In the case of New York City, the actual number was calculated by breaking up the time period and also was provided by borough (county) within New York City given the size of the city.

Ecological Footprints

Wackernagel and Rees (1996) popularized the ecological footprint concept. The Global Footprint Network (GFN) tracks environmental capacity and resource usage routinely primarily by country but also has conducted a few case studies (Global Footprint Network, 2015). Calculators now exist for specific resources and often facilities, and although a few enable citywide computations, most are based on smaller geographic identifiers such as zip codes. Calculators need to be used with caution, given that the selection of the elements in the calculator is often constrained by their design and may or may not be sensitive to certain changes in inputs used for the calculators, the parameters measured are often simplified in terms of both what is included and their measurement, and most calculators use carbon dioxide emissions as the output (though the GFN uses "number of planets" equivalent to the Earth's resources), whereas sustainability is often broader than what calculators are based on (Zimmerman, 2012). Again, it must be emphasized that footprint analysis in the context of urban sustainability needs to consider both direct and indirect consumption and impact.

Parkland

The Trust for Public Land has assembled numerous indicators for parkland and recreational facilities for selected U.S. cities. The indicators described by the Trust for Public Land for facilities focus on play areas and recreational facilities. Density and usage indicators are two types of indicators also included in their survey. Density is measured as park acreage per 1,000 residents and as a percent of city area. Usage is measured as visitation rates (The Trust for Public Land, 2015). Data on parkland were only found initially for four of the cities in this report, and other sources would need to be tapped for others.

ECONOMIC INDICATORS

Business Sectors

A general, descriptive indicator for a city's economic health begins with the relative concentration of employment, dollar value of business, and other metrics across economic sectors. Sectors initially provided by the U.S. Census for employment (number of workers 16 years old or older) are as follows:

- Agriculture forestry, fishing, hunting, and mining;
- Construction;
- Manufacturing;
- Wholesale trade;
- Retail trade;
- Transportation, warehousing, and utilities;
- Information and finance and insurance, and real estate and rental and leasing;
- Professional, scientific, management, and administrative, waste management services;
- Educational services, and health care and social assistance;
- Arts, entertainment, and recreation, and accommodation and food services;
- Other services (except public administration);
- Public administration; and
- Armed forces (U.S. Census Bureau, 2014b).

There are many other ways of portraying economic condition by business sector such as value and number of establishments. Other aggregate city measures exist, such as gross city product. Still other indicators compare concentrations in particular industries with overall industry levels (for employment or value) for cities versus their regions, for example, and this method generally is under the heading of "shift-share" techniques.

Financial Status: Bond Ratings

Bond ratings are one indicator of financial health and hence sustainability. These are conducted, for example, by Moody's Investors Service, Standard & Poor's (S&P), and Fitch Ratings, Inc., for municipal services as well as for general obligation bonds that can be used to fund public services such as infrastructure. The scale for S&P ratings, for example, for investment grade (from high to low) is AAA, AA+, AA, AA-, A+, A, A-, BBB+, BBB, and BBB- (other S&P ratings are below investment grade).

Unemployment

The definition of unemployment used in this report is the "[p]ercentage of population ages 16 and older unemployed but seeking work" by geographic area and time period (RWJF and University of Wisconsin Population Health Institute, 2015).

Infrastructure

Both infrastructure capacity and usage rates are important indicators of the sustainability of infrastructure to support economic and social needs. Capacity measures are a combination of the resources available and the usage of those resources. Another term that was used to characterize this measure at least dating from the 1970s is "carrying capacity" (Bishop et al., 1974). Examples of usage rates are given below, for resources associated with basic infrastructures, i.e., transportation, energy, and water, and the same sources of the data usually give capacity measures as well. A common set of metrics that emphasize the social dimensions of public services are availability, accessibility, quality and reliability of the service, cost, and convenience.

(a) Transportation

The U.S. Census provides statistical information on transportation usage for the journey to work (for commuters 16 years old or older) by mode and purpose (U.S. Census Bureau, 2014b). For road-based travel, vehicle miles of travel (VMT) is a common indicator and is available by urbanized area and type of roadway for 2010 (FHWA, 2014). Number of state licensed drivers and registrations is another (FHWA, 2016). Transportation mode share is available from the U.S. Census (for example, percentage of workers using public transit) (U.S. Census Bureau, 2014b). Public transportation usage is measured in terms of passenger trips and miles of passenger travel by the American Public Transportation Association (APTA) and the U.S. Department of Transportation (DOT) Bureau of Transportation Statistics (APTA, 2015). Other measures that reflect facility performance are provided by these sources as well, and local jurisdictions add others as well such as "mean distance between failures" to capture failure rates of transit vehicles. Other indicators come into play in the context of extreme events that threaten urban areas among other areas, such as the recovery rate of transportation services (see, for example, Zimmerman [2014] for transit recovery rates following Hurricane Sandy). The use of some alternative modes is captured in a ranking system by walkscore.com (out of 100) (Walk Score, 2015a). Scores are given for walking, transit, and biking by city based on the proximity of people to daily activities and places that are defined and preselected by walk score (Walk Score, 2015b).

A number of transportation measures exist that reflect what users experience. Congestion measures, for example, for roadways are presented annually by the Texas Transportation Institute and INRIX, and the measures they use that combine facility and user characteristics are as follows:

- "Travel Time Index—The ratio of travel time in the peak period to the travel time at free-flow conditions. A value of 1.30 indicates a 20-minute free-flow trip takes 26 minutes in the peak period.
- Excess Fuel Consumed—Increased fuel consumption [in gallons] due to travel in congested conditions rather than free-flow conditions.

- Congestion Cost—Value of travel time delay (estimated at $17.67 per hour of person travel and $94.04 per hour of truck time) and excess fuel consumption (estimated using state average cost per gallon for gasoline and diesel)"[3] (Schrank et al., 2015, p. 18).

(b) Energy

Energy intensity is a key indicator for energy usage. Energy usage varies for different sectors of the economy as shown in Appendix B. The U.S. per capita energy consumption in 2011 is cited as 312 million Btu per person (U.S. Department of State, 2014, p. 65). The incidence and duration of power outages is another critical indicator, and trends in these characteristics appear to point to increasing trends. The measure may be difficult to capture at an urban level, given the widespread nature of most outages. Energy reliability is expressed in terms of the System Average Interruption Duration Index (SAIDI).[4] The costs of electric power services are important indicators presented in Appendix B. The average residential electricity rate shows how much money the average person spends at home per kilowatt hour consumed.[5] The use of light-emitting diode street lighting reflects the use of sustainable means of providing energy for certain uses. The use of solar and wind power are also important sources of renewable power that support sustainability.

(c) Water usage

County-level water consumption figures are available in terms of domestic gallons per capita per day (USGS, 2014a). Many cities reach well beyond their borders to obtain a water supply. For New York City the farthest reach of the watershed is about 125 miles from the center of the city. For Los Angeles, it is several hundred miles. For water quality, the quantity in terms of restrictions on use (for example, under drought conditions), quality relative to standards of purity, and cost of the supply are user-oriented indicators.

SOCIAL INDICATORS[6]

Population and Population Density

Population was measured based on Census data for those living in the city and for those living in the Core Based Statistical Area (CBSA). A CBSA is a core area with a significant population nucleus in which neighboring communities are closely economically and socially integrated with the population nucleus (U.S. Census Bureau, 2014c). Population density is another important population characteristic, measured as the number of people per square mile within a defined geographic area (U.S. Census Bureau, 2014c).

Demographics

The U.S. Census Bureau provides data on the racial and ethnic composition of a city. Median age and gender reveal further information about the demographic background of a community (U.S. Census Bureau, 2014c).

[3] These definitions are drawn directly from the Texas A&M Transportation Institute and INRIX 2015 Urban Mobility Scorecard, p. 18, for the "national congestion tables."

[4] SAIDI reflects the average amount of time per year that power supply to a customer is interrupted, expressed in minutes per customer per year. It applies to the territory or service area of the principal utility company serving the city and is not coterminous with the city of the metro area.

[5] Applies to the territory served by the principal utility company serving the city (see Local Electricity, 2015).

[6] See U.S. Census Bureau (2014a, 2015a).

Education

Education can be measured through a variety of means usually based on educational level attained in formal schooling systems and generally based on U.S. Census Bureau measures. One measure used here is the percentage of high school graduates in the population who are 25 years and older. A second measure is the percentage of those aged between 25 and 44 who have attended some college. Finally, education was measured based on those 25 and older who possess bachelor's degrees (U.S. Census Bureau, 2014c).

Poverty and Wealth

Numerous measures of population wealth and poverty exist, namely, income (as household, individual, or family median or mean annual income), percentage of the population below the federal poverty level (HHS CMS, 2015),[7] and income gaps in terms of the ratio of the population above the 80th percentile and below the 20th percentile in gross annual income (RWJF and University of Wisconsin Population Health Institute, 2015; U.S. Census Bureau, 2014b). These are also available by demographic characteristics of the population.

Housing characteristics are also described in terms of a number of indicators that directly or indirectly reflect wealth. Some examples are housing value or cost (assessed or market value, monthly rent), ratio of owners to renters, rent-to-income ratios for rental housing, and the percentage of household income spent on housing ownership.

Safety

Overall crime statistics are measured in terms of types of crime and rates per capita (RWJF and University of Wisconsin Population Health Institute, 2015). For vehicular accidents, the Federal Highway Administration (FHWA) Highway Statistics give data on fatality rate per 100 million annual VMT, 2013, by functional system, that is, the type of federally aided roadway (FHWA, 2014). The National Highway Traffic Safety Administration (NHTSA) manages the DOT Fatality Analysis Reporting System database, which is also a central place for vehicular accident information (NHTSA, 2015a,b).

Health

Health indicators comprise a large set of characteristics and outcomes typically standardized by a measure of population or population sector such as that adjusted by age. Examples of outcome measures are mortality, morbidity, years of life, or potential life lost. There are numerous cause-specific indicators, including disease-specific indicators and behaviors that contribute to adverse health conditions (RWJF and University of Wisconsin Population Health Institute, 2015). The City of New York has developed community health profiles at the borough-wide (county) level and for its 59 community health districts; for these units, it provides several dozen indicators that are demographic as well as health related (DOHMH, 2015).

CONCLUSIONS

A number of conclusions are suggested from the meta-review and analysis of indicators:

- Three common dimensions dominate—environmental, economic, and social—and these are interrelated and overlapping; that is, any given indicator may fall within more than one dimension.
- An added fourth dimension would highlight institutional and governance aspects of sustainability and is a direction for future research. Examples of these indicators would include performance and oversight capabilities and the ability to obtain resources to attain environmental, economic, and social aims. These indicators or their combinations are often specific to individual areas.

[7] This level is in terms of income by family size.

- Few standards, benchmarks, and thresholds exist among the dozens of indicators and metrics that comprise urban sustainability systems.
- There is a lack of common and standardized indicators and metrics.
- It is difficult to draw strong scientific conclusions about drivers of sustainability because of the limited experimentation and the lack of counterfactual evidence.
- There is a lack of data to populate many metrics (e.g., distributional metrics other than the income Gini coefficient) that often requires other geographic levels to substitute for or represent urban areas.
- It is easy to be overwhelmed by the abundance of indicators. Also, the most common indicators are not necessarily the most important. Some can be surrogates for others. Indicator selection is a process that combines science, judgment, and the involvement of numerous parties; the process needs to be better understood.
- Going forward, rapidly developing information and communication technologies in combination with social media and "big data" approaches will open up new opportunities for monitoring and understanding urban sustainability in ways that can potentially better exploit large quantities of time-series, high-resolution, near-instantaneous measurements. Mapping and visualization will become increasingly important to identify and integrate indicators. The quality of indicators and metrics benefits from the increasing research in numerous areas that pertain to the sustainability dimensions covered in the report; however, to make these actionable will require continued investment in the infrastructure to monitor and measure attributes that comprise the indicators.
- Metrics are not all logically actionable. It is important to identify what is truly exogenous—conditions that cannot be altered but that influence the ability of policies and actions to promote sustainability.
- To be sure the task of selecting a narrow suite of indicators to better understand urban sustainability is by no means easy. The uncertainties of doing so herein are not quantitatively addressed. Instead the committee provides an initial set of set of indicators, to serve as the basis for future research and development.

Using the described indicator dimensions and corresponding individual indicator descriptions, Appendix B provides the foundation for applying these indicators to the profile cities in Chapter 4. Where possible, indicators are designated at the city or metropolitan area scale. Counties (see Table 2-2) were used in instances where city data were not available. For comparative purposes, U.S. values are also reported, where they are available or applicable. Information from Appendix B is used to provide a comparative snapshot of the nine cities in the form of the spider charts presented in Chapter 4 (see Figure 4-22).

3

Principles of Urban Sustainability: A Roadmap for Decision Making

It must be recognized that ultimately all sustainability is limited by biophysical limits and finite resources at the global scale (e.g., Burger et al., 2012; Rees, 2012). A city or region cannot be sustainable if its principles and actions toward its own, local-level sustainability do not scale up to sustainability globally. Thus, localities that develop an island or walled-city perspective, where sustainability is defined as only activities within the city's boundaries, are by definition not sustainable.

At its core, the concept of sustainable development is about reconciling "development" and "environment" (McGranahan and Satterthwaite, 2003). Development, i.e., the meeting of people's needs, requires use of resources and implies generation of wastes. The environment has finite resources, which present limits to the capacity of ecosystems to absorb or break down wastes or render them harmless at local, regional, and global scales.

If development implies extending to all current and future populations the levels of resource use and waste generation that are the norm among middle-income groups in high-income nations, it is likely to conflict with local or global systems with finite resources and capacities to assimilate wastes. As described in Chapter 2, many indicators and metrics have been developed to measure sustainability, each of which has its own weaknesses and strengths as well as availability of data and ease of calculation. Some of the most prevailing indicators include footprinting (e.g., for water and land) and composite indices (e.g., well-being index and environmental sustainability index). It is beyond the scope of this report to examine all available measures, and readers are directed to any of the numerous reviews that discuss their relative merits (see, for example, Čuček et al., 2012; EPA, 2014a; Janetos et al., 2012; Wiedmann and Barrett, 2010; Wilson et al., 2007; The World Bank, 2016; Yale University, 2016). New sustainability indicators and metrics are continually being developed, in part because of the wide range of sustainability frameworks used as well as differences in spatial scales of interest and availability (or lack thereof) of data. In recent years, city-level sustainability indicators have become more popular in the literature (e.g., Mori and Christodoulou, 2012).

Here we use the concept of ecological footprint, which has been proposed as an analytic tool to estimate the "load" imposed on the ecosphere by any specified human population (Berkowitz and Rees, 2003). We choose it not because it is without controversy, but rather because it is one of the more commonly cited indicators that has been widely used in many different contexts around the world. The metric most often used is the total area of productive landscape and waterscape required to support that population (Rees, 1996; Wackernagel and Rees, 1996). Ecological footprint analysis has helped to reopen the controversial issue of human "carrying capacity." The ecological footprint of a specified population is the area of land and water ecosystems required continuously over time to produce the resources that the population consumes, and to assimilate the wastes that the population produces, wherever on Earth the relevant land and/or water is located.

Ecological footprint calculations show that the wealthy one-fifth of the human family appropriates the goods and life support services of 5 to 10 hectares (12.35 to 24.70 acres) of productive land and water per capita to support their consumer lifestyles using prevailing technology. Only about 2 hectares (4.94 acres) of such ecosystems are available, however, for each person on Earth (with no heed to the independent requirements of other consumer species). In discussing sustainability from a global perspective, Burger et al. (2012) argued that the laws of thermodynamics and biophysical constraints place limitations on what is possible for all systems, including human systems such as cities. Given the relevance and impact of these constraints to the discussion of various pathways to urban sustainability, a further examination of these issues and their associated challenges are described in Appendix C (as well as by Day et al., 2014; Seto and Ramankutty, 2016; UNEP, 2012).

Daly (2002) proposed three criteria that must be met for a resouce or process to be considered sustainable:

- For a renewable resource—soil, water, forest, fish—the sustainable rate of use can be no greater than the rate of regeneration of its source.
- For a nonrenewable resource—fossil fuel, high-grade mineral ores, fossil groundwater—the sustainable rate of use can be no greater than the rate at which a renewable resource, used sustainably, can be substituted for it.
- For a pollutant—the sustainable rate of emission can be no greater than the rate at which that pollutant can be recycled, absorbed, or rendered harmless in its sink.

Fiala (2008) pointed to two issues that can be raised regarding the ecological footprint method. One is that the ecological footprint is dominated by energy as over 50 percent of the footprint of most high- and middle-income nations is due to the amount of land necessary to sequester greenhouse gases (GHGs). The other is associated to the impact of technology intensity that is assumed for characterizing productivity in terms of the global hectare. The results do show that humans' global ecological footprint is already well beyond the area of productive land and water ecosystems available on Earth and that it has been expanding in the recent decades.

DESCRIPTION OF PRINCIPLES

Urban sustainability has been defined in various ways with different criteria and emphases, but its goal should be to promote and enable the long-term well-being of people and the planet, through efficient use of natural resources and production of wastes within a city region while simultaneously improving its livability, through social amenities, economic opportunity, and health, so that it can better fit within the capacities of local, regional, and global ecosystems, as discussed by Newman (1999).

Because an increasing percentage of the world's population and economic activities are concentrated in urban areas, cities are highly relevant, if not central, to any discussion of sustainable development. While urban areas can be centers for social and economic mobility, they can also be places with significant inequality, debility, and environmental degradation: A large proportion of the world's population with unmet needs lives in urban areas.

Although cities concentrate people and resources, and this concentration can contribute to their sustainability, it is also clear that cities themselves are not sustainable without the support of ecosystem services, including products from ecosystems such as raw materials and food, from nonurban areas. Indeed, it is unrealistic—and not necessarily desirable—to require cities to be solely supported by resources produced within their administrative boundaries. Thinking about cities as closed systems that require self-sustaining resource independence ignores the concepts of comparative advantage or the benefits of trade and economies of scale. Since materials and energy come from long distances around the world to support urban areas, it is critical for cities to recognize how activities and consumption within their boundaries affect places and people outside their boundaries. Here it is important to consider not only the impact on land-based resources but also water and energy that are embodied in products such as clothing and food.

Ultimately, all the resources that form the base on which urban populations subsist come from someplace on the planet, most often outside the cities themselves, and often outside of the countries where the cities exist. Indeed, often multiple cities rely on the same regions for resources. Thus, urban sustainability cannot be limited to what happens *within* a single place. The sustainability of a city cannot be considered in isolation from the planet's finite resources, especially given the aggregate impact of all cities. Therefore, urban sustainability will require making explicit and addressing the interconnections and impacts on the planet.

Urban sustainability is therefore a multiscale and multidimensional issue that not only centers on but transcends urban jurisdictions and which can only be addressed by durable leadership, citizen involvement, and regional partnerships as well as vertical interactions among different governmental levels.

In this context, we offer four main principles to promote urban sustainability, each discussed in detail below:

Principle 1: The planet has biophysical limits.
Principle 2: Human and natural systems are tightly intertwined and come together in cities.
Principle 3: Urban inequality undermines sustainability efforts.
Principle 4: Cities are highly interconnected.

Principle 1: The Planet Has Biophysical Limits

Urban areas and the activities within them use resources and produce byproducts such as waste and pollution that drive many types of global change, such as resource depletion, land-use change, loss of biodiversity, and high levels of energy use and greenhouse gas emissions. Over the long term and at global scales, economic growth and development will be constrained by finite resources and the biophysical limits of the planet to provide the resources required for development, industrialization, and urbanization. Currently, many cities have sustainability strategies that do not explicitly account for the indirect, distant, or long-lived impacts of environmental consumption throughout the supply and product chains. Because urban systems connect distant places through the flows of people, economic goods and services, and resources, urban sustainability cannot be focused solely on cities themselves, but must also encompass places and land from which these resources originate (Seto et al., 2012). Consequently, what may appear to be sustainable locally, at the urban or metropolitan scale, belies the total planetary-level environmental or social consequences. Urban sustainability strategies and efforts must stay within planetary boundaries,[1] particularly considering the urban metabolism, constituted by the material and energy flows that keep cities alive (see also Box 3-1) (Burger et al., 2012; Ferrão and Fernández, 2013). Without paying heed to finite resources, urban sustainability may be increasingly difficult to attain depending on the availability and cost of key natural resources and energy as the 21st century progresses (Day et al., 2014, 2016; McDonnell and MacGregor-Fors, 2016; Ramaswami et al., 2016). In practice cities could, for example, quantify their sustainability impacts using a number of measures such as per capita ecological footprint and, making use of economies of scale, make efforts to reduce it below global levels of sustainability. Together, cities can play important roles in the stewardship of the planet (Seitzinger et al., 2012).

In an increasingly urbanized and globalized world, the boundaries between urban and rural and urban and hinterland are often blurred. In an era that is characterized by global flows of commodities, capital, information, and people, the resources to support urban areas extend the impacts of urban activities along environmental, economic, and social dimensions at national and international levels, and become truly global; crossing these boundaries is a prerequisite for sustainable governance. Ultimately, given its U.S. focus and limited scope, this report does not fully address the notion of global flows. It nevertheless serves as an indicator for advancing thinking along those lines.

[1] Planetary boundaries define, as it were, the boundaries of the "planetary playing field" for humanity if we want to be sure of avoiding major human-induced environmental change on a global scale (Rockström et al., 2009). The concept of planetary boundaries has been developed to outline a safe operating space for humanity that carries a low likelihood of harming the life support systems on Earth to such an extent that they no longer are able to support economic growth and human development . . . planetary boundaries do not place a cap on human development. Instead they provide a safe space for innovation, growth, and development in the pursuit of human prosperity in an increasingly populated and wealthy world (Rockström et al., 2013).

BOX 3-1
Implications of Principle 1

In short, urban sustainability will require a reconceptualization of the boundaries of responsibility for urban residents, urban leadership, and urban activities. It will require recognition of the biophysical and thermodynamic aspects of sustainability. Simply put, any sustainability plans, including those applied in urban areas, cannot violate the laws of nature if they are to achieve acceptable, long-term outcomes for human populations. Cities have central roles in managing the planet's resources sustainability (Seitzinger et al., 2012).

There are many policy options that can affect urban activities such that they become active and positive forces in sustainably managing the planet's resources. In many ways, this is a tragedy of the commons issue, where individual cities act in their own self-interest at the peril of shared global resources. One challenge in the case of cities, however, is that many of these shared resources do not have definable boundaries such as land. Moreover, because most cities are geographically separated from their resource base, it is difficult to assess the threat of resource depletion or decline. Thus, some strategies to manage communal resources, such as community-based, bottom-up approaches examined by Ostrom (2009a), may be more difficult to obtain in urban settings. Another approach is for government intervention through regulation of activities or the resource base.

As one example, McGranahan and Satterthwaite (2003) suggested that adding concern for ecological sustainability onto existing development policies means setting limits on the rights of city enterprises or consumers to use scarce resources (wherever they come from) and to generate nonbiodegradable wastes. Such limits can be implemented through local authorities' guidelines and regulations in planning and regulating the built environment, e.g., guidelines and regulations pertaining to building material production, construction, building design and performance, site and settlement planning, and efficiency standards for appliances and fixtures. Ultimately, the laws of thermodynamics limit the amount of useful recycling.

Goals relating to local or global ecological sustainability can be incorporated into the norms, codes, and regulations that influence the built environment. But city authorities need national guidelines and often national policies. In most political systems, national governments have the primary role in developing guidelines and supporting innovation allied to regional or global conventions or guidelines where international agreement is reached on setting such limits.

The effort of promoting sustainable development strategies requires a greater level of interaction between different systems and their boundaries as the impacts of urban-based consumption and pollution affect global resource management and, for example, global climate change problems; therefore, pursuing sustainability calls for unprecedented system boundaries extensions, which are increasingly determined by actions at the urban level. This is to say, the analysis of boundaries gives emphasis to the idea of "think globally, act locally."

Principle 2: Human and Natural Systems Are Tightly Intertwined and Come Together in Cities

Healthy people-environment and human-environment interactions are necessary synergistic relationships that underpin the sustainability of cities. In order for urban places to be sustainable from economic, environmental, and equity perspectives, pathways to sustainability require a systemic approach around three considerations: scale, allocation, and distribution (Daly, 1992). Human well-being and health are the cornerstones of livable and thriving cities although bolstering these relationships with myopic goals that improve human prosperity while disregarding the health of natural urban *and* nonurban ecosystems will only serve to undermine both human and environmental

BOX 3-2
Implications of Principle 2

Healthy people, healthy biophysical environments, and healthy human-environment interactions are synergistic relationships that underpin the sustainability of cities (Liu et al., 2007).

urban sustainability in the long run. The future of urban sustainability will therefore focus on win-win opportunities that improve both human and natural ecosystem health in cities. These win-win efficiencies will often take advantage of economies of scale and adhere to basic ideas of robust urbanism, such as proximity and access (to minimize the time and costs of obtaining resources), density and form (to optimize the use of land, buildings, and infrastructure), and connectedness (to increase opportunities for efficient and diverse interactions).

Local decision making must have a larger scope than the confines of the city or region. Discussions should generate targets and benchmarks but also well-researched choices that drive community decision making. Sustainability is a community concern, not an individual one (Pelletier, 2010). Healthy human and natural ecosystems require that a multidimensional set of a community's interests be expressed and actions are intentional to mediate those interests (see also Box 3-2).

Principle 3: Urban Inequalities Undermine Sustainability Efforts

Reducing severe economic, political, class, and social inequalities is pivotal to achieving urban sustainability. Many of these class and cultural inequalities are the products of centuries of discrimination, including instances of officially sanctioned discrimination at the hands of residents and elected leaders (Fullilove and Wallance, 2011; Powell and Spencer, 2002). Extreme inequalities threaten public health, economic prosperity, and citizen engagement—all essential elements of urban sustainability. Although perfect class and economic equality is not possible, severe urban disparities should remain in check if cities are to realize their full potential and become appealing places of choice for multigenerational urban dwellers and new urban immigrants alike.

Discriminatory practices in the housing market over many decades have created racial segregation in central cities and suburbs. Restrictive housing covenants, exclusionary zoning, financing, and racism have placed minorities and low-income people in disadvantaged positions to seek housing and neighborhoods that promote health, economic prosperity, and human well-being (Denton, 2006; Rabin, 1989; Ritzdorf, 1997; Sampson, 2012; Tilley, 2006). Poor neighborhoods have felt the brunt of dumping, toxic waste, lack of services, and limited housing choices (Collin and Collin, 1997; Commission for Racial Justice, 1987). There is evidence that the spatial distribution of people of color and low-income people is highly correlated with the distribution of air pollution, landfills, lead poisoning in children, abandoned toxic waste dumps, and contaminated fish consumption. Inequitable environmental protection undermines procedural, geographic, and social equities (Anthony, 1990; Bullard, 1995). These same patterns of inequality also exist between regions and states with poor but resource-rich areas bearing the cost of the "resource curse" (see also Box 3-3).

Principle 4: Cities Are Highly Interconnected

Cities are not islands. Urban systems are complex networks of interdependent subsystems, for which the degree and nature of the relationships are imperfectly known. The spatial and time scales of various subsystems are different, and the understanding of individual subsystems does not imply the global understanding of the full system. Meeting the challenges of planetary stewardship demands new governance solutions and systems that respond to the realities of interconnectedness. Currently, urban governance is largely focused on single issues such as water,

BOX 3-3
Implications of Principle 3

As networks grow between extended urban regions and within cities, issues of severe economic, political, and class inequalities become central to urban sustainability. Efforts to reduce severe urban disparities in public health, economic prosperity, and citizen engagement allow cities to improve their full potential and become more appealing and inclusive places to live and work (UN, 2016b). Policies and cultural norms that support the outmigration, gentrification, and displacement of certain populations stymie economic and environmental progress and undermine urban sustainability (Fullilove and Wallace, 2011; Powell and Spencer, 2002; Williams, 2014). Long-term policies and institutionalized activities that can promote greater equity can contribute to the future of sustainable cities.

transportation, or waste. A multiscale governance system that explicitly addresses interconnected resource chains and interconnected places is necessary in order to transition toward urban sustainability (Box 3-4).

Urban sustainability requires the involvement of citizens, private entities, and public authorities, ensuring that all resources are mobilized and working toward a set of clearly articulated goals. This is particularly relevant as places undergo different stages of urbanization and a consequent redrawing of borders and spheres of economic influence. Sustainable solutions are to be customized to each of the urban development stages balancing local constraints and opportunities, but all urban places should strive to articulate a multiscale and multipronged vision for improving human well-being. An important example is provided by climate change issues, as highlighted by Wilbanks and Kates (1999): Although climate change mainly takes place on the regional to global scale, the causes, impacts, and policy responses (mitigation and adaptation) tend to be local.

As discussed by Bai (2007), the fundamental point in the scale argument is that global environmental issues are simply beyond the reach and concern of city government, and therefore it is difficult to tackle these issues at the local level. As simple and straightforward as this may sound, the scale argument encompasses more than spatial scale—it is composed of multiple dimensions and elements. Bai (2007) points to three—the spatial, temporal, and institutional dimensions—and in each of these dimensions, three elements exist: scale of issues, scale of concerns, and scale of actions and responses. Understanding these interconnections within system boundaries, from urban to global, is essential to promote sustainability. In particular, the institutional dimension plays an important role in how global issues are addressed, as discussed by Gurr and King (1987), who identified the need to coordinate two levels of action: the first relates to "vertical autonomy"—the city's relationship with federal administration—and the second relates to the "horizontal autonomy"—a function of the city's relationship with local economic and social groups that the city depends on for its financial and political support.

BOX 3-4
Implications of Principle 4

A holistic view, focused on understanding system structure and behavior, will require building and managing transdisciplinary tools and metrics. This requirement applies to governance vertically at all levels of administration, from local to federal and international, and horizontally among various urban sectors and spaces. Durable sustainability policies that transcend single leaders, no matter how influential, will also be necessary to foster reliable governance and interconnectedness over the long term for cities.

BUILDING AN URBAN SUSTAINABILITY ROADMAP

Designing a successful strategy for urban sustainability requires developing a holistic perspective on the interactions among urban and global systems, and strong governance. This lens is needed to undergird and encourage collaborations across many organizations that will enable meaningful pathways to urban sustainability. In order to facilitate the transition toward sustainable cities, we suggest a decision framework that identifies a structured but flexible process that includes several critical elements (Figure 3-1).

The roadmap is organized in three phases: (1) creating the basis for a sustainability roadmap, (2) design and implementation, and (3) outcomes and reassessment. A description of each of these phases is given below.

Phase 1: Creating the Basis for a Sustainability Roadmap

Adopt Urban Sustainability Principles

This is the first step to establish an urban sustainability framework consistent with the sustainability principles described before, which provide the fundamental elements to identify opportunities and constraints for different contexts found in a diversity of urban areas.

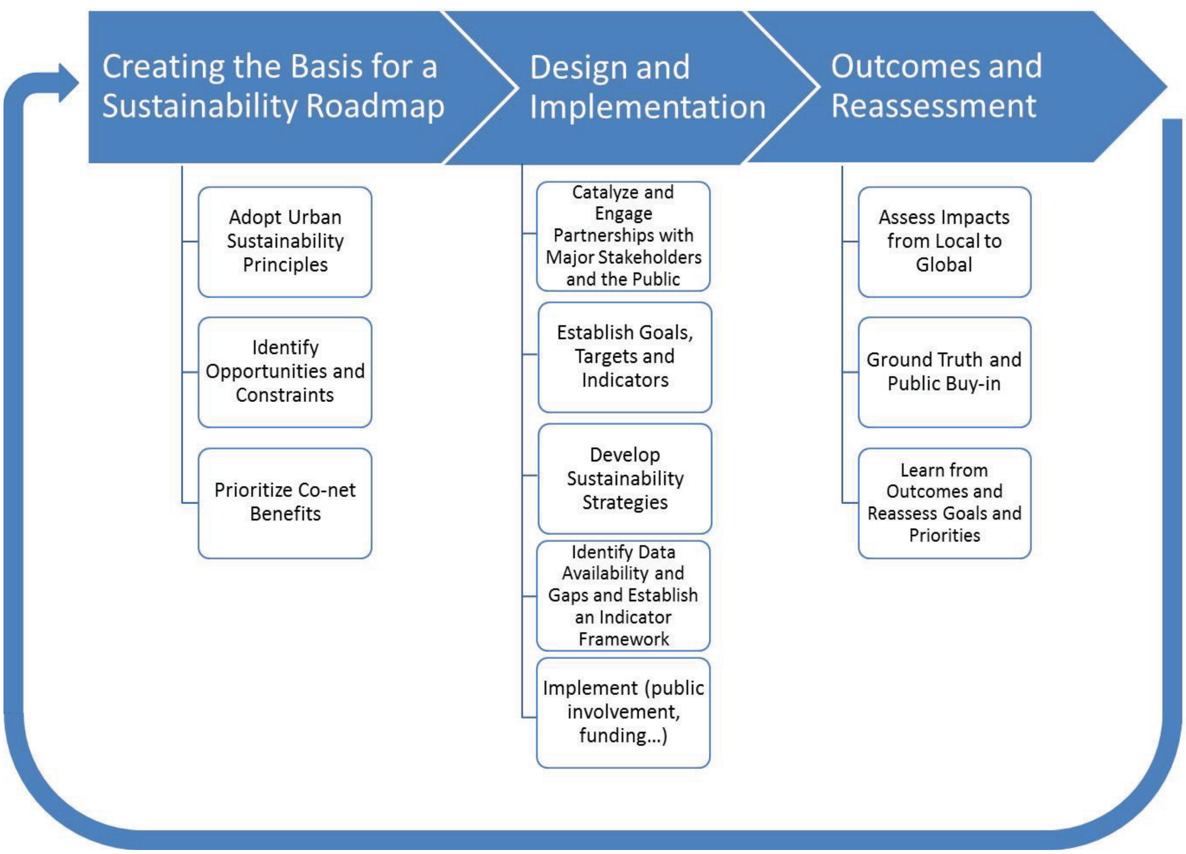

FIGURE 3-1 An urban sustainability roadmap. SOURCE: Committee generated.

Identify Opportunities and Constraints

Any urban sustainability strategy is rooted in place and based on a sense of place, as identified by citizens, private entities, and public authorities. In this step it is critical to engage community members and other stakeholders in identifying local constraints and opportunities that promote or deter sustainable solutions at different urban development stages. Community engagement will help inform a multiscale vision and strategy for improving human well-being through an environmental, economic, and social equity lens. Often a constraint may result in opportunities in other dimensions, with an example provided by Chay and Greenstone (2003) on the impact of the Clean Air Act amendments on polluting plants from 1972 and 1987. They found that while those companies lost almost 600,000 jobs compared with what would have happened without the regulations, there were positive gains in health outcomes. Complementary research showed that clean air regulations have reduced infant mortality and increased housing prices (Chay and Greenstone, 2005; EPA, 1999). This study provides direct and easily interpreted estimates of the air quality and infant health benefits of the 1970 Act. The results imply that poor air quality had substantial effects on infant health at concentrations near the U.S. Environmental Protection Agency–mandated air quality standard and that roughly 1,300 fewer infants died in 1972 than would have in the absence of the Act. Furthermore, this study's findings cross-validate the findings of earlier work examining the recession-induced pollution reductions of the early 1980s.

Prioritize and Identify Co-net Benefits

Decision making at such a complex and multiscale dimension requires prioritization of the key urban issues and an assessment of the co-net benefits associated with any action in one of these dimensions. Where possible, activities that offer co-occurring, reasonably sized benefits in multiple dimensions of sustainability should be closely considered and pursued as primary choices while managing tradeoffs. Activities that provide co-benefits that are small in magnitude, despite being efficient and co-occurring, should be eschewed unless they come at relatively small costs to the system.

Phase 2: Design and Implementation

Catalyze and Engage Partnerships with Major Stakeholders and the Public

Urban sustainability requires durable, consistent leadership, citizen involvement, and regional partnerships as well as vertical interactions among different governmental levels, as discussed before. Furthermore, the governance of urban activities does not always lie solely with municipal or local authorities or with other levels of government. Nongovernmental organizations and private actors such as individuals and the private sector play important roles in shaping urban activities and public perception.

Establish Goals, Targets, and Indicators

Commitment to sustainable development by city or municipal authorities means adding new goals to those that are their traditional concerns (McGranahan and Satterthwaite, 2003). Meeting development goals has long been among the main responsibilities of urban leaders. These goals generally include attracting new investment, improving social conditions (and reducing social problems), ensuring basic services and adequate housing, and (more recently) raising environmental standards within their jurisdiction. These goals do not imply that city and municipal authorities need be major providers of housing and basic services, but they can act as supervisors and/or supporters of private or community provision. A concern for sustainable development retains these conventional concerns and adds two more. The first is to consider the environmental impacts of urban-based production and consumption on the needs of all people, not just those within their jurisdiction. The second is an understanding of the finite nature of many natural resources (or the ecosystems from which they are drawn) and of the capacities of natural systems in the wider regional, national, and international context to absorb or break down wastes.

Develop Urban Sustainability Strategies

Urban sustainability goals often require behavior change, and the exact strategies for facilitating that change, whether through regulation or economic policies, require careful thought. Specific strategies can then be developed to achieve the goals and targets identified. These strategies should not be developed in isolation, but rather in collaboration with, or ideally, developed by, the practitioners responsible for achieving the goals and targets. This helps to facilitate the engagement, buy-in, and support needed to implement these strategies.

The strategies employed should match the context. Specifically, market transformation can traditionally be accomplished by first supporting early adopters through incentives; next encouraging the majority to take action through market-based approaches, behavior change programs, and social norming; and, finally, regulating to prompt action from laggards. This common approach can be illustrated in the case of urban food scraps collection where many cities first provided in-kind support to individuals and community groups offering collection infrastructure and services, then rolled out programs to support social norming in communities (e.g., physical, visible, green bins for residents to be put out at the curb), and finally banned organics from landfills, providing a regulatory mechanism to require laggards to act.

Identify Data Availability and Gaps and Establish an Indicator Framework

The development of analysis to improve the sustainability of urbanization patterns, processes, and trends has been hindered by the lack of consistent data to enable the comparison of the evolution of different urban systems, their dynamics, and benchmarks. Providing the data necessary to analyze urban systems requires the integration of different economic, environmental, and social tools. These tools should provide a set of indicators whose political relevance refers both to its usefulness for securing the fulfillment of the vision established for the urban system and for providing a basis for national and international comparisons, and the metrics and indicators should be policy relevant and actionable. Furthermore, the development of indicators should be supported with research that expresses the impact of the indicator. Every indicator should be connected to both an implementation and an impact statement to garner more support, to engage the public in the process, and to ensure the efficiency and impact of the indicator once realized. Understanding indicators and making use of them to improve urban sustainability could benefit from the adoption of a DPSIR framework, as discussed by Ferrão and Fernández (2013). The DPSIR framework describes the interactions between society and the environment, the key components of which are driving forces (D), pressures (P) on the environment and, as a result, the states (S) of environmental changes, their impacts (I) on ecosystems, human health, and other factors, and societal responses (R) to the driving forces, or directly to the pressure, state, or impacts through preventive, adaptive, or curative solutions. Such a framework of indicators constitutes a practical tool for policy making, as it provides actionable information that facilitates the understanding and the public perception of complex interactions between drivers, their actions and impacts, and the responses that may improve the urban sustainability, considering a global perspective.

Practitioners starting out in the field would be well served by adopting one or more of the best practice standards (e.g., United Nations Sustainable Development Goals, Urban Sustainability Directors Network Sustainability Tools for Assessing and Rating Communities, and International Organization for Standardization Sustainability Standards) rather than endeavoring to develop their own unique suite of metrics as their data would be more comparable between cities and would have some degree of external validity built in. A practitioner could complement the adopted standard(s) with additional indicators unique to the city's context as necessary.

Implementation

Institutional scale plays an important role in how global issues can be addressed. For example, as discussed by Bai (2007), at least two important institutional factors arise in addressing GHG emission in cities: The first is the vertical jurisdictional divide between different governmental levels; the second is the relations between the local government and key industries and other stakeholders. According to the definition by Gurr and King (1987), the first relates to vertical autonomy, which is a function of the city's relationship with senior-level government, and the second relates to horizontal autonomy, which is a function of the city's relationship with local economic and social groups that the city depends on for its financial and political support. The implementation of long-term institutional governance measures will further support urban sustainability strategies and initiatives.

Phase 3: Outcomes and Reassessment

Assessing Impacts from Local to Global

Conceptually, the idea that there is an ecological footprint, and that sustainable cities are places that seek to minimize this footprint, makes great sense (Portney, 2002). Assessing a city's environmental impacts at varying scales is extremely difficult. In practice, simply trying to pin down the size of any specific city's ecological footprint—in particular, the ecological footprint per capita—may contribute to the recognition of its relative impacts at a global scale.

How many goods are imported into and exported from a city is not known in practically any U.S. city. Getting an accurate picture of the environmental impacts of all human activity, including that of people working in the private sector, is almost impossible. However, some cities are making a much more concerted effort to understand the full range of the negative environmental impacts they produce, and working toward reducing those impacts even when impacts are external to the city itself. Cities that are serious about sustainability will seek to minimize their negative environmental impacts across all scales from local to global.

Develop Ground Truthing and Public Buy-in

As discussed by Bai (2007), although there are factors beyond local control, the main obstacles to bringing the global concerns onto the local level are the reflection of contradictory perceptions, concerns, interests, and priorities, rather than the scale of the issue. Therefore, the elimination of these obstacles must start by clarifying the nature of the issue, identifying which among the obstacles are real and which can be handled by changing perceptions, concerns, and priorities at the city level. For instance, over the past 50 years, many U.S. cities experienced unprecedented reductions in population, prominently driven by highly publicized perceptions that city environments are somehow innately unsafe. However, recent scientific analyses have shown that major cities are actually the safest areas in the United States, significantly more so than their suburban and rural counterparts, when considering that safety involves more than simply violent crime risks but also traffic risks and other threats to safety (Myers et al., 2013). It is crucial for city leaders to be aware of such perceptions, both true and artificial, and the many opportunities that may arise in directly addressing public concerns, as well as the risks and consequences of not doing so.

Some of the major advantages of cities as identified by Rees (1996) include (1) lower costs per capita of providing piped treated water, sewer systems, waste collection, and most other forms of infrastructure and public amenities; (2) greater possibilities for, and a greater range of options for, material recycling, reuse, remanufacturing, and the specialized skills and enterprises needed to make these things happen; (3) high population density, which reduces the per capita demand for occupied land; (4) great potential through economies of scale, co-generation, and the use of waste process heat from industry or power plants, to reduce the per capita use of fossil fuel for space heating; and (5) great potential for reducing (mostly fossil) energy consumption by motor vehicles through walking. There is the issue, however, that economic and energy savings from these activities may suffer from Jevon's Paradox in that money and energy saved in the ways mentioned above will be spent elsewhere, offsetting local efficiencies (Brown et al., 2011; Hall and Klitgaard, 2011).

Learning from Outcomes and Ongoing Reassessment of Goals and Priorities

The continuous reassessment of the impact of the strategy implemented requires the use of metrics, and a DPSIR framework will be particularly useful to assess the progress of urban sustainability. Here we advocate a DPSIR conceptual model based on indicators used in the assessment of urban activities (transportation, industry, tourism, etc.), as discussed in Chapter 2. Classifying these indicators as characterizing a driver, a pressure, the state, the impact, or a response may allow for a detailed approach to be used even in the absence of a comprehensive theory of the phenomena to be analyzed. The use of a DPSIR model posits an explicit causality effect between different actors and consequences and ensures exhaustive coverage of the phenomena contained in the model (Ferrão and Fernandez, 2013).

Developing new signals of urban performance is a crucial step to help cities maintain Earth's natural capital in the long term (Alberti, 1996). The task is, however, not simple. The challenge is to develop a new understanding of how urban systems work and how they interact with environmental systems on both the local and global scale. Three elements are part of this framework:

1. Key variables to describe urban and environmental systems and their interrelationships;
2. Measurable objectives and criteria that enable the assessment of these interrelationships; and
3. Feedback mechanisms that enable the signals of system performance to generate behavioral responses from the urban community at both the individual and institutional levels.

A DPSIR framework is intended to respond to these challenges and to help developing urban sustainability policies and enact long-term institutional governance to enable progress toward urban sustainability.

RESEARCH AND DEVELOPMENT NEEDS

Urban sustainability is a large and multifaceted topic. The following discussion of research and development needs highlights just a few ways that science can contribute to urban sustainability. This discussion focuses on promoting a systems approach—connections, processes, and linkages—that requires data, benchmarks, and guidance on what variables are relevant and what processes are most critical to understanding the relationships among the parts of the system. As such, there are many important opportunities for further research. These opportunities can be loosely placed in three categories: first, filling quantitative data gaps; second, mapping qualitative factors and processes; and third, identifying and scaling successful financing models to ensure rapid adoption.

First, large data gaps exist. Efforts have been made by researchers and practitioners alike to create sets of indicators to assist in measuring and comparing the sustainability of municipalities, but few thresholds exist, and those that do often seem unattainable to municipal leaders. For example, in order to ensure that global warming remains below two degrees Celsius, the theoretical "safe limit" of planetary warming beyond which irreversible feedback loops begin that threaten human health and habitat, most U.S. cities will need to reduce GHG emissions 80 percent by 2050. This is a target that leading cities have begun to adopt, but one that no U.S. city has developed a sound strategy to attain. Second, cities exist as part of integrated regional and global systems that are not fully understood. Further mapping of these processes, networks, and linkages is important in order to more fully understand the change required at the municipal level to support global sustainability. Some promising models exist, such as MIT's Urban Metabolism framework, that warrant further development (Ferrão and Fernández, 2013). Third, the critical task of developing finance models to support urban sustainability action requires urgent attention. Successful models exist elsewhere (such as British Columbia, Canada's, carbon tax), which can be adapted and scaled to support urban sustainability action across America.

A summary of major research and development needs is as follows.

Urban Metabolism

Urban metabolism[2] may be defined as the sum of the technical and socioeconomic processes that occur in cities, resulting in growth, production of energy, and elimination of waste (Kennedy et al., 2007).

[2] Abel Wolman (1965) developed the urban metabolism concept as a method of analyzing cities and communities through the quantification of inputs—water, food, and fuel—and outputs—sewage, solid refuse, and air pollutants—and tracking their respective transformations and flows. See also Holmes and Pincetl (2012).

Characterizing the urban metabolism constitutes a priority research agenda and includes quantification of the inputs, outputs, and storage of energy, water, nutrients, products, and wastes, at an urban scale. This task is complex and requires further methodological developments making use of harmonized data, which may correlate material and energy consumption with their socioeconomic drivers, as attempted by Niza et al. (2009), NRC (2004), Pina et al. (2015), and Rosado et al. (2014).

Once established, urban metabolism models supported by adequate tools and metrics enable a research stream to explore the optimization of resource productivity and the degree of circularity of resource streams that may be helpful in identifying critical processes for the sustainability of the urban system and opportunities for improvement.

Flows Between Places, Linkages, and Network Characterization

Much of the current information on urban areas is about "stocks" or snapshots of current conditions of a single place or location. However, what is needed is information on *flows* between places, which allows the characterization of networks, linkages, and interconnections across places. This type of information is critically important to develop new analyses to characterize and monitor urban sustainability, especially given the links between urban places with global hinterlands.

Research Aimed at Detecting Thresholds

To improve the threshold knowledge of sustainability indicators and their utility in defining an action strategy, it is necessary to have empirical tests of the performance and redundancy of these indicators and indicator systems.[3] This is of increasing importance to policy makers and the public as human production and consumption put increased stress on environmental, economic, and social systems. In each parameter of sustainability, disruptions can only be withstood to a certain level without possible irreversible consequences. To avoid negative consequences, it is important to identify the threshold that is available and then determine the actual threshold values. The scientific study of environmental thresholds, their understanding, modeling, and prediction should also be integrated into early warning systems to enable policy makers to understand the challenges and impacts and respond effectively (Srebotnjak et al., 2010).

Understanding Different Types of Data

There is a need to go beyond conventional modes of data observation and collection and utilize information contributed by users (e.g., through social media) and in combination with Earth observation systems. The key here is to be able to provide information on processes across multiple scales, from individuals and households to blocks and neighborhoods to cities and regions.

Decision-Making Processes That Link Across Scales

Very little information on the phases of urban processes exists, be it problem identification or decision making. Information is needed on how the processes operate, including by whom and where outcomes and inputs are determined as well as tipping points in the system.

All of the above research needs derive from the application of a complex system perspective to urban sustainability. In other words, the needs call for the study of cities as complex systems, including the processes at different scales, determining factors, and tipping points to avoid adverse consequence. Ultimately, the goal of urban sustainability is to promote and enable the long-term well-being of people and the planet, yet doing so requires recognition of the biophysical constraints on all human and natural systems, as well as the acknowledgment that urban sustainability is multiscale and multidimensional, both encompassing and transcending urban jurisdictions.

[3] Clark, C. M. 2015. Statement at NAS Exploratory Meeting, Washington, DC. October 15, 2015.

Urban sustainability therefore requires horizontal and vertical integration across multiple levels of governance, guided by four principles: the planet has biophysical limits, human and natural systems are tightly intertwined and come together in cities, urban inequality undermines sustainability efforts, and cities are highly interconnected. A comprehensive strategy in the form of a roadmap, which incorporates these principles while focusing on the interactions among urban and global systems, can provide a framework for all stakeholders engaged in metropolitan areas, including local and regional governments, the private sector, and nongovernmental organizations, to enable meaningful pathways to urban sustainability. Science can also contribute to these pathways by further research and development of several key facets of urban areas including urban metabolism, threshold detection of indicators, comprehension of different data sets, and further exploration of decision-making processes linked across scales.

4

City Profiles

As described in Chapter 1, the committee was tasked with examining examples from metropolitan regions to understand how and if sustainability practices could contribute to the development, growth, and regeneration of major metropolitan regions in the United States. As part of its evidence-gathering process, the committee organized a series of public data-gathering meetings in two metropolitan regions, Los Angeles, California, and Chattanooga, Tennessee, to examine issues relating to urban sustainability. Los Angeles and Chattanooga were selected for the committee's public data-gathering meetings due to their varying urban characteristics including size, geography, and contextual sustainability challenges such as water supply, air pollution, and energy. The additional seven city profiles, including New York City, New York; Vancouver, British Columbia; Philadelphia, Pennsylvania; Pittsburgh, Pennsylvania; Grand Rapids, Michigan; Cedar Rapids, Iowa; and Flint, Michigan, were selected to reflect the diversity of U.S. urban contexts along dimensions of city size and density, geographic location, primary industries, and the key challenges to sustainability (Figure 4-1). Topics under consideration included energy, natural resource management, climate adaptation, economic development, hazard mitigation, public health, social equity, and land-use considerations. The committee was responsible for developing the agenda for each meeting in consultation with regional stakeholders in an effort to ensure that the presentations reflected place-based knowledge and approaches to sustainability.

The city profiles are designed to serve as "guideposts"—highlighting, for specific urban contexts, opportunities and challenges that illustrate the committee's urban sustainability "roadmap." Each profile begins with a description of the urban area, including relevant metrics drawn from Chapter 2 and specific sustainability challenges, and then outlines noteworthy sustainability efforts the city undertook along with other significant issues discovered during the committee's research, largely guided by the urban sustainability principles outlined in Chapter 3. The city descriptions end with a series of summary observations and recommendations based on that city and a table that links the city's specific urban contexts back to each step in the aforementioned urban sustainability "roadmap" (see Figures S-1 and 3-1). For example, each table provides illustrative examples of steps drawn from real-world examples, including the first phase (adopting principles, identifying opportunities and constraints, and prioritizing co-net benefits), the second phase (engaging partnerships, establishing goals, developing strategies, identifying data gaps, and implementation), and the third phase (assessing impacts from local to global scales, securing public buy-in, and feedback row) (see Tables 4-2, 4-4, 4-6, 4-8, 4-10, 4-12, 4-14, 4-16, and 4-18). The set of urban sustainability indicators and metrics in Chapter 2 provide much of the empirical evidence that form the basis of the city profiles, and in many instances indicators are included in local climate, energy, and water plans. Moreover,

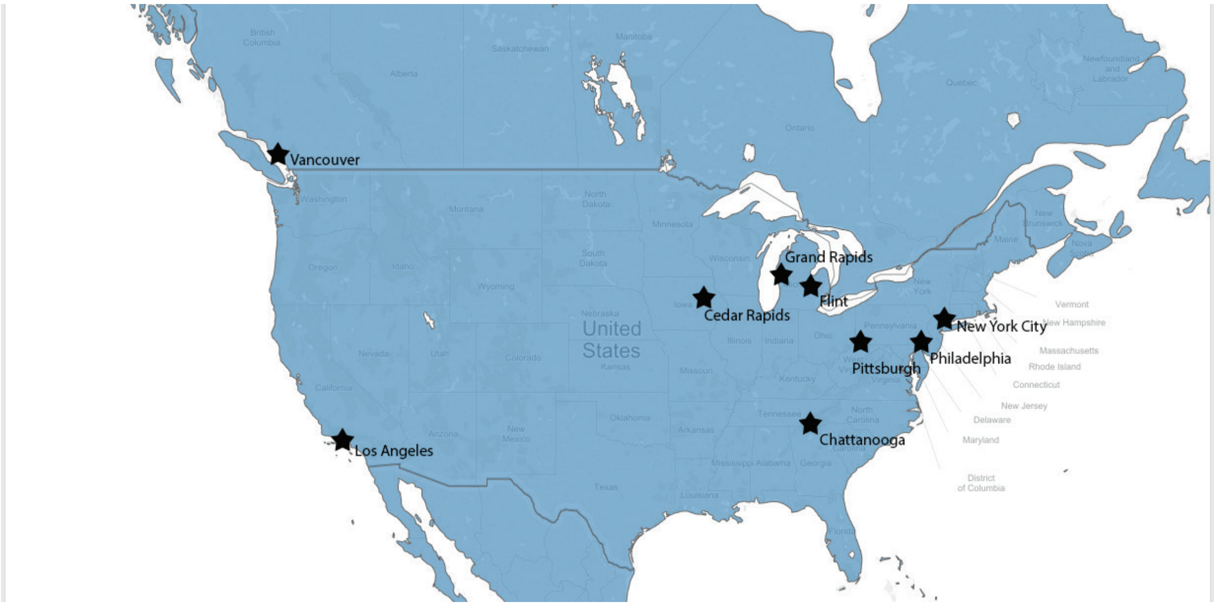

FIGURE 4-1 Map showing the locations of the cities examined by the committee. SOURCE: Prepared by Brent Heard, Consultant to the STS Program.

the profiles are structured to highlight specific urban contexts, opportunities, and challenges that can be linked to the four guiding urban sustainability principles, as described in Chapter 3. For example, many of the city's sustainability challenges directly reflect Principle 1—the planet has biophysical limits—as well as Principle 3—urban inequality undermines sustainability efforts. Principles 2—human and natural systems are tightly intertwined and come together in cities—and 4—cities are highly interconnected—are inherently illustrated throughout many of the city's major sustainability efforts, other significant sustainability activities, and the summary observations which conclude each profile. Thus the profiles in structure and content connect with the Chapter 5 findings and recommendations.

LOS ANGELES

The Los Angeles metropolitan region, both at the city and county levels, faces a number of sustainability challenges, the most prominent of which pertain to water quality and supply, a severe drought, poor air quality, and urban sprawl. The city has confronted these obstacles by developing an aggressive results-based sustainability plan, called the Sustainable City pLAn, that combines specific targets and outcomes pertaining to the environment, the economy, and equity with multistakeholder engagement across institutions and departments, as well as innovative new science-based technologies and solutions. The city also developed an action plan for climate change, embodied in Green LA and its corresponding implementation program Climate LA, which is a "living" document, which is continually updated and modified. Moreover, throughout the Los Angeles metropolitan region, cities such as Santa Monica and Long Beach have taken unique approaches to sustainability strategies based on their specific urban contexts (City of Los Angeles, 2007, 2008; Garcetti, 2015a).

Overall, a combination of regulation and policy instruments has stimulated progress in areas such as water conservation and air quality, with legislation and directives being passed at both the local and state levels, while technological innovations in renewable energy, energy storage, and vehicle electrification have positively impacted sustainability-driven change in transportation and energy. However, ongoing issues relating to poverty and homelessness—Los Angeles County has the highest rate of homelessness in the nation, and poverty levels remain 2 percent above the national average—demonstrate the importance of integrating social issues into sustainability decision making.

BACKGROUND

Building upon its Spanish colonial past, modern Los Angeles, California, began with rapid industrial growth and development in the 1880s and the advent of streetcars and railroads, the surge in real estate markets, and the efflorescence of Hollywood, resulting in rapid population growth that rose from barely 100,000 in 1900 to surpassing 1 million by 1920 (California State Data Center, 2011; City of Los Angeles, 2007). Almost 100 years and 3 million additional inhabitants later, the city of Los Angeles is part of a sprawling urban metropolis, a hub of global trade, and an iconic epicenter of global entertainment (City of Los Angeles, 2007; Heimann et al., 2009). Table 4-1 presents an overview of some of the key characteristics for the city, including environmental, economic, and social indicators, providing a glimpse into Los Angeles' sustainability performance as compared to the national average.

Geography

According to the 2010 U.S. Census, the city of Los Angeles has a population of approximately 3,800,000 people, making it the largest city in California and the second largest city in the United States behind New York (U.S. Census Bureau, 2015b). The majority of the population lives in Central Los Angeles, in the neighborhoods of Koreatown and Westlake (Data Desk, 2015). Known as the cultural hub of the Pacific Rim, the city has a diverse, multiethnic population, with foreign-born individuals composing 38.3 percent of the city population (LATCB, 2015). The largest ethnicity represented is Hispanic or Latino, at 48.5 percent, followed by Caucasian at 28.7

TABLE 4-1 Key Characteristics for Los Angeles

Indicator	Los Angeles	United States
ENV Average Annual Precipitation (inches/year)	18.7	40.8
ENV Existing Tree Canopy (% of land cover)	21%	25%
ENV Roadway Fatalities (per 100 million annual vehicle miles traveled)	0.9	1.1
ENV Particulate Matter 2.5 (ppm)	8.1	10.2
ENV Residential Carbon Footprint (metric tons of CO_2 per capita from residential energy consumption)	1.6	3.4
ECON Financial Health	AA-	AA+
ECON Average Residential Electricity Rate (cents/kWh)	13.0	11.9
SOCIAL Black or African American	9.2%	13.2%
SOCIAL Hispanic or Latino	48.4%	17.4%
SOCIAL Asian	14.8%	5.4%
SOCIAL Home Ownership (2009-2013)	46.9%	64.9%
SOCIAL High School Graduate (25 or older, 2009-2013)	77%	86%
SOCIAL Below Poverty Level	17.8%	15.4%
SOCIAL Violent Crimes (per 100,000 people)	474	191

NOTE: ENV, ECON, and SOCIAL refer to the three dimensions of sustainability: environmental, economic, and social, respectively. SOURCE: Appendix B.

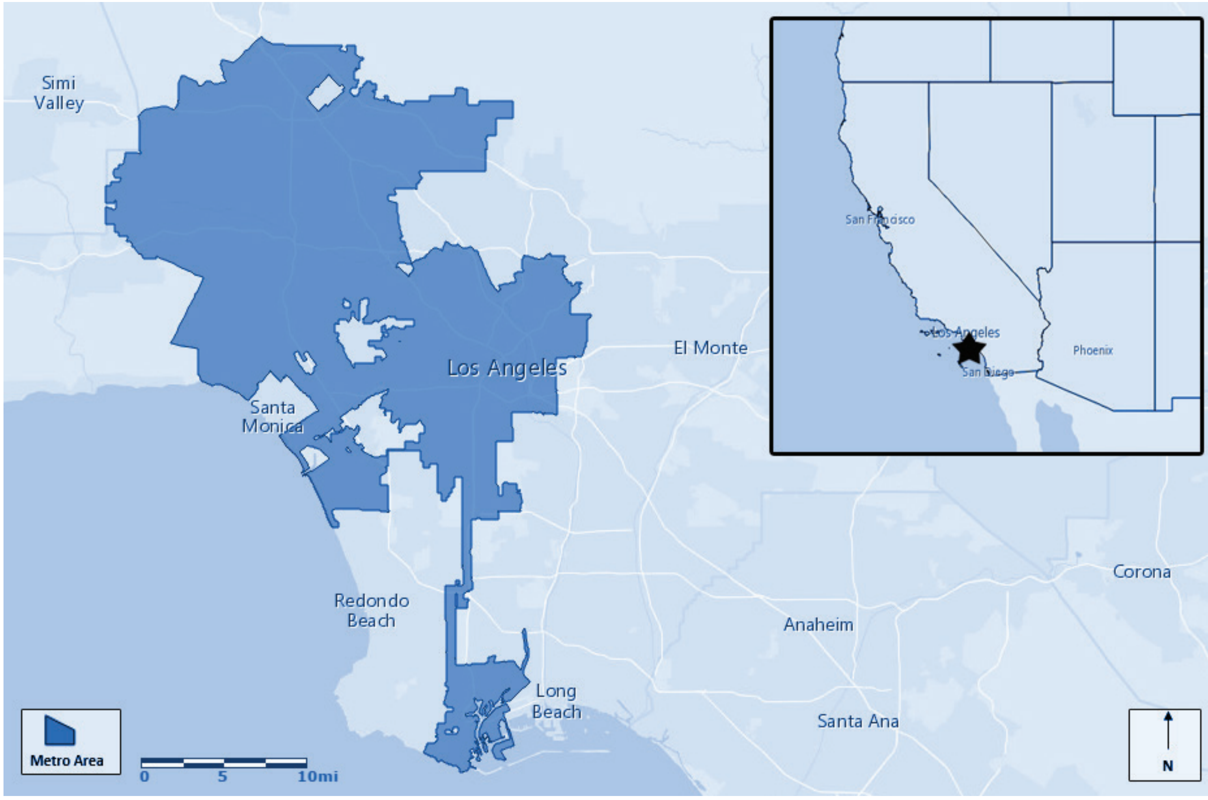

FIGURE 4-2 Map showing the administrative boundaries of the Los Angeles metropolitan area in California. SOURCE: Prepared by Brent Heard, Consultant to the STS Program.

percent, Asian 11.3 percent, African American 9.6 percent, American Indian and Alaska Native 0.7 percent, and Native Hawaiian and Other Pacific Islander 0.1 percent (U.S. Census Bureau, 2015b).

The Los Angeles metropolitan area is defined by the U.S. Census Bureau as the Los Angeles-Long Beach-Anaheim, CA Metropolitan Statistical Area, comprising both Los Angeles and Orange counties. Figure 4-2 shows the administrative boundaries of the Los Angeles metropolitan area (U.S. Census Bureau, 2013). The county of Los Angeles has a population of 10 million spread out across 4,058 square miles, 469 of which comprise the city of Los Angeles proper, encompassing a widely diverse geographic area. The Los Angeles metropolitan area sits in a basin created by the San Gabriel Mountain range in the east, the Santa Monica Mountains in the north, and bounded by 75 miles of Pacific Ocean coastline in the south and west. The Los Angeles, Rio Hondo, San Gabriel, and Santa Clara are the prominent local rivers, and the majority of their flow occurs only during rain events (LATCB, 2015; U.S. Census Bureau, 2015b).

Well known for its moderate weather, the climate of the area is categorized as Mediterranean under the modified Köppen classification system—typified by dry summers and cool winters, pronounced variability in rainfall, and relatively modest transitions in temperature. Its most conspicuous weather feature is a marine layer produced from the eastern Pacific high-pressure area that moderates temperatures during the summer months (Morris, n.d.).

Environmental Issues

Two interconnected environmental issues long synonymous with the metropolitan area of Los Angeles are water supply and air pollution. The history of water in the Los Angeles metropolitan region has shaped the character of the area and, more recently, its sustainability efforts. Los Angeles regularly operates at a water deficit. The lack of available water, which the city has largely offset using water imports through an aqueduct system, has been a challenge for the city since its early development. Los Angeles exhausted its local sources of water from the Los Angeles River and its tributary groundwater basin by 1900, and this prompted William Mulholland, chief engineer of the new Los Angeles Department of Water and Power, to design and orchestrate a water import system for the city via the construction of the Owens Valley Aqueduct, completed in 1913. However, continued population and urban growth demanded more water resources, resulting in new diversion works in the Owens River Valley and extension of the aqueduct further north into the Mono Basin. The city's diversions prompted disputes with Owens Valley residents, as well as diminishment and degradation of the Mono Basin lake and ecosystem, to such a degree that the California Supreme Court decreed that the public trust doctrine establish a fundamental limit on the exercise of water rights (Hanak and Lund, 2011). In 1970, a second aqueduct was built to augment aqueduct flow from the Owens Valley. Given this tumultuous history of water resources in the region and facing continued pressures on water supply, the city of Los Angeles began implementing conservation measures, such as water metering and water reclamation programs, by the 1970s (LADWP, 2015b).

Currently, the Los Angeles Department of Water and Power (LADWP) supplies water to the City of Los Angeles from the Los Angeles Aqueduct, recycled water, local groundwater, and purchased imported water from the Metropolitan Water District of Southern California. This tangibly demonstrates the concept of city footprints which extend beyond municipal boundaries (Gold et al., 2015b). In recent decades, LADWP has made large efforts toward increased water independence by cultivating local resources such as groundwater, recycled water, and stormwater. These efforts, however, are hindered due to industrial contamination of a large share of the groundwater basins in the Los Angeles area, thereby preventing further development of local groundwater resources (Hughes et al., 2013; Morris, n.d.). Recently, the prolonged and unprecedented drought in California has placed additional pressure on Los Angeles' water supply and water governance. Some have argued that the current drought may be the new normal condition given that the paleo record shows the region has more often experienced dry conditions than the relatively wet conditions of the past century (Ingram and Malamud-Roam, 2013).

Los Angeles has also struggled with air pollution and smog since its rapid industrialization in the late 19th and early 20th centuries due to oil refining, manufacturing, trucks, automobiles, and the combination of these pollutants with the city's geographic location in a basin. In Southern California, levels of ozone (O_3), particulate matter less than 10 microns in diameter (PM_{10}), and nitrogen dioxide (NO_2) have long been among the highest in the United States, and carbon dioxide (CO_2) emissions resulting from activities by all sectors within the city of Los Angeles are estimated at 51.6 million metric tons (City of Los Angeles, 2007, 2008). Again, Los Angeles provides an illustration of the importance of considering urban footprints as extending beyond city boundaries. For example, particulate matter 2.5 (ppm) emissions for the city of Los Angeles appear to be lower than the national average; however, this is due to the downwind impacts of pollutants originating in the city. Thus, air quality issues in Los Angeles are best considered at the basin scale rather than only at the city or county level (Gold et al., 2015a). Air pollution is exacerbated due to Los Angeles' characteristic marine layer, which traps particulates and gases in a layer near the ground. Air pollution and smog were first recognized as issues of concern in 1943, though the attribution of primary cause to automobiles did not occur until a few years later. Over the next decade, the Los Angeles metropolitan region led the way in attempting to ameliorate these issues by establishing a Bureau of Smoke Control in the city in 1945, and an Air Pollution Control District in the county in 1947. Through a combination of policy directives, regulations, and innovative programs at the city, county, and state levels, air quality in the Los Angeles metro region has improved, though it remains a significant challenge to sustainability efforts (CARB, 2015; LAWeekly, 2005).

In addition to water and air issues, the climate, geography, and geology of the Los Angeles metropolitan area render the city vulnerable to various environmental risks and resulting disasters. The region has a history of winter storms producing incredible rates of rainfall and resulting flooding and mudslides. The 24-hour record rainfall for California, 26.12 inches, occurred just north of downtown Los Angeles in 1943 in the San Gabriel Mountains foothills. These significant rainfall events are often due to sea surface temperature anomalies in the Pacific Ocean, commonly known as the El Niño/La Niña effects, which have historically produced heavy rainfall in Southern California. Other environmental hazards include the large incidence of wildfires that are especially destructive along the region's extensive wildland-urban interface. Major earthquakes produced by the large fault network in Southern California have had an occasional but significant negative impact on the region's economy and health, particularly among less-resilient populations (Doocy et al., 2013).

The social and economic impacts of these environmental hazards are not evenly distributed. Although all are exposed to hazards, such as earthquakes, wildfires, and floods, in the Los Angeles region, as well as in other regions of the country, socially and underprivileged populations are often concentrated in areas where environmental vulnerabilities are most severe. Epstein et al. (2014) noted that in Los Angeles, vulnerability is very irregularly distributed across society. For example, the 1994 Northridge Earthquake destroyed over 49,000 housing units and the Red Cross was housing up to 7,000 per night during the crisis. As a result of this earthquake, housing and housing-related issues became a significant challenge, especially related to affordable housing and vulnerable populations. This continues to be a significant challenge for the region (Epstein et al., 2014).

Economic Issues

In Los Angeles County, leisure and hospitality are the leading industries, with the motion picture and entertainment industry generating approximately $120 billion annually (LATCB, 2015). In the city of Los Angeles, the education, professional, leisure, and retail sectors constitute the largest share of the local economic drivers, with 61 percent of jobs in 2013 (Southern California Association of Governments, 2015). In terms of economic well-being, per capita income in 2013 in the city averaged $27,829, on par with that of the county, while median household income in the city totaled $49,497, with the state average being $60,094 and the national average $51,939 (U.S. Census Bureau, 2015b).

As an integral component of the economy of California—the eighth largest in the world—the Los Angeles metropolitan area is a center of global trade and entertainment. Combined, the Port of Los Angeles and the Port of Long Beach are a gateway to more than 43 percent of all goods entering the United States, with $426 billion handled through the Los Angeles Customs District in 2014. LADWP is the largest municipal utility in the United States, and LAX airport, along with LA Ontario International Airport and Van Nuys Airport, served over 80 million passengers worldwide in 2014 (City of Los Angeles, 2007; LATCB, 2015).

Social and Cultural Issues

Poverty remains a significant issue in Los Angeles. In the city of Los Angeles, 22 percent of the population lives below the poverty level, compared to 17.8 percent in Los Angeles County, 15.9 percent in the state of California, and 14.5 percent nationally (U.S. Census Bureau, 2015b). A large portion of this percentage is due to housing-induced poverty, housing constituting the single largest expenditure of households throughout the nation (McConnell, 2012). The city contains approximately 1,300,000 housing units for close to 4,000,000 people (U.S. Census Bureau, 2015b). In addition, in spite of featuring the largest health and social services system available to the homeless in the United States, Los Angeles County continues to have the highest concentration of homeless individuals in the nation (Garcetti, 2015a; Guerrero et al., 2014). In September 2015, Mayor Eric Garcetti announced a homelessness crisis in the city of Los Angeles, along with a comprehensive strategy to tackle the situation that includes $100 million in annual city funding—the latest 2015 estimates place 25,686 homeless in the city of Los Angeles and 44,359 in the county (Garcetti, 2015b). A census of the homeless in Los Angeles County released in May 2015 found that the number of people bedding down in tents, cars, and makeshift encampments had grown to nearly double the number from 2 years earlier (Holland, 2015).

In terms of education, the Los Angeles Unified School District is the largest public school district in California and the second largest in the nation, following New York. The latest data for the 2014-2015 school year placed student enrollment at 899,190 throughout the entire district, as compared to 985,695 (2014 data) in New York City. In LA County, 74.5 percent of the population have obtained a high school diploma (86 percent in both New York City and the United States, according to 2013 data), while only 31.1 percent (58.9 percent in New York and 28.8 percent nationally, according to 2013 data) have a bachelor's degree or higher, despite the prevalence of higher education institutions in the area. Los Angeles has 113 accredited colleges and universities (LATCB, 2015;

Los Angeles Unified School District, 2015; NYC Department of Education, 2015; U.S. Census Bureau, 2015a). In higher education, the University of California system has made important strides related to economic diversity, as gauged by the percentage of students enrolled who receive Pell Grants, or grants provided to undergraduates with family incomes of less than $20,000, with 28 percent of students at the University of California, Los Angeles (UCLA) receiving Pell Grants (Leonhardt, 2015).

MAJOR SUSTAINABILITY EFFORTS

The Los Angeles metropolitan region, as described above using both city and county examples, faces several key sustainability challenges, including water quality and supply issues, a severe drought, poor air quality, urban sprawl, poverty, high housing costs, and severe natural hazards. These challenges are compounded by projections of significant population growth, with the Los Angeles metropolitan area expecting a population increase of more than 500,000 by 2035 (Garcetti, 2015a). Some select challenges and related initiatives are described below. Many of these were described in a recent review of the state of the environment in Los Angeles, conducted by UCLA, that developed the county's first environmental report card using indicators on water, air, ecosystem health, waste, energy and greenhouse gases, and environmental quality of life (Gold et al., 2015c). In 2015, the mayor of Los Angeles also released LA's Sustainable City pLAn, an outcome-based plan for the city that provides specific targets for meeting sustainability goals related to air, energy, water, transportation, and urban ecosystems (Garcetti, 2015a). In terms of the Los Angeles metropolitan area, some cities have taken unique overall approaches to sustainability efforts: for example, Santa Monica's sustainability "Bill of Rights" and Long Beach's initiative of a climate-resilient city (see Box 4-1).

BOX 4-1
Long Beach: A Climate-Resilient City

Building an urban sustainability strategy rooted and based on a sense of place identified by citizens, private entities, and public authorities, the city of Long Beach is fashioning itself as the model for a climate-resilient city. The mayor's new Climate Resilient City initiative identifies specific opportunities and constraints unique to the city's urban context with the overarching goal of being a city able to continue to function in the face of challenging circumstances due to climate change and to recover quickly from disruptions. The initiative will focus on a framework of resilience that centers around four dimensions.

Health and Well-Being: all city inhabitants have access to what they need to survive and thrive;
Economy and Society: the social and financial systems that enable urban populations to live peacefully and act collectively are in place;
Leadership and Strategy: the processes that promote effective leadership, inclusive decision making, empowered stakeholders, and integrated planning are in place; and
Infrastructure and Environment: the human and natural systems that provide critical services and protect and connect urban assets enabling the flow of goods, services, and knowledge are in place.[a]

This human-centered approach to urban sustainability that emphasizes the needs of those most vulnerable is a successful example of engaging the community in a multiscale vision for improving human well-being through an environmental, economic, and social equity lens.

[a] Schubel, J. 2015. Comments by Jerry Schubel of the Aquarium of the Pacific to the National Academies of Sciences, Engineering, and Medicine's Committee on Urban Sustainability: Pathways and Opportunities. Los Angeles: Climate Resolve. Long Beach: Aquarium of the Pacific. See also Aquarium of the Pacific (2015).

Water

The Los Angeles metropolitan area's water supply system is vulnerable, particularly to climate change; warmer and wetter winters mean less snow pack and the current system relies on snow pack, not winter rain. A significant portion of the city's water comes from the Sacramento-San Joaquin River Delta, which is susceptible to earthquakes (levee failure) and ecosystem stresses, and the San Fernando Valley aquifers have a legacy of contaminates from industry pollution. Restrictions on water withdrawals from Mono Lake and dust emission controls from the Owens Lake bed have reduced water from those sources. Future water sources will likely be more diverse and drawn from local groundwater, stormwater capture, conservation efforts, and water recycling.[1]

The area is currently experiencing extreme drought conditions for a fourth year, which has resulted in an emergency declaration by Governor Jerry Brown and the passage of numerous drought-response measures, including requirements for statewide water conservation and increased water use reporting. Governor Brown called for immediate, voluntary 20 percent reductions. The Water Conservation Act of 2009 set a goal of reducing per capita urban water use by 10 percent by December 31, 2015, and by 20 percent by December 31, 2020, while the Water Action Plan, released in 2013, provides specific measures for improving water supply and quality in the state (Gold et al., 2015c). In addition, Proposition 1 was also passed, which provided essential resources for local water supply through water recycling, groundwater cleanup, and stormwater capture.

The UCLA environmental report card has provided an assessment of the county's water quality and quantity. The following are several highlights:

- "Currently, approximately 58% of the water used in LA County is sourced from outside the region.
- Between 2000 and 2013, per capita water demand dropped by roughly 16%; however, there have not been gains in these areas in the last few years and use increased from approximately 155 gallons per capita per day [GPCD] in 2010 to 160 GPCD in 2013.
- Based on the publicly available sources of data, nearly everyone in the Los Angeles area was provided with clean water in 2012.
- Contamination of groundwater wells is prevalent countywide. The principal contaminants include solvents, nitrates, benzene, MTBE and perchlorate" (Gold et al., 2015c, p. 4).

LADWP manages the Los Angeles water system, which is the largest municipal water system in the United States, providing power and water to over 4 million people per day. The LADWP provides over 494 million gallons of water delivered per day or 553,900 acre-feet per year.[2]

Several initiatives are under way including distributing stormwater capture from large dams and centralized storage ponds to cisterns, rain gardens, and rain barrels; using purple pipe for nonpotable reused water; taxing stormwater in Santa Monica; increased investment in groundwater pollution remediation; and moving water storage to underground tanks rather than open reservoirs, among others.[3]

Los Angeles Mayor Garcetti issued Executive Directive 5, which calls for a 20 percent water use reduction from 2014 consumption levels (131 GPCD as of June 2014) by January 2017 and a 50 percent reduction in purchased imported water (89 percent in 2013) by 2024 and creates an integrated water strategy (Garcetti, 2015a).[4] In addition, the recently released Los Angeles Sustainable City pLAn includes several near-term goals (by 2017) for the city related to water, including the following:

- "Secure additional funding for San Fernando Groundwater Basin clean up
- Establish Water Cabinet to implement key aspects of local water policy
- Expand recycled water production by at least 6 million gallons per day by 2017 (MGD)

[1] Sutley, N. 2015. Comments by Nancy Sutley of the Los Angeles Department of Water and Power to the National Academies of Sciences, Engineering, and Medicine's Committee on Urban Sustainability: Pathways and Opportunities. Los Angeles, April 29.

[2] Sutley, N. 2015.

[3] Sutley, N. 2015.

[4] Sutley, N. 2015

- Replace 95 miles of water pipe infrastructure
- Reduce number of annual sewer spills to less than 12."

In addition, the entire region has initiated aggressive lawn replacement programs with rebates of up to $3.75 per square foot in the city (Garcetti, 2015a, p. 20).

Air Pollution

Since its industrialization in the 19th and 20th centuries, Los Angeles has struggled with issues of air quality, pollution, and smog. According to the American Lung Association 2014 State of the Air report, Los Angeles County ranks among the top five polluted areas in the United States for ozone and $PM_{2.5}$ (particulate matter with diameter equal to or less than 2.5 microns), while the U.S. Environmental Protection Agency (EPA) has categorized the Los Angeles metropolitan region as having the worst quality of any other region in the country (Garcetti, 2015a; Gold et al., 2015a).

While the Los Angeles region has relatively poor air quality today, the city has made large improvements since the mid-20th century. Los Angeles County was the first county in California to establish an Air Pollution Control District, as well as one of the first to standardize "Visible Emissions Programs" throughout the country (CARB, 2015). The Los Angeles basin has made significant improvements in improving air quality for national ambient air standards and air toxics: reducing the number of smog days from over 200 in the 1980s to less than 50 in 2005, reducing diesel particulate matter in the Port of Los Angeles by 80 percent since 2005, and enacting several laws and regulations by the California Air Resources Board (CARB). Despite these improvements, air pollution and toxic emissions remain a substantial sustainability challenge—the metropolitan area continues to be in nonattainment (air pollutants exceeding federal standards) for ozone and particulate matter, as well as at continuing risk regarding diesel particulates, despite significant emissions reductions. In general, 90 percent of the air pollutants in 2012 were attributed to mobile source emissions, with the outstanding 10 percent from stationary sources such as large industrial factories and refineries (Gold et al., 2015a).

To address this critical issue of air pollution, the City of Los Angeles has set a number of goals, outlined in the 2015 Sustainable City pLAn, which largely focuses on technological fixes, i.e., transitioning to low- or zero-emissions transportation sources, as well as low- to zero-emissions commercial goods movement. The city intends to install 1,000 new publicly available electric vehicle charging stations by 2017, to have zero nonattainment days by 2025, to have electric or zero-emissions vehicles constitute 25 percent of light-duty passenger vehicles in use by 2035, and to have 25 percent of all commercial goods movement employ zero-emissions technology, also by 2035. In addition, the city will require 85 percent of its fleet, 100 percent of city refuse collection trucks and street sweepers, and 100 percent of Metropolitan Transportation Authority buses be powered by alternative fuels, such as compressed natural gas (Los Angeles County Metropolitan Transportation Authority, 2007). The Port of Los Angeles is also in the process of fully implementing the San Pedro Bay Ports Clean Air Action Plan, while Los Angeles World Airports has been focusing on a comprehensive strategy to green Los Angeles metro area airports, including use of alternative fuels and evaluation methods for aircraft-related greenhouse gas (GHG) emission reduction (City of Los Angeles, 2007). Furthermore, the city is addressing air quality through a literal greening of the city. The 2007 initiative to plant 1 million trees in Los Angeles has since been combined with LADWP's Trees for a Green LA to make one unified tree planting program for the city, called City Plants, with a focus on low-canopy areas versus tree numbers. Moreover, 35 new parks have been added to the city since 2010 (City of Los Angeles, 2007; Garcetti, 2015a; McPherson et al., 2011).

Transportation

Wachs (2015) noted that "transportation policy and planning is intimately related to sustainability in two primary ways. First, travel is an essential activity in urban areas to support economic, social, and cultural activity, but all modes of travel require the use of energy and because vehicular transportation relies on fossil fuel energy it contributes to environmental pollution and greenhouse gas emissions. Many strategies for achieving sustainability in other dimensions worsen traffic congestion and increase emissions." California, including the city of Los Angeles, is making important strides to address significant transportation challenges related to sprawl and auto dependency, particularly related to vehicles, fuels, and mobility.

As mentioned previously, the metropolitan area has two of the largest ports in the United States and transports nearly half of the containers from Asia to the United States. It is an international travel hub with five commercial airports and has dozens of major freeways. In addition, the Los Angeles County Metropolitan Transportation Authority is the third largest transit agency in the country. Growth in travel is expected to substantially increase, though with limited growth potential in capital expansion of transportation networks (Wachs, 2015). The infrastructure and financial support for the region's transportation system also faces challenges; the infrastructure is badly in need of repair and modernization and the revenue needed to support the system is in decline, as it relies on user fees which have not been raised. Measured progress in reforming transportation systems has occurred through technological changes and controls. These include smog controls on vehicles, trains, ships, and planes, as well as vehicle electrification (Sperling, 2015). HOT (High Occupancy/Toll) lanes, open to multiple-occupant vehicles without charge and single-occupant vehicles for a toll, are also a promising option, according to Wachs.

California policies have been able to influence the national discussion on these issues, including requirements related to GHG light-duty vehicle standards, requirements for trucks, and a state action plan for zero-emission vehicles (described below). California policies have also increased investments in and sales of plug-in electric vehicles and low-carbon biofuels, thereby stimulating innovations in new low-carbon technologies (Sperling and Eggert, 2014). Other impacts include state regulation such as Assembly Bill 32, the Global Warming Solutions Act of 2006, which mandated the state to reduce its GHG emissions to 1990 levels by 2020. In addition, the Sustainable Communities and Climate Protection Act of 2008 addressed the following:

- Land-use growth pattern that accommodates the region's future employment and housing needs and that protects sensitive habitat and resource areas;
- A transportation network that consists of public transit, highways, local streets, bikeways, and walkways;
- Transportation Demand Management measures that reduce or eliminate peak-period demand on the transportation network, such as carpooling, telecommuting, vanpooling, and other innovative programs such as "parking pay-out" (employers offer the cash value of a parking subsidy to any employee who does not drive to work in the form of a transit, vanpool, or carpool/walk/bike subsidy); and
- Transportation System Management measures that maximize the efficiency of the transportation network, such as signal timing, freeway ramp metering, and bottleneck relief/auxiliary lane projects (Wachs, 2015).

The Los Angeles metropolitan area and the state in general have embraced transit-oriented development, rail and express bus improvements, and smart growth. This is evidenced by the $40 billion being invested in rail, rapid bus, and other improvements, expanding the current rail system by 26 miles in the city alone (Garcetti, 2015a). The Los Angeles Sustainabile City pLAn includes several long- and short-term targets related to transportation as well as some general strategies. The latter include

- Improving pedestrian and bicycle infrastructure and other sustainable transport, emphasizing connections to mass transit;
- Expanding high-quality transit options across the city;
- Leveraging zoning, planning, and community vibrancy to move Angelenos closer to work and transit; and
- Securing new funds for mobility projects.

Overall, the California policy model which comprises a comprehensive mix of rules, incentives, and market instruments provides an illustrative example of progress made within the transport sector (Sperling and Eggert, 2014).

OTHER SIGNIFICANT ACTIVITIES

California has been a leader in renewable portfolio standards and greenhouse gas reduction, as well as building energy efficiency standards. CARB's enforceable cap and trade regime requires that the state lower its GHG emission levels 25 percent by 2020. California additionally has a 33 percent renewable portfolio standard requirement. However, the city is still one of the largest electricity importers in the state, while Los Angeles County still generates 99.1 million metric tons of CO_2, approximately 21.7 percent of California's 2009 total GHG emissions. This is largely due to automobile and truck fossil fuel consumption. The county's GHG emissions are largely comprised of building energy, 39.2 percent; on-road transportation, 33.5 percent; and stationary sources, 19.7 percent (Gold et al., 2015a). The last available data for the city itself placed GHG emissions for the city of Los Angeles at 51.6 million metric tons of CO_2 in 2004.

To transform Los Angeles into a more sustainable and efficient metropolis, the city's living Climate LA Program document and Sustainable City pLAn both outline a number of goals regarding renewable energy, green buildings, and energy efficiency for the city. Currently, the LADWP's energy resources consist of 20 percent renewables (mostly wind at 13 percent), 21 percent natural gas, 10 percent nuclear, 4 percent hydroelectric, 33 percent coal, and 12 percent other or unspecified sources (LADWP, 2015a).

LADWP has established its own renewable portfolio standard goal of 35 percent renewable energy by 2020. To meet this renewable energy goal, LADWP has focused on developing new renewable energy projects in Southern California and their associated transmission lines. The department has been developing a number of resources, such as wind in the Tehachapi Pass area north of the city and geothermal in Salton Sea to the east. LADWP is also aiming to reduce the use of coal-fired power plants, with the goal of divesting completely from coal power by 2025 (City of Los Angeles, 2007; Garcetti, 2015a). Los Angeles already has the most installed capacity of megawatts of solar power in the United States and upwards of 1,500 megawatts (MW) of energy storage provided by LADWP's Castaic Pumped-Storage Plant. Moreover, the city's sustainability plan includes goals of 1,800 MW of solar power by 2035 and 1,750 MW of energy storage by 2025, with concrete targets in funding the Solar Incentive Program, expanding the Feed-in-Tariff program, energy grid modernization plans, energy storage pilot technology, and solar installations on new and existing city projects (such as the Los Angeles Convention Center). Overall, the city is pursuing ambitious goals of a 45 percent reduction of GHG emissions from 1990 baselines levels by 2025, 60 percent by 2035, and 80 percent by 2050 (Garcetti, 2015a). In addition, local mitigation through "cool roofs" is another element in the region's concept of energy sustainability as a science-driven solution; in December 2013, Los Angeles became the first major city to require every new and refurbished home to have a "cool roof," with a goal of installing 10,000 by 2017 and reducing the heat island effect by 3 degrees by 2035 (Climate Resolve, 2013).[5]

The city hosts the largest municipal green-building program (requiring Leadership in Energy & Environmental Design [LEED] Silver or better) and has the most EPA-rated Energy Star certified buildings in the United States, with LADWP's energy efficiency program being one of the most aggressive in the state. The city has set goals to reduce the energy use per square foot below the 2013 baseline for all building types by at least 14 percent by 2025 and 30 percent by 2035, and to use energy efficiency for 15 percent of all of LA's projected electricity deliverables needs by 2020 (Garcetti, 2015a). Los Angeles endeavors to reduce energy consumption in all city departments, perform energy-efficient retrofits on city buildings, and implement energy-efficient strategies and technologies on wastewater equipment and drinking water treatment and distribution facilities (City of Los Angeles, 2008).

SUMMARY OBSERVATIONS

Despite facing a number of sustainability challenges, the Los Angeles metropolitan region has introduced several innovative initiatives related to energy and transportation, while the current drought has forced changes to water consumption and related behavior. These challenges have driven the city to develop an aggressive results-based sustainability plan, with specific targets and outcomes, that relies on fruitful collaborations across municipal departments and institutions (rather than top-down approaches) and the proliferation of innovative new science

[5] Parfrey, J. 2015. Comments by Jonathan Parfrey of Climate Resolve to the National Academies of Sciences, Engineering, and Medicine's Committee on Urban Sustainability: Pathways and Opportunities. Los Angeles, CA: Climate Resolve.

and technologies. The city of Santa Monica has taken an even more comprehensive approach to sustainability, by, for example, developing a Sustainability Bill of Rights and a stormwater tax, demonstrating a mentality that is unafraid to implement divergent, innovative ideas and to fail.[6] Progress toward the realization of quantitative actionable goals is illustrated in such initiatives such as City Plants—the result of combining LADWP's Trees for a Green LA Program and the city's former tree planting program Million Trees LA—which focuses on expanding and maintaining LA's green canopy, and is enshrined in the urban ecosystem topic area of Los Angeles' Sustainable City pLAn ("expand number of parks and open spaces for Angelenos"); as well as the Great Streets initiative—a partnership with the Mayor's Office, City Council, and a team of various stakeholders to develop community partnerships and receive targeted city services to activate streets as public spaces—which is also identified in the pLAn as part of the livable neighborhoods topic area ("implement improvements on 15 commercial corridors/Great Streets"), of which the first 15 "great streets" have already been identified, and resources for the second round of "great streets" is being currently sought after (Garcetti, 2015a; Great Streets, 2016; McPherson et al., 2011).

More broadly, the state is often able to drive national changes related to sustainability issues, including transportation and climate change. For example, Sperling and Eggert (2014, p. 88) note that "California has been a leader in advancing policy solutions to environmental and energy challenges since the 1960s. Many of those policy innovations have spread worldwide. Beginning with statutes passed by the California legislature starting in 2002 and continuing through today, California is adopting a comprehensive set of policies, regulations, and incentives to reduce greenhouse gas emissions, with particular emphasis on those associated with transportation, vehicles, fuels, and mobility."

Nevertheless, other lessons learned from the Los Angeles case include those sustainability challenges that are still lacking in innovative solutions. Though the region has begun to take strides in addressing social sustainability issues, such as the recent programs initiated by the United Way of Los Angeles in addressing homelessness by implementing a three-part systems approach uniquely focusing on providing services to individuals, income inequality and other social issues have not yet been integrated fully into sustainability decision making.[7,8]

Taken as whole, Los Angeles has made significant progress (see Figure 4-3) toward some of the most prominent sustainability challenges, largely through a combination of regulation, technological advancement, cross-cutting collaboration, and aggressive policy changes.[9] Despite the continued obstacles and thus far unaddressed gaps that remain, LA provides important lessons regarding the importance of partnerships, connectivity, and multiscale processes and, moreover, provides an innovative example of where mixing these approaches can supply multiple benefits.

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[6] Gold, M. 2015. Comments by Mark Gold of the UCLA Institute of the Environment and Sustainability to the National Academies of Sciences, Engineering, and Medicine's Committee on Urban Sustainability: Pathways and Opportunities. Los Angeles: UCLA Institute of Environment and Sustainability.

[7] Gold, M. 2015.

[8] Margiotta, C. 2015. Comments by Christine Margiotta of the United Way of Greater Los Angeles to the National Academies of Sciences, Engineering, and Medicine's Committee on Urban Sustainability: Pathways and Opportunities. Los Angeles: United Way of Greater Los Angeles.

[9] Gold, M. 2015.

FIGURE 4-3 A sample of the performance tracking dashboard of sustainability metrics related to the nearest-term goals identified in the Los Angeles Sustainable City pLAn. SOURCE: City of Los Angeles, powered by Socrata, Inc., 2013. Data adopted from City of Los Angeles. 2016. pLAN. Online. Available at https://performance.lacity.org. Accessed April 19, 2016.

TABLE 4-2 Example Highlighting Actions for Los Angeles that Illustrate Steps in Urban Sustainability Roadmap (see Chapter 3, Figure 3-1)

City	Los Angeles
Adopt Principles	P1, P2, P3, P4
Opportunities and Constraints	Opportunities: Water supply; air pollution Constraints: Poverty, vulnerability to environmental risks and disasters: floods, earthquakes, wildfires.
Prioritize Co-net Benefits	Water supply; air pollution; poverty; housing affordability; ability to decarbonize; inequality and the capability and planning for climate change.
Partnerships	City Plants, Adopt the pLAn, LA 2030, LA Better Buildings Challenge.
Goals	LA Sustainable City pLAn vision set around 14 topic areas: local water, local solar power, energy-efficient buildings, carbon & climate leadership, waste & landfills, housing & development, mobility & transit, prosperity & green jobs, preparedness & resiliency, air quality, environmental justice, urban ecosystem, livable neighborhoods, and lead by example.
Strategies	LA Sustainable City pLAn, Green LA and corresponding implementation plan: Climate LA; LADWP established its own renewable portfolio standard; Santa Monica’s sustainability “bill of rights”; Long Beach’s Climate Resilient City initiative.
Data Gaps	Distinguishing between city, county, metropolitan-area-level data.
Implementation	Groundwater, recycled water and stormwater program – 1970. Bureau of Smoke Control in the city in 1945. Air Pollution Control District in the county in 1947. Water metering and water reclamation programs – resourced by Proposition 1 – Water Action Plan, 2013; LADWP established its only renewable portfolio standard.
Local to Global	Regulation by the California Air Resources Board – reduce diesel particulate matter Assembly Bill 32, Global Warming Solutions Act of 2006.
Public Buy-in	Voluntary 20% reductions in water consumption, lawn replacement programs.
Feedback	Performance tracking for LA Sustainable City pLAn, UCLA Environment Report Card, investment in rail, rapid bus, and pedestrian and bicycle infrastructure.

NEW YORK CITY

As the city of New York navigated the opening decades of the 21st century, major forces, both exogenous and endogenous, have shaped and reshaped New York’s approach to economic, social, and environmental dimensions of urban sustainability. High on the list of exogenous forces that occurred in the early part of the 21st century was Superstorm Sandy, which affected many dimensions of everyday life and the societal responses at many levels (neighborhood, borough, citywide, state led, and federal) and from many quarters (including the private, public, and independent sectors and collaborations among those sectors). High on the list of endogenous forces is the decision by the administration of Mayor Bill de Blasio to redefine urban sustainability as the development of policies and projects that generate “growth, equity, sustainability and resilience” as articulated in the administration’s 2015 *One New York: The Plan for a Strong and Just City* (henceforth referred to as *OneNYC*) initiative and the initiative’s explanatory document, the 300-plus-page roadmap in *OneNYC*.

Throughout its many initiatives, New York City is intensifying its reliance on 21st-century science and technology, including informatics and big data. Climate change on the Eastern Seaboard, including the New York metropolitan region, and the need to address climate hazards, vulnerabilities, and risks in a sustained and thorough manner led New York’s local government to institutionalize and mandate the periodic collection and analysis of scientific data on climate-related issues. Superstorm Sandy and its aftermath reacquainted New Yorkers with the negative consequences of a long-standing structural arrangement within New York City and its region: the tendency

BOX 4-2
New York City's Integrated Planning Initiatives for Sustainability

- "Our Growing, Thriving City" committed to a "dynamic urban economy" (NYC Office of the Mayor, 2015a, p. 5),
- "Our Just and Equitable City . . ." offering "well-paying jobs and opportunity for all," including lifting "800,000 New Yorkers out of poverty or near poverty by 2025" (NYC Office of the Mayor, 2015a, p. 6),
- "Our Sustainable City," committed to a "goal to reduce greenhouse gases by 80 percent by 2050 (80X50)" (NYC Office of the Mayor, 2015a, p. 6) and striving to be a leader in both mitigation and adaption efforts required to deal with climate change, and
- "Our Resilient City," designed to equip neighborhoods, government services, the private sector, publicly run infrastructure systems like water and privately held infrastructure systems like energy and telecom to become resilient in the short and long term (NYC Office of the Mayor, 2015a, p. 6).
- The Local Law 42 institutionalized and mandated the New York Panel on Climate Change (NPCC).

toward the division of power and responsibility for critical, lifeline infrastructure networks in the public sector, in part a result of the scale and complexity of the city's infrastructure and its financial base. Public and private infrastructure entities within the city and the region have acknowledged this issue; in many of these cases, entities have formed working groups to map vulnerabilities and interdependences related to the status quo for managing over the course of a natural or human-made event through recovery.

As New York City pursues the four-dimensional sustainability agenda embodied in the *OneNYC* blueprint (Box 4-2), it may present both strengths and challenges. To manage the distribution of responsibility and power, the art of intergovernmental collaboration and partnership, along with public-private partnerships, will need to be operationalized and optimized if New York City is to achieve its urban sustainability goals within the timeframes articulated on Earth Day 2015.

BACKGROUND

The sustainability of the City of New York encompasses numerous dimensions—social, economic, and environmental (including climate related)—and their interrelationships. Those dimensions have been shaped by the city's scale, location, and diversity of its population and economic base. Given the city's unique characteristics, it often tests the limit of sustainability goals. Due to New York City's role as a test bed for many socioeconomic innovations in the 19th and 20th centuries, its 21st-century approaches may turn out to be scalable and suitable for adaption in other cities and metropolitan regions.

Geography

New York City's geography and topography set the stage for both sustainability challenges and opportunities (Figure 4-4). Though often overlooked and underappreciated, most of New York City is part of an archipelago; the only part of the city that is not on an island is the borough of the Bronx, the city's only segment on the mainland of the Lower 48. New York City is comprised of five boroughs (officially designated as counties) surrounded by waterways, totaling more than 500 miles of coastline. The boroughs are connected by numerous bridges and tunnels, estimated at more than 2,000, owned and operated by multiple entities.[10] This network of infrastructure

[10] This number of bridges in New York City is often cited; for example, J. Ganley. 2008. New York City's Bridges: Construction and Maintenance, New York, NY: New York Public Library; New World Encyclopedia. New York. Online. Available at http://www.newworldencyclopedia.org/entry/New_York. Accessed April 12, 2016.

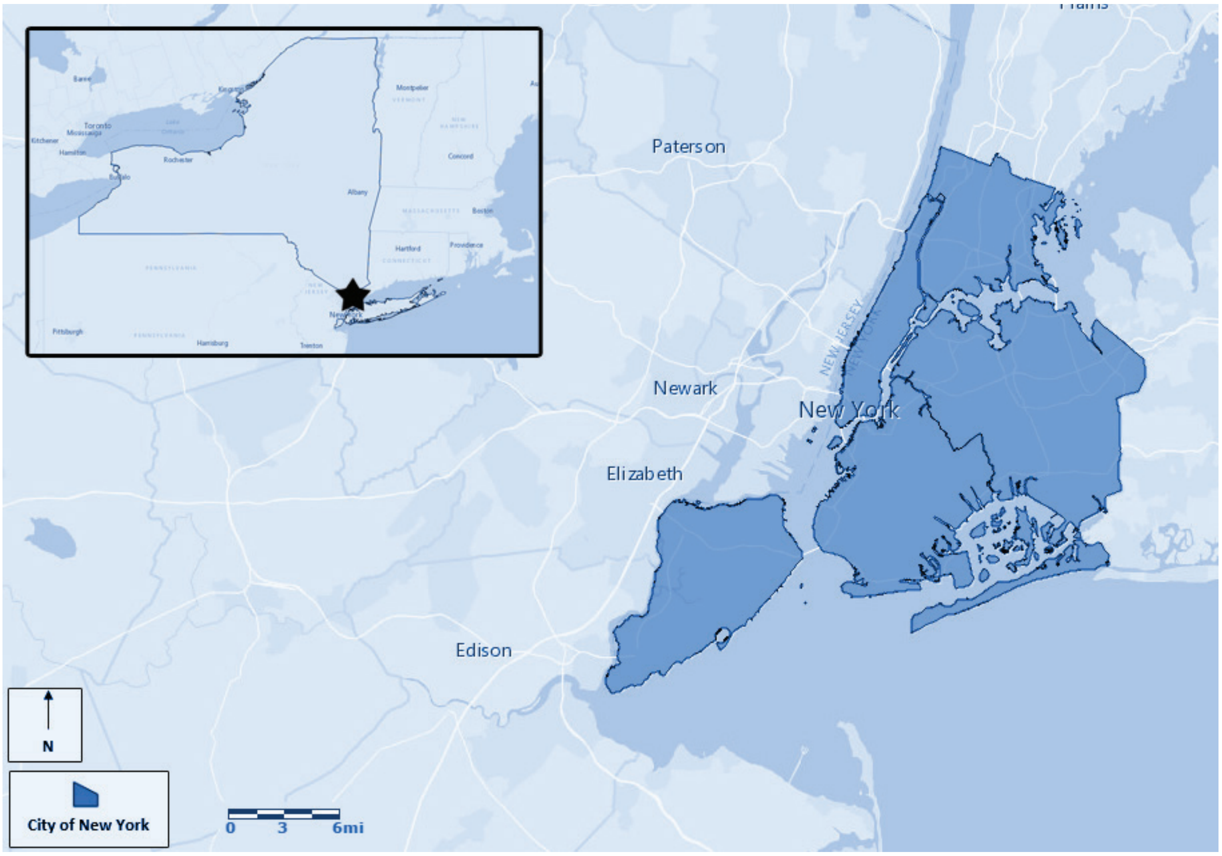

FIGURE 4-4 Map showing the New York City administrative boundary and location in New York State. SOURCE: Prepared by Brent Heard, Consultant to the STS Program.

enhances circulation but adds complexity to the movement of goods and people in and around the city. A natural harbor has supported the city and its region, which ranks among the top ports in the United States in terms of total calls and other measures of port activity such as tonnage and value (PANYNJ, 2015a,b); it reached a record volume of activity in mid-2015 (Whelan, 2015). New York City's vast coastline has long been a contested space, resulting in competition and disputes between and among social groups, economic interests, and political jurisdictions; ownership of the coastline continues to be balkanized. The de Blasio administration's *OneNYC* plan and the previous administration's PlaNYC, other city waterfront plans, and other entities in the private and nonprofit sectors have proposed strategies and projects to deal with coastline and waterfront issues.

Social Context and Demography

Population, population change, and population density are important inputs for building indicators of urban sustainability. New York City and the greater New York metropolitan region have the highest population and population density in the United States (Powell, 2014). The sustainability challenge confronting the city is marshaling the regional resources required to match the needs of such a large, diverse, dense, and changing population. New York City's 2014 population is estimated to be 8,491,079, the largest of any other U.S. city (Cohen et al., 2015; U.S. Census Bureau, 2014a). According to U.S. Census Bureau data, the city's population has been increasing since

1980 and that trend is projected to continue (NYC Office of the Mayor, 2015a). New York City is at the core of a world-city region defined in a number of ways.[11] The city's population is about one-third of the population of the combined statistical area and a larger portion of the metropolitan statistical area.[12] In addition to the resident population, the city accommodates a large, constant flow of commuters and visitors, both foreign and domestic. Between 2010 and 2014, the U.S. Census reported a rate of change for the city's resident population of 3.9 percent, compared with 1.9 percent for New York State and 3.3 percent for the United States (U.S. Census Bureau, 2015b).

New York City also ranked highest in population density among large urban places, with 27,781.2 people per square mile reported in 2013 (Cohen et al., 2015). This is many times higher than New York State's population density of 411.2 persons per square mile (2010) and the U.S. density of 87.4 (2010) (U.S. Census Bureau, 2015b).[13] Within New York City, however, population density and changes in density are not uniform, and between 1970 and 2010, for example, population density declined in many lower-income neighborhoods, which has been attributed to population losses in the latter part of the 20th century, while density increased in middle-income and upper-income areas (NYU Furman Center, 2015).

The 2010 American Community Survey (ACS)[14] of race and ethnicity characteristics from 2009-2013 indicated that New York City was 46.5 percent white, 27.3 percent black or African American, 13.9 percent Asian, 2.4 percent American Indian and Alaska Native, and 0.3 percent Native Hawaiian and Other Pacific Islander. Hispanics or Latinos comprised about 28.6 percent during this same period; 15.1 percent were categorized as members of some other race or group (Powell, 2014). Blacks and Latinos constitute a larger share of the overall New York City population when compared to their share of population in New York State or in the United States as a whole (U.S. Census Bureau, 2015b). The change in the racial and ethnic makeup of the city has been noteworthy, for example, with the share of some minority groups (Asian and Hispanic). The percent of elderly (those over 65 years) is also increasing, according to the U.S. Census.

Poverty alleviation and job creation are critical cornerstones of the *OneNYC* plan (NYC Office of the Mayor, 2015a). Poverty takes its toll, degrading access to education, safety, health care, and jobs (Kneebone, 2014). Chetty et al. (2015) linked long-term, subpar social outcomes to living in a high-poverty neighborhood as opposed to better social outcomes for those who lived in a lower-poverty neighborhood. New York City was one of the five cities they studied. Poverty is measured in many ways, such as percentage of the population below the federal poverty line or by income (NRC, 1995). The ACS average for the population living below the poverty line in New York City from 2009 to 2013 is 20.3 percent, though it varies for different population groups (Powell, 2014). By comparison, the poverty rates for New York State and the United States are 15.3 and 15.4 percent, respectively. In *OneNYC*, City Hall identifies three levels of poverty: 23.6 percent near poverty, 15.8 percent in poverty, and 5.7 percent in extreme poverty; according to the plan, together these three categories total 45.1 percent of the city's residents. People who fall into these three groups are unevenly distributed across New York City boroughs and 59 community districts (NYC Office of the Mayor, 2015b). The NYU Furman Center (2013) notes that over time "[t]he percentages of both high- and low-income households in New York City have grown as the share of middle-income households has shrunk."

Lowrey (2014) identified a positive relationship between poverty and rich-poor disparities and found that the New York City metropolitan area ranked among the top few U.S. cities with such disparities. A Brookings Institution study in 2014 identified the movement of the poor from cities to suburbs, a trend in many large metropolitan areas, including the New York City region. The study found that for the New York City metropolitan area suburbs,

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[11] The 31-county metropolitan area is defined in various ways: as a 31-county, tristate metropolitan region (Yaro and Hiss, 1996, p. 20) and alternatively as the NY-NJ-PA Metropolitan Statistical Area and the Combined Statistical Areas (that encompass portions of Connecticut as well) and Metropolitan Divisions. See Executive Office of the President, 2013, p. 16. According to one definition, there are 15 counties in New Jersey, 12 in New York, and 4 in Pennsylvania (A. Strauss-Wieder, Inc., February 2014, p. 4).

[12] The U.S. Census Bureau defines New York, New Jersey, and counties in northeastern Pennsylvania as a metropolitan statistical area and a combined statistical area that includes portions of Connecticut that had a population of about 23 million in 2010, which is also the area with the highest population in the United States.

[13] The U.S. and New York State density figures are overall indicators of density, not specific to urban areas.

[14] The percentages cited in the text differ slightly from those cited in ACS Appendix Table 2 of indicators and in Table 4-3 above for NYC due to the method of aggregating the time period.

TABLE 4-3 Key Characteristics for New York City

Indicator	New York City	United States
ENV Average Annual Precipitation (inches/year)	46.2	40.8
ENV Existing Tree Canopy (% of land cover)	21%	25%
ENV Roadway Fatalities (per 100 million annual vehicle miles traveled)	0.9	1.1
ENV Particulate Matter 2.5 (ppm)	10.8	10.2
ENV Residential Carbon Footprint (metric tons of CO_2 per capita from residential energy consumption)	1.8	3.4
ECON Financial Health	AA	AA+
ECON Average Residential Electricity Rate (cents/kWh)	23.2	11.9
SOCIAL Black or African American	28.1%	13.2%
SOCIAL Hispanic or Latino	29.0%	17.4%
SOCIAL Asian	14.4%	5.4%
SOCIAL Home Ownership (2009-2013)	32.8%	64.9%
SOCIAL High School Graduate (25 or older, 2009-2013)	79%	86%
SOCIAL Below Poverty Level	20.4%	15.4%
SOCIAL Violent Crimes (per 100,000 people)	628	191

NOTE: ENV, ECON, and SOCIAL refer to the three dimensions of sustainability: environmental, economic, and social, respectively. SOURCE: Appendix B.

the poor population increased by 21 percent between the 2000 and 2008-2012 time periods compared with a decline of 3 percent in the poor population in the urban portion of the region (Kneebone, 2014). (See Table 4-3 for key characteristics of New York City.)

There is generally a deficit of public transportation services in areas that surround urban areas, which can compromise the ability of the poor to access jobs (Zimmerman, 2012). In addition, in New York City, Zimmerman et al. (2014) found that one tendency was that for areas with a higher percentage of the population below the poverty line in a census tract in which a subway station was located, fewer buses were likely to stop within a tenth-of-a-mile radius around those stations, thereby potentially compromising multimodal connections.

Housing and Housing Affordability

Poverty also shows relationships to housing affordability. New York City's housing across all demographic groups is affected by policy, programs, land-use plans, and market forces. The city's housing stock has experienced pricing boom and bust periods, yet shows an overall net increase: "New York City housing prices experienced two periods of rapid increase—1980-1989 and 1996-2006—and two periods of decline—1974-1980 and 1989-1996. Fortunately, both booms were substantial, and both busts, although difficult, were relatively small. Overall, prices increased by 250 percent from 1974 to 2006" (NYU Furman Center, 2008, p. 9). Though high-end housing has been achieving record prices, affordable housing and rental units are still a major public policy priority. The de Blasio administration intends to address this gap by planning to create 200,000 affordable units over 10 years (NYC Office of the Mayor, 2015a). The goal of the city's housing plan is to generate construction and permanent jobs at an estimated cost of $41.4 billion over the same period (NYC Housing and Economic Development, 2015).

Through mid-2015, the city was apparently ahead of its target. However, the allocation of these units has raised potential segregation issues (Davis and Appelbaum, 2015; Ramey and Kusisto, 2015).

The share of rental versus owner-occupied housing is higher in New York City than in other cities, and the New York City Department of City Planning notes that "approximately two-thirds of dwellings in New York are renter-occupied, over twice the national average" (NYC DCP, n.d.). New York City and New York State have recently renewed legislation that will protect rent-stabilized apartment units. An affordability measure for rental housing is the rent-to-income ratio. New York City renter incomes did not rise as fast as rents between 2005 and 2012, and in 2012 about one-half of the renter population was paying almost one-third of its incomes for rent, which is considered "rent burdened" (NYC Housing and Economic Development, 2015).

Environmental Issues

Many dimensions of the built environment and associated land use in New York City have a significant impact on New York City's capacity to pursue and achieve environmental sustainability, including building in a manner that will not compromise ecologically sensitive areas and areas particularly vulnerable to adverse environmental conditions associated, for example, with extreme weather events and climate change. Many of those areas, either ecologically sensitive or vulnerable to climate-related risks, are candidates for economic development projects and social sustainability projects. New York's density generally supports a land-use pattern that is associated with lower per capita car ownership and lower vehicle miles traveled than in other U.S. cities; in turn, this set of conditions contributes to lower direct sources of locally generated GHG emissions enabled by extensive use of mass transit (buses, subways, and regional rail) (U.S. Census Bureau, 2015a). From a social sustainability perspective, the nature of land use is such that the distance between residences and workplaces necessitates a commute averaging almost 45 minutes in New York City (U.S. Census Bureau, 2014d). The *OneNYC* plan notes the variability in access to jobs via public transit and notes that low-income populations have longer commute times via public transit (NYC Office of the Mayor, 2015a).

The built environment is estimated to account for the largest source of New York City's carbon emissions—more than 70 percent (City of New York, 2014, p. 24), which probably reflects direct emissions. Addressing emissions from the built environment is among the challenges elevated in the *OneNYC* roadmap, which divided its pursuit of policies, projects, and goals into "growth, equity, sustainability and resilience" (NYC Office of the Mayor, 2015a).

Environmental conditions are often summarized as global carbon or environmental footprints or overall rankings of a number of different climate-related dimensions, as described in Chapter 2. The Economist Intelligence Unit (2011), the Global Footprint Network, and others have conducted environmental and climate-related assessments of New York City. The city's environmental conditions have been characterized by the quality of its air and water with health implications and environmentally sensitive areas, such as wetlands. Climate change is addressed in a separate section.

In general, the city's environmental conditions have improved in terms of meeting or making incremental progress toward achieving federal standards for clean air and clear water, described below. Like elsewhere in the United States and the rest of the developed urbanized world, reducing GHG emissions and other factors associated with it remains a major challenge. Reducing GHG emissions from the built environment, the city's largest source of locally generated emissions, is fundamental to managing climate change and building resilience for extreme weather events. Land-use decisions over decades, many of which were incremental, resulted in construction on and extension of low-lying areas that have since been vulnerable to water inundation from more intensive storms, sea-level rise (SLR) and storm surge, and especially the interaction of SLR, storm surge, and tidal cycles. In addition, numerous accidents involving privately held lifeline infrastructure have disrupted and damaged New York City, including the citywide 2003 Northeast–Canada electric power blackout and those preceding it. The hard, direct economic impact of the September 11, 2001, terrorist attack on the World Trade Center is now well understood. The attack cost the city over $30 billion (Bram et al., 2002); it took years for the city to recover from that damage. The collateral effects and costs of September 11, 2001, are not as well understood. Many of the services rebounded while many residents and workers continue to grapple with the lingering social, emotional, and health effects of the attack.

Each of these circumstances had different origins, exposures, recovery times, and short-term and long-term approaches to resolution. In order to address these issues in the context of sustainability, the city has engaged in numerous planning and legislative processes. These included citywide broadly based efforts, the latest of which are covered, for example, in PlaNYC and *OneNYC* (NYC, 2007, 2011, 2013; NYC Office of the Mayor, 2015a).

The government of New York City exercises direct control over a small share of the built environment through ownership or use for governmental purposes as well as regulation over other sectors. Mazria (2015) offered a guide to proposed changes in the New York City Energy Conservation Code to support energy efficiency and renewable energy in order to catalyze a reduction of GHG emissions from the built environment that is largely controlled by the private sector and nonprofit or civic sector.

Initiatives also appear in the sustainability strategies for specific sectors. In transportation, the following sustainability actions have been undertaken: the addition of many more miles of bike lanes, the creation of a bike share system, and the implementation of sustainable measures in its mass transit and other transportation systems, including the rollout of the Metropolitan Transportation Authority (MTA) Select Bus Service (the MTA's move into a form of Bus Rapid Transit in Manhattan and other boroughs). In water, New York City's water supply system has benefited from the utilization of an ecosystem-services-based remote water sourcing strategy. The system consists of four water supplies: the Catskill/Delaware supply, the Croton supply, the city's original upstate supply, and a groundwater supply system in southeastern Queens. Through a combination of land acquisition, land management, and partnership programs, New York City's Department of Environmental Protection (NYC DEP) has demonstrated extensive efforts to protect the city's watersheds, particularly through the use of land stewardship approaches in the Catskills (NYC DEP, 2013a).

Wetlands in New York City have declined as they have in many other places in the country. New York City estimates the loss at 85 percent for coastal wetlands and 90 percent for freshwater wetlands (City of New York, 2012b, p. 3). Governance of wetland resources is comprised of public and private ownership and the wide variety of management structures that exist for it (NYC, 2012). Federal and state regulatory efforts are addressing the decline through a number of regulatory and planning programs. The city is surrounded by more than 500 miles of coastline, owned, operated, and maintained by numerous jurisdictions. The New York City Department of Parks and Recreation maintains about 150 miles of coastal parkland, or about 30 percent of the city's coastline (NYC, 2014b). The NYC waterfront plan routinely addresses the waterfront and its uses. The Hudson River Estuary, New York Harbor, Jamaica Bay, Long Island Sound, and East River, and various smaller areas, such as the Bronx River and Gowanus, are other important environmentally sensitive areas, all with separate planning efforts and public, private, and nonprofit jurisdictions and mechanisms in place to improve or maintain their quality (EPA, 2012a). Water quality citywide is reflected in 1,546 waterways characterized as "impaired" under section 303(d) of the Clean Water Act (EPA, 2012b). There are numerous indicators of water quality. Dissolved oxygen is one of the major indicators, with higher values signifying better water quality and the ability to sustain aquatic ecosystems. The 2014 report by the city indicated that dissolved oxygen levels have improved over the decades and are now reported as averaging 6.0 mg/l, above the highest standard, which is 5.0 mg/l.[15] Concentrations of bacteria have been reported as improving and are below the standards (NYC DEP, 2012).

Economic Issues

Over the centuries, the city has survived a series of financial catastrophes, including the mid-1970s brush with bankruptcy, economic losses sustained from the September 11, 2001, terrorist attack on the World Trade Center, and national recession, including the Great Recession following the collapse of Lehman Brothers during 2008. The city's economic and financial strength is reflected in a series of indicators, including its bond ratings,

[15] Dissolved oxygen standards vary from waterway to waterway and depend on the designated usage of a given waterway. For "bathing and other recreational uses," which is among the highest use with more stringent water quality standards, the city indicates that the dissolved oxygen standard is 5.0 mg/l.

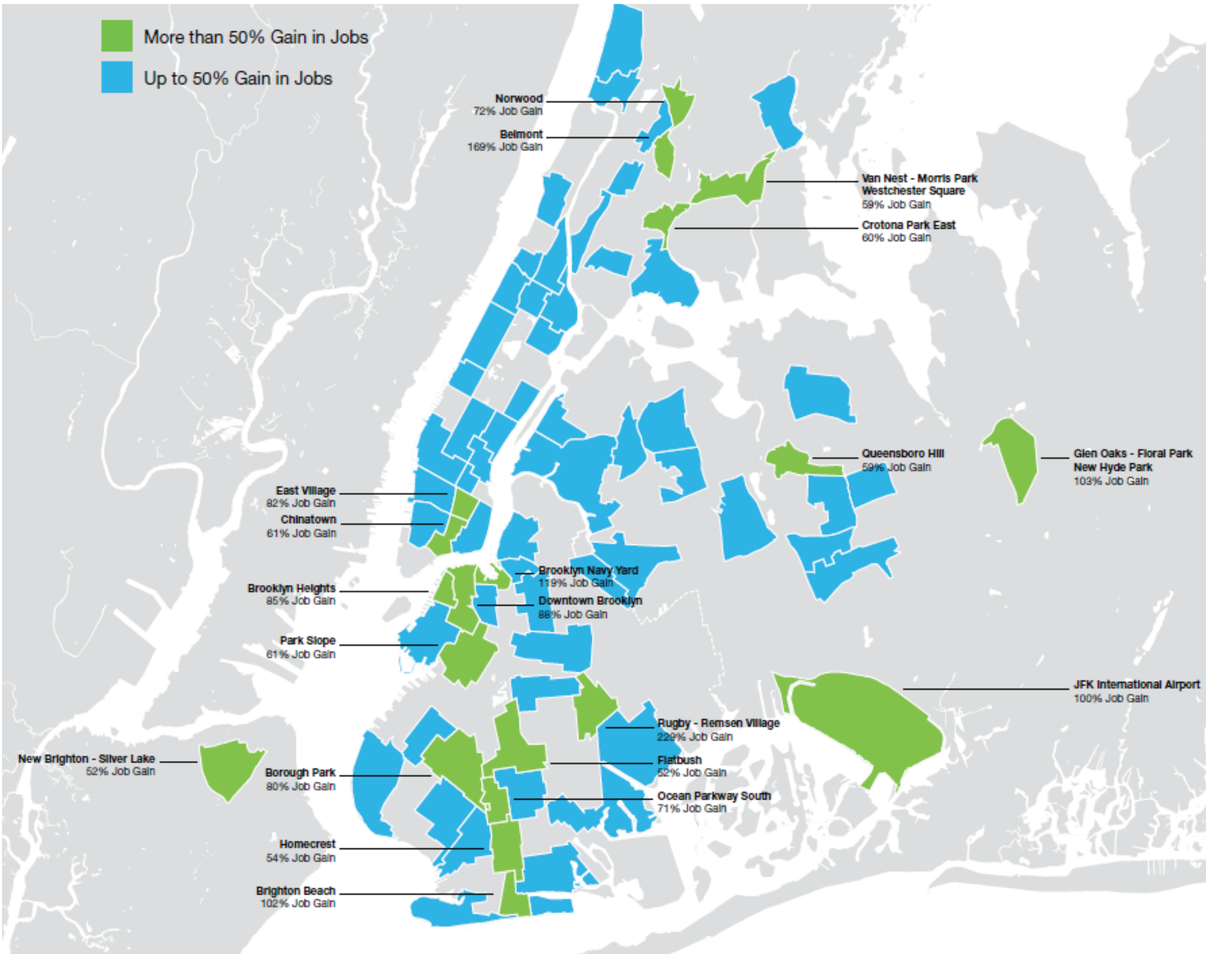

FIGURE 4-5 Map showing employment change in total jobs, 2001-2011, in New York City.
SOURCE: NYC Office of the Mayor, 2015a. Permission granted from U.S. Census Bureau. LEHD Origin-Destination Employment Statistics, v. 7. Geography: Neighborhood Tabulation Area.

gross city product, workforce characteristics, and income levels. As a result of the mid-1970s fiscal crisis, the city embarked upon a strategy of diversification of lending sources through the New York State Municipal Assistance Corporation. By 2015 the city reported that Moody's rated New York City general obligation (GO) bonds at Aa2, and Standard & Poor's (S&P) and Fitch rated GO bonds AA, the third highest S&P rating, levels it has maintained for a number of years (NYC, 2015b). The gross domestic product (GDP) and gross city product (GCP) of New York, measures of economic performance, continue to increase (NYC Comptroller, 2014). Median income levels continue to rise. However, those in poverty and those caught up in intergenerational poverty continue to constitute a large share of the city's population (Figure 4-5). This reflects a longstanding socioeconomic problem within the city including the factors associated with poverty, such as availability of jobs and education, racial and ethnicity conflicts, health problems, health outcomes, and quality of life. Social and economic strife resulting in riots and labor strikes also affected the stability of the city.

The distribution of economic establishments in New York City is identified in the U.S. Census. According to Bram and Orr (2015), the New York City economy continues to maintain its robustness with New York City job growth exceeding that of the United States since 2007.

The U.S. Census reports that the distribution of the workforce 16 years old or older in the New York Core Based Statistical Area (CBSA) indicates that the top three sectors are (1) education; (2) information and technology, finance, insurance, and real estate; and (3) professional services. Together they account for over one-half of the employment (Executive Office of the President, 2000; U.S. Census Bureau, 2014a).

A few sectors exemplify patterns and trends in the economy, namely the Finance, Insurance, and Real Estate (F.I.R.E.) and Technology sectors. The F.I.R.E. sector and professional services in terms of salaries, wages, and contributions to the City's GDP/GCP are key to New York City's economic base, a shift from over a century ago when the economic base was largely manufacturing. Technology sectors have had a unique history in New York City. Bram and Ploezke (2015) found employment increased between 2007 and 2014 in the technology sectors, while acknowledging the challenges in defining that sector. New initiatives in the technology arena in New York City include the emerging Cornell University technology center on Roosevelt Island and the Center for Urban Science and Progress at New York University, which both received startup grants from the Bloomberg administration. This example shows how stakeholders can better integrate science, technology, and research into catalyzing and supporting sustainability initiatives.

The city's goods movement sector is among the largest in the United States, which is reflected in marine, air, and ground transportation, and some of these sectors produce flows across city boundaries that contribute to its sustainability. In the marine sector, the size and capacity of marine ports are measured as number of containers and twenty-foot equivalent units (TEUs), calls, tonnage (as metric tons), value of cargo or market share, and other measurements. The Port Authority of New York and New Jersey (PANYNJ) is considered the largest on the East Coast and third largest after Los Angeles and Long Beach in the United States in terms of TEUs handled (PANYNJ, 2015a,b). PANYNJ reported that in 2014, metric tons of all cargo increased 2.7 percent, value increased 2.5 percent, and containers increased 5.6 percent over 2013 levels (PANYNJ, 2015b). Strauss-Wieder's model estimated that PANYNJ supported the following in terms of job generation and related economic support: "165,350 direct jobs, 296,060 total jobs in the Region, over $18.3 billion in personal income, nearly $28.9 billion in business income, and more than $6.1 billion in federal, state and local tax revenues, with local and state tax revenues of over $2.05 billion and federal tax revenues of nearly $4.07 billion" (A. Strauss-Wieder, Inc., 2014, p. 2). Of this bistate total, A. Strauss-Wieder noted that the port supports in New York City alone "17,040 direct jobs, 34,830 total jobs in the City, nearly $3.3 billion in personal income, almost $7.6 billion in business income, and over $1 billion in federal, state and local tax revenues, with local and state tax revenues of almost $414 million and federal tax revenues of over $640 million" (A. Strauss-Wieder, Inc., 2014). The city's economy—via investments by PANYNJ, a public benefit corporation controlled by the governors of those two states—benefits from dredging programs that deepen the channels for larger cargo vessels, which helps the bistate port remain competitive with other major ports.

In summary, the city's economy by a number of measures related to business outcomes and employment has shown mixed trends. The government has addressed financial issues in part by diversifying its sources of funds, which higher bond ratings now reflect.

Public Health Issues

Human health is measured using numerous indicators: years of potential life lost, death rates, injuries, and incident and mortality rates for specific diseases for different population sectors, for example, by age (children and the elderly), income, gender, race, and ethnicity. The overall premature age-adjusted mortality per 100,000 for the five counties of New York City indicate that the Bronx has the highest premature age-adjusted mortality per 100,000, followed by Richmond (Staten Island), Kings (Brooklyn), Queens, and New York (Manhattan) (RWJF and University of Wisconsin Population Health Institute, 2015). Other indicators have been provided by the city's Community Health Profiles issued in 2015. The New York City Community Health Profile reports show that the infant mortality rate per 1,000 live births citywide is 4.7, obesity citywide is 24 percent, flu vaccination rates are

40 percent, and perception of health status is 78 percent citywide indicating excellent, very good, or good (NYC Department of Health and Mental Hygiene, 2015).

In general, relationships between income and availability, access, and affordability of health care are critical concerns in urban areas. The NYCHealth health goals were supported by meeting clean air goals set in the PlaNYC 2007 plan, and improvements in asthma, cardiovascular disease, and death rates have been attributed in part to declines in $PM_{2.5}$, commonly known as soot (NYC Health, 2013a).

The National Ambient Air Quality Standards (NAAQS) are the benchmarks for ambient urban air quality; however, almost 200 hazardous air pollutants are also major benchmarks (EPA, 2014c). The New York State Department of the Environment identified 17 air quality monitoring sites in NYC for all parameters (NYS DEC, 2015). Ozone areas designated as attainment or nonattainment with respect to NAAQS are defined by the EPA. Transportation-related air quality issues in New York City and counties to the north and west are addressed in conformity regulations under the Clean Air Act and dealt with as part of the New York Metropolitan Transportation Council reviews. The Air Quality Index values for New York City for 2012 indicate a maximum (out of 500) of 150 and a median of 55 on a scale of 0 (the best) to 500 (the worst) (EPA, 2015a).

Attainment with NAAQS is an important measure of air quality. As of October 1, 2015, EPA listed the five NYC counties of the CBSA as being in nonattainment for the 8-hour ozone standard (of 2008), and New York County was listed in moderate nonattainment for PM_{10} (EPA, 2008). The micrograms per cubic meter of $PM_{2.5}$ ranged from 10.7 to 10.9 depending on the county within NYC (RWJF and University of Wisconsin Population Health Institute, 2015).

Linkages between air quality and health are continually made. New York City as of the first part of the 21st century has been considered a nonattainment area for ozone and had been a nonattainment area for $PM_{2.5}$, though it is now in compliance with $PM_{2.5}$ (NYS DEC, 2014). The NYC Health Department attributes ozone pollution largely to traffic density, and traffic is also a key source of $PM_{2.5}$ (NYC Health, 2013b). NYC-reported results of its street-level monitoring program, the New York City Community Air Survey, found over the period from 2008 through 2013 increases in three pollutants—fine particles ($PM_{2.5}$), sulfur dioxide (SO_2), and nickel (Ni)—where building concentrations were high, and therefore the Clean Heat program was introduced to eliminate residual oil for heating (NYC, 2013).[16] Traffic is another source of NAAQS pollutants, particularly particulate matter. Zimmerman and Restrepo portrayed the potential for exposure to particulate matter and other traffic-related air pollutants in the South Bronx, New York, in terms of the proximity of schools to roadways (Zimmerman and Restrepo, 2004-2009).

Asthma has been potentially viewed as linked to air quality, and New York City ranks high relative to the rest of New York State in terms of indicators such as prevalence rates, emergency department visits, and hospital discharge rates: "Geographic differences continue to be seen. Adults who live in New York City had higher current asthma prevalence in 2011, and also had higher age-adjusted asthma emergency department visit, hospital discharge, and mortality rates for 2009-2011 when compared to residents in the rest of the State" (NYS Department of Health, 2013, p. 2). At the county level, asthma emergency department visit and hospital discharge rates varied across New York State for 2009-2011, with the highest rates in the Bronx, and for the Bronx specifically, the age-adjusted emergency department visit rate was 231.4 per 10,000 residents, the hospital discharge rate was 63.3, and the death rate was 43.5 per million—all the highest in the state (NYS Department of Health, 2013). The NYC Community Health Profile data report child asthma hospitalization rates per 10,000 children, and the average citywide is 36, ranging from 72 in the Bronx to 15 in Staten Island (NYC Department of Health and Mental Hygiene, 2015).

Climate and Weather Risks

Locally generated GHG emissions are targeted to be 80 percent lower by 2050 than in 2005 (80x50), and the city has already reported a 19 percent drop in those emissions, which it indicates is "nearly two-thirds of the

[16] The U.S. Energy Information Administration defines residual fuel oil as "heavier oils, known as No. 5 and No. 6 fuel oils, that remain after the distillate fuel oils and lighter hydrocarbons are distilled away in refinery operations."

way toward an intermediary goal of reducing GHG emissions 30 percent by 2030"; that in turn is attributed to the increased use of natural gas (NYC, 2015a). New York City conducts a buildings emissions inventory every year to ascertain its performance.

Extremes of temperature and precipitation and storm frequencies occur in New York City. From 1971 to 2000, "New York City averaged 18 days per year with maximum temperatures at or above 90°F, 0.4 days per year at or above 100°F, and two heat waves per year" (Horton et al., 2015, p. 25). For low-temperature extremes: "From 1971 to 2000, Central Park averaged 71 days per year with minimum temperatures at or below 32°F" (Horton et al., 2015, p. 25). Precipitation extremes measured as "the number of occurrences per year of precipitation at or above 1, 2, and 4 inches per day for New York City (at the weather station in Central Park) since 1900" indicate that historically "between 1971 and 2000, New York City averaged 13 days per year with 1 inch or more of rain, 3 days per year with 2 inches or more of rain, and 0.3 days per year with 4 inches or more of rain. As with extreme temperatures, year-to-year variations in extreme precipitation events are large. There has been a small but not statistically significant trend toward more extreme precipitation events in New York City since 1900" (Horton et al., 2015, p. 25).

The National Oceanic and Atmospheric Administration storm events database lists 656 extreme weather events of all types in the five boroughs alone between 2005 and June 1, 2015, resulting in 123 deaths. The New York City Hazard Mitigation Plan provides a count of just coastal storms from 1785 to 2012: There were 26 storms listed and 10 of these (38.5 percent) occurred since 1990 (NYC, 2014b, 2015a). Specific extremes are noteworthy, namely Hurricane Irene and Superstorm Sandy. In addition to hurricanes, flash flooding episodes occurred most recently in the first decade of the 21st century, disabling infrastructure. An August 2007 rainstorm that occurred during the morning rush hour shut down many subway lines and stations, and disrupted service for parts of the Long Island Rail Road and Metro-North Railroad. Major snowstorms, most notably the December 26, 2010, "snowmaggedon," had similar impacts. The frequency and persistence of these events are important to incorporate into any sustainability strategy for the city, and the *OneNYC* plan emphasizes that.

The Mayor's Management Report (2014) outlined a set of accomplishments designed to address the consequences of Superstorm Sandy (NYC, 2014a). New York City is investing $3.7 billion in physical coastal protection planning, including coastal dunes, berms, trapbags, sand nourishment, green infrastructure, bluebelt projects, the creation of resilience standards for key assets, applications for Federal Emergency Management Agency support, reconstruction and rebuilding, environmental monitoring, legislation, and grants and loans for rebuilding.

New York City's reported achievements, as measured against its sustainability goals, are in energy efficiency, energy-use analyses, promotion of alternative energy sources, GHG emissions reductions (19 percent between 2005 and 2012), changes in the Air Pollution Control Code for air quality improvements, solid waste reduction, and other cleanup efforts (NYC, 2014a).

Infrastructure

New York City continues to see an increase in the demand, use, and consumption of its infrastructure services, new levels of demand that often seem to exceed capacity and resources. The extent of use of infrastructure facilities and the extent and condition of infrastructure are key metrics. The Center for an Urban Future (2014) identified persistent infrastructure conditions such as age and breakdowns that affect lifeline infrastructure's capacity to meet rising demands.

Ownership, operation, and jurisdiction over New York City's streets, roads, bridges, and mass transit are balkanized. The City of New York manages almost half (789) of the bridges that connect its boroughs and the city to adjacent regions (NYC Department of Transportation, n.d.). Trans-Hudson bridges and tunnels are owned and operated by PANYNJ, a bistate public benefit corporation that is under the jurisdiction of the governors of those two states. Nine other crossings (two tunnels and seven bridges) are owned and operated by the MTA, a New York State–run public benefit corporation.

Commuting characteristics show that public transit dominates, and has the highest number of passenger trips and passenger miles of travel by public transit, about six times the trips in the second ranking city, Los Angeles (APTA, 2015, Appendix B). Box 4-3 depicts some selected highlights of transit activity throughout the metropolitan

BOX 4-3
Selected Transportation Activity in New York City

Mass transit ridership (year ending December 31, 2014) (MTA, 2015)

- Annual MTA NYC Transit ridership (subways in four boroughs and buses in five boroughs): 2,427,233,073
- Average MTA NYC Transit weekday bus and subway passengers: 7,660,606
- Annual MTA Staten Island Railway ridership: 4,367,616
- Average MTA Staten Island Railway weekday passengers: 15,458
- Annual MTA Bus Co. ridership: 125,581,237
- Average MTA Bus Co. weekday ridership: 407,115

Road travel is reflected in a number of indicators listed below.

- Annual Vehicle Miles of Travel (FHWA) in thousands (New York-Newark urbanized area, NY, NJ, CT): 290,116 (DOT, 2014; FHWA, 2014)
- Licensed drivers per 1,000 driving age population (state only): 705
- Mean travel time to work in minutes (all modes) 2014: 44.6 minutes[a]

The quality of travel is reflected in measures of congestion –TTI (auto only) (Schrank et al., 2015)[b] listed below:

- Yearly delay (hours/commuter): 74
- Excess fuel (gallons): 35
- Cost (dollars/commuter): 1,739

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[a] U.S. Census Bureau. 2014d. American Community Survey. Online. Available at https://www.census.gov/programs-surveys/acs. Accessed August 25, 2016.

[b] "Travel Time Index—The ratio of travel time in the peak period to the travel time at free-flow conditions. A value of 1.30 indicates a 20-minute free-flow trip takes 26 minutes in the peak period; Excess Fuel Consumed—Increased fuel consumption [in gallons] due to travel in congested conditions rather than free-flow conditions; Congestion Cost—Value of travel time delay (estimated at $17.67 per hour of person travel and $94.04 per hour of truck time) and excess fuel consumption (estimated using state average cost per gallon for gasoline and diesel)."

area. For example, 58.7 percent of worker trips use public transportation (DOT, 2015). New York City accounts for 81 percent of the New York-New Jersey-Connecticut region's unlinked passenger trips and 55 percent of the passenger miles (computed from APTA, 2015, Appendix B), reflecting the density of travel and corresponding density of transit mileage for those trips. Mass transit use continues to increase, and it achieved record levels in 2015 (MTA, 2015). The MTA has developed and implemented a number of sustainability initiatives, including energy and water conservation and renewable energy projects (MTA, 2009). Walk score calculations for NYC indicate 88, 81, and 65 out of a maximum of 100 for walking, transit, and biking modes, respectively (Walk Score, 2015a).

The New York State Independent System Operator (ISO) reported that electric power usage in New York City has been declining slightly since 2010 (around 1 percent per year). ISO reports that over three-quarters of the generation capacity of the city relies on "dual fuel" or the gas and oil (with some units being able to switch between the two) (NYS ISO, 2015). An overall reliability index, the System Average Interruption Duration Index, for New York City's Con Edison service area is 19 minutes per customer per year (EIA, 2015a; Interstate Power and Light Company, 2012; NYS DPS, 2014). Resiliency measures have been identified for weather and climate protection initiated in part by Superstorm Sandy (Consolidated Edison and Orange and Rockland Utilities, 2013). New York City is targeting the building sector in its energy reduction strategies because annual building inventories continue to show the dominance of that sector for energy consumption and carbon emissions from energy (NYC, 2014a). To promote renewable energy, a number of financial incentives exist for solar panel installations, such as property tax credits and New York State's sales tax exemptions and rebates. In addition, New York City and Con Edison are partnering to designate "Solar Empowerment Zones." New York City ranked seventh among the 57 cities that Environment America identified for "cumulative solar PV Capacity (MW)," but with a rank of 41 for per capita levels (DOE, n.d.; Environment America Research & Policy Center, 2015).

The U.S. Geological Survey reports water consumption as 75 domestic gallons per capita per day for each of New York City's counties (USGS, 2010). The city's water supply, some of which is drawn from as far as 125 miles to the north, continues to provide reliable water in terms of quality and quantity, and in terms of NYC DEP jurisdiction, did so before, during, and after Superstorm Sandy. Once the supply leaves the city's jurisdiction and reaches private property, however, supplies can become compromised by loss of power required to pump the water, which happened in high-rise apartment buildings as Superstorm Sandy moved through the city and region (Zimmerman et al., 2015).

The City of New York relies upon structural and nonstructural approaches to reduce water pollution from both sanitary sewers and runoff over land surfaces. As part of the recovery from Superstorm Sandy, the NYC DEP identified where vulnerabilities were in relation to each wastewater treatment plant and its components (NYC DEP, 2013b).

For solid waste management, the *OneNYC* initiative focused on ending the disposal of solid waste at landfills, and forecasts that the city could reach its zero solid waste goal by 2030. In mid-2015, the city announced requiring the diversion of food wastes from large-scale facilities amounting to about 50,000 tons per year (NYC, 2015c). The Mayor's Management Report indicated that they were "continuing to work with the Department of Sanitation on the Food Waste Challenge to divert organic waste from landfills, which reduced waste by 2,500 tons in the last six months" (NYC, 2014a).

Institutional Efforts

As illustrated in Box 4-2, New York City has implemented a number of integrated initiatives aimed at furthering sustainability efforts for the metropolitan region. Other notable institutional efforts include a governance structure involving 59 community boards that are required to review and approve plans that affect neighborhoods within the boundaries of each community board; review processes for capital programs, for example, for transportation through the New York Metropolitan Transportation Council; zoning ordinance changes, e.g., Zone Green, to accommodate green infrastructure; and construction and energy codes incorporated into numerous sustainability initiatives, as well as citywide and areawide plans and programs, such as the Regional Plan Association fourth regional plan, along with ongoing studies of the distribution of inequities in the region (NYC, 2012; RPA, 2015a,b).

MAJOR SUSTAINABILITY EFFORTS: A SUMMARY

Three key sustainability efforts for New York City are (1) the ability to decarbonize or reduce carbon emissions from infrastructure and other components of the built environment as a means of mitigation and adaptation with respect to climate change, (2) inequality, and (3) infrastructure needs and interdependencies.

Decarbonization and Climate Change

New York City faces continual challenges in meeting its resource needs and the targets it has set for renewable energy resources, waste management, and GHG emission reductions. These are especially formidable challenges given the scale of the city and the vulnerabilities it faces. In response to these needs, the city regularly inventories its emissions particularly from what it has identified as the key emission sector—buildings. It participates in LEED and other programs for emissions reduction. The projections for climate change and their ramifications, for example, for extreme heat, precipitation and downpours, storms, and sea-level rise have been identified toward the end of the 21st century by the NPCC and others. These projections yield considerable escalations in all of the consequences and the vulnerability of the built environment and the social and economic systems that they support. These analytical efforts, as well as a commitment to reduce emissions, have led to a very large and diversified program for adaptation in New York City.

Inequality

Of particular importance is the ability to address existing and projected needs of the poorest segments of society. Though the city's economy continues to grow and the environment and public health are generally improving, poverty and housing needs and pockets of health issues continue to affect major segments of the city's residents and neighborhoods, according to the *OneNYC* plan. To address this need, the city has undertaken an affordable housing program and programs to support the workforce.

Infrastructure Needs and Interdependencies

A continually eroding infrastructure base to which funding gaps contribute cannot meet the needs of its current and anticipated users equitably. The agencies that control the infrastructure stock within the city's borders make interim and often short-term adjustments to this situation given funding constraints. Exacerbating the situation is the control by both public and private entities beyond the city's and the region's borders of these physical systems, and they often have competing interests. This is magnified in many ways by the interconnections among infrastructures and between city services and the region from which it draws resources and gives back services. In severe weather conditions and other natural hazards, these interconnections often magnify the adverse consequences. They need to be understood and acted upon. The organizations within the city and the region have acknowledged these issues, and in many cases have formed working groups among the responsible organizations to target these problems.

TABLE 4-4 Example Highlighting Actions for New York City that Illustrate Steps in Urban Sustainability Roadmap (see Chapter 3, Figure 3-1)

City	New York City
Adopt Principles	P1, P2, P3, P4
Opportunities and Constraints	Opportunities: Affordable housing to address widening income gap and persistent pockets of poverty; vulnerability to climate change with major programs under way for adaptability and mitigation. Constraints: Infrastructure investments are a major constraint to bringing services to or maintaining services at sustainable levels.
Prioritize Co-net Benefits	Density: transport, CO_2, access to jobs; linkages between air quality and health.
Partnerships	Community Boards/Districts Public-sector partnerships within a number of different venues, e.g., the NYC Mayor's Office of Recovery and Resiliency and New York City Panel on Climate Change task forces. Emergence hubs of innovation where academics, corporations, and government collaborate, e.g., Cornell and NYU centers of innovation and others.
Goals	The goals of the *OneNYC* Plan (pp. 5-6): • "Growing, Thriving City" through "a dynamic urban economy" • A "just and equitable city" through jobs and "lifting 800,000 New Yorkers out of poverty or near poverty by 2025" • A "sustainable city" with a "goal to reduce greenhouse gasses by 80 percent by 2050" • A "resilient city"

TABLE 4-4 Continued

City	New York City
Strategies	Jobs Affordable housing Reaching climate change goals by emphasizing building-sector emissions and emphasizing adaptation and mitigation planning and implementation. Generally reaching environmental goals, e.g., water and air in conformance with federally approved state and city regulations. Increased tree canopy through the planting of a million trees.
Data Gaps	Citywide resource usage and emission inventories. Partitioning of resources and emissions between NYC, the region, and elsewhere.
Implementation	Green Zoning Numerous environmental laws (see text). Sustainability goals (http://www.nyc.gov/sustainability). Adaptation and mitigation planning and implementation and funding to approach these efforts. Plan to create 200,000 units of affordable housing units over 10 years. Financial incentives for solar panel installations, such as property tax credits and New York States sales tax exemptions and rebates. As of April 2015, more than 949,000 trees have been planted as part of the Million Trees Initiative.
Local to Global	Federal standards for clean air and water, implemented by state and local government.
Public Buy-in	Public opinion polls conducted over time to ascertain public opinion about the city's environment and various issues within that context that reflect public buy-in at a broad level. These surveys tend to show variable results over time and often depend on what issue is the focus of the poll. The NYC community board/district review process and review processes of other entities are mechanisms for public buy-in.
Feedback	GHG: Energy efficiency in buildings and "flood resilience text amendment"; Equity: affordable housing.

VANCOUVER

A coastal seaport city located on the west coast of Canada, Vancouver is the eighth largest city in Canada and the second largest city on the U.S.-Canadian border. With a population of 600,000 in a region of 2.3 million, Vancouver has diversified its economy away from the resource extraction of its early days and transitioned to using its natural resources as quality-of-life amenities to attract residents and businesses (Statistics Canada, 2011).

BACKGROUND

Vancouver, unlike other British Columbia (BC) municipalities, is incorporated under a charter, the Vancouver Charter (Province of British Columbia, 1953). This legislation, passed in 1953, grants the city more and different powers than other BC municipalities. These powers have allowed Vancouver to make policies and introduce practices that have uniquely placed the city ahead of many other cities in Canada, the United States, and globally in terms of sustainability.

Vancouver is bounded by ocean and rivers on three sides and is located close to sprawling temperate rainforest and mountains (Figure 4-6). Vancouver's natural resources made it a natural settling place for the Coast Salish First Nations around 2000 BCE and for European and Asian immigrants starting in the 1800s (Musqueam: A Living Culture, 2011). European settlers focused on extracting those resources—first with the aggressive harvesting of

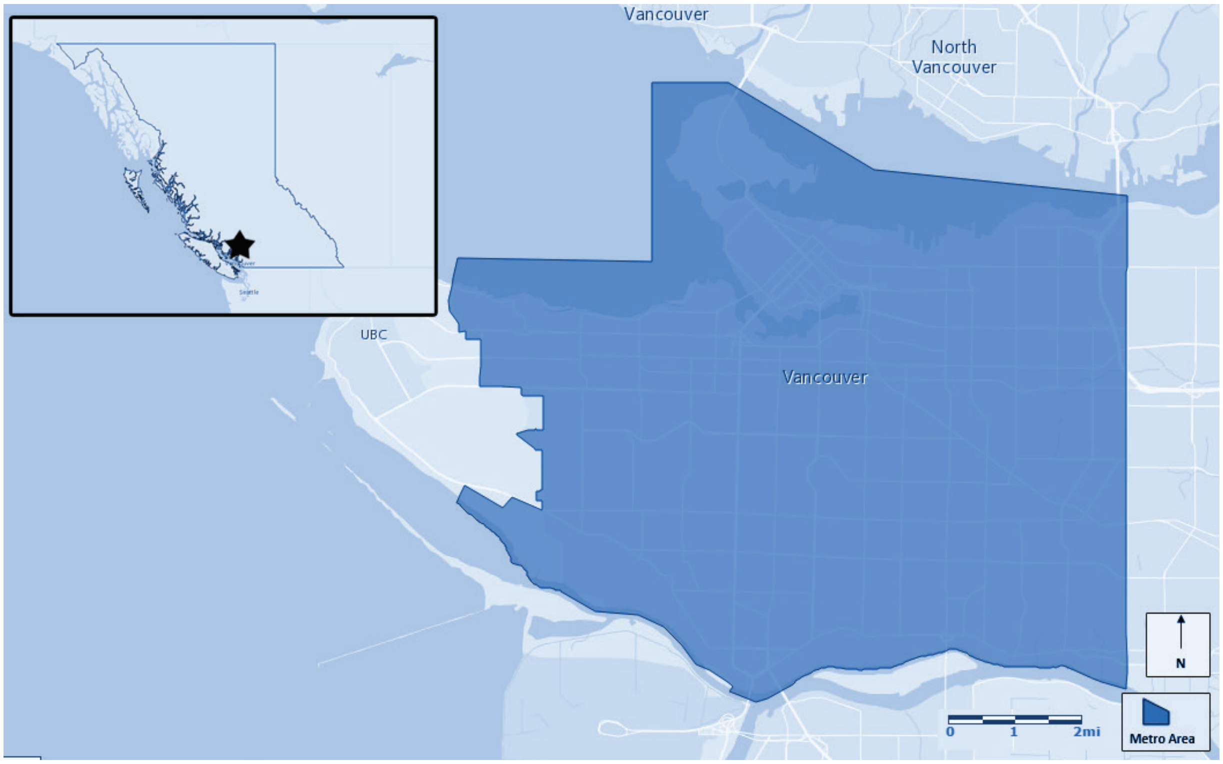

FIGURE 4-6 Map showing the city of Vancouver administrative boundary and location in British Columbia. SOURCE: Prepared by Brent Heard, Consultant to the STS Program.

fish and timber, and then in the mid-1800s with the extraction of minerals. Vancouver was also a supply post for teams bound north to stake their claim during the Klondike Gold Rush.

A particularly destructive period in the area's history spanned from 1850 to 1950. Old-growth forests were quickly harvested to build the city of Vancouver, which was incorporated in 1886. That same year, a clearing fire, set to prepare land for development, swept out of control and burned the city down. The city was rebuilt and Vancouver's waterfront became home to heavy industry that, in turn, resulted in contamination of the soil and water.

The midpoint of the 20th century proved to be a turning point for the city as a shift in public consciousness and environmental awareness prompted residents to see Vancouver's natural surroundings not as a resource to be exploited, but as an asset to be protected. With the advent of accessible airplane travel, tourism became a more popular activity globally, and Vancouver's access to nature made it a popular destination for those interested in outdoor activities such as backpacking, skiing, rock climbing, and kayaking. These activities also became popular pastimes for Vancouver's residents. As the value of nature activities to the city increased, local wild spaces were protected as parks, and extractive industries moved elsewhere.

By the end of the 20th century, tourism, the information economy, and trade had replaced extractive industries as the city's primary economic drivers (Vancouver Economic Commission, 2010). Globalization, inexpensive shipping, and Vancouver's fortunate proximity to Asia made it possible for the city's port to thrive. Commodities from afar flowed through this strategic location. Global events, such as the World Exposition in 1986 and the Winter Olympic Games in 2010, facilitated the restoration and development of formerly contaminated sites. The city became a magnet for highly skilled workers who settled, started, and grew knowledge-based businesses, and skied and sailed on weekends.

TABLE 4-5 Key Characteristics for Vancouver

Indicator	Vancouver	United States
ENV Average Annual Precipitation (inches/year)	46.8	40.8
ENV Existing Tree Canopy (% of land cover)	18%	25%
ENV Roadway Fatalities (per 100 million annual vehicle miles traveled)	0.7	1.1
ENV Particulate Matter 2.5 (ppm)	6.6	10.2
ENV Residential Carbon Footprint (metric tons of CO_2 per capita from residential energy consumption)	0.8	3.4
ECON Financial Health	AA+	AA+
ECON Average Residential Electricity Rate (cents/kWh)	7.8	11.9
SOCIAL Black or African American	1%	13.2%
SOCIAL Hispanic or Latino	1.6%	17.4%
SOCIAL Asian	41%	5.4%
SOCIAL Home Ownership (2009-2013)	48.5%	64.9%
SOCIAL High School Graduate (25 or older, 2009-2013)	92%	86%
SOCIAL Below Poverty Level		15.4%
SOCIAL Violent Crimes (per 100,000 people)		191

NOTE: ENV, ECON, and SOCIAL refer to the three dimensions of sustainability: environmental, economic, and social, respectively. SOURCE: Appendix B.

Ironically, Vancouver's popularity both as a place to visit and as a place to live is what threatened its future sustainability. In the early 2000s, pressure from population growth brought forests down in the neighboring north-shore mountains for housing developments. Urban sprawl in the eastern suburbs (the only direction in which sprawl could travel due to geographical constraints) created increased congestion on arterial roads and an increased need for public transit. Densification became the only practical solution to meet the demand for growth in the urban core. Land and housing scarcity drove housing prices up, making the city unaffordable for young families. The urban tree canopy thinned as blocks of single-family homes were replaced with towers (City of Vancouver, 2014b). At the turn of the 21st century, Vancouver stood at a crossroads of two opposite futures: foster systemic change to ensure that the city grows while protecting the natural beauty that makes it a desirable world-class destination or become a victim of its own success and let growth continue unchecked, destroying the natural beauty that was once its draw.

MAJOR SUSTAINABILITY EFFORTS

Vancouver residents chose a green future. In 2009, Mayor Gregor Robertson was elected on a platform to make Vancouver the "greenest city in the world." Upon taking office, he assembled a team of experts to set goals and targets for Vancouver to achieve this bold objective by 2020. During 2010 and the first half of 2011, over 35,000 members of the public were engaged to develop strategies to achieve these targets (City of Vancouver, 2011). These formed the basis of the Greenest City 2020 Action Plan, which was adopted by Vancouver's City Council in July 2011. It includes a series of goals and targets to be achieved by 2020 (see Box 4-4).

This clear, ambitious, measurable plan has changed the way the city government operates, spawned hundreds of aligned initiatives both inside and outside of the city organization, and changed the face of Vancouver. The

BOX 4-4
City of Vancouver Greenest City Action Plan 2020 Targets

CARBON
- Reduce community-based greenhouse gas emissions by 33 percent from 2007 levels.
- Require all buildings constructed from 2020 onward to be carbon neutral in operations.
- Reduce energy use and greenhouse gas emissions in existing buildings by 20 percent over 2007 levels.
- Make the majority (over 50 percent) of trips by foot, bicycle, and public transit.
- Reduce average distance driven per resident by 20 percent from 2007 levels.

WASTE
- Reduce solid waste going to landfill or incinerator by 50 percent from 2008 levels.

HEALTHY ECOSYSTEMS
- All Vancouver residents live within a 5-minute walk of a park, greenway, or other green space.
- Plant 150,000 new trees.
- Meet or beat the strongest of British Columbian, Canadian, and appropriate international drinking water quality standards and guidelines.
- Reduce per capita water consumption by 33 percent from 2006 levels.
- Always meet or beat the most stringent of air quality guidelines from Metro Vancouver, British Columbia, Canada, and the World Health Organization.
- Increase citywide and neighborhood food assets (local growing, processing, and distribution facilities) by a minimum of 50 percent over 2010 levels.

OVERARCHING GOALS
- Double the number of green jobs (based on the United Nations Environment Programme definition of the term) over 2010 levels.
- Double the number of companies that are actively engaged in greening their operations over 2011 levels.
- Reduce Vancouver's ecological footprint by 33 percent over 2006 levels.

SOURCE: Climate Research Team (2015).

Greenest City Action Plan provides the top-level strategy, under which a host of enabling strategies, policies, programs, and regulations have been and are being developed. Of particular note are the following.

Climate Leadership

Approved by the City Council in 2012, Vancouver's Neighborhood Energy Strategy is the city's blueprint to create a network of low-carbon district energy systems to heat buildings in high-density neighborhoods across Vancouver. Supporting city regulation requires developers within identified zones throughout the city to connect buildings to district energy systems as they come online. The area served by Vancouver's flagship Neighbourhood Energy Utility currently produces 56 percent fewer GHG emissions than a typical neighborhood (City of Vancouver, 2015b). The overall goal of the Greenest City Action Plan is to eliminate dependence on fossil fuels. The plan sets a target to reduce community-based GHG emissions by 33 percent from 2007 levels.

Green Buildings

In Canada, cities have only those authorities expressly granted to them by the province in which they are situated (Government of Canada, 1867). For historical reasons, Vancouver is the only municipality in the province of British Columbia that has its own Municipal Charter and its own building code and therefore has regulative authority beyond those of all other cities in the province (Province of the British of Columbia, 1953). The City of Vancouver regularly updates its building code to increase energy efficiency standards. As a result, today a home built in Vancouver uses 50 percent less energy than those built elsewhere in the province (City of Vancouver, 2014a). The Action Plan strives to have all existing buildings reduce energy use and GHG emissions by 20 percent over 2007 levels and requires all buildings constructed after 2020 to be carbon neutral in operations.

Green Transportation

Approved by the Vancouver Council in 2012, Vancouver's Transportation 2040 Plan is a roadmap for meeting the Action Plan's Green Transportation goal to make walking, cycling, and public transit residents' preferred modes of transport. The 2040 plan prioritizes action based on transportation mode. From highest to lowest priority: walking is followed by cycling, then transit, taxis and shared vehicles, and finally the private car (City of Vancouver, 2012). New infrastructure investment is prioritized based on this hierarchy. As part of this effort, the city has created a network of over 275 kilometers (km) of bike routes throughout the city, including a continuous 28-km path along the waterfront (City of Vancouver, 2015a). Designed for all ages and abilities, these lanes are supporting thousands of trips daily and contributing to an important outcome: Today, half of all trips in the city are made by foot, bike, or transit (City of Vancouver, 2015a).

Zero Waste

The Action Plan calls for Vancouver to reduce waste to landfill by 50 percent. One way to encourage waste reduction is through Extended Producer Responsibility (EPR) programs, which make the producer of a product responsible for taking that product back at the end of its useful life and recycling it. This, in turn, supports a shift in the way producers design products toward reducing the amount of materials used in production and packaging and increasing the ease of diverting these materials from the landfill. Significant environmental and economic benefits have been realized from early EPR programs such as these measured by the Province of BC in 2007 (Gardner Pinfold Consulting, 2008): An annual reduction of 267,000 metric tonnes of carbon dioxide equivalent (MTCO2e), 5.3 million gigajoules in annual energy savings, and 2,100 additional full-time equivalent positions. Because of this, British Columbia continues to roll out EPR regulation for an increasing number of consumer products, most recently in 2014, for paper and packaging. The city of Vancouver is responsible for residential garbage collection, so it works closely with the province and producers to design EPR programs and ensure their efficacy.

Access to Nature

Passed in 2014, the Urban Forest Strategy Framework established the goal of increasing Vancouver's canopy cover (a measure of the area of the city covered by trees) from 18 to 22 percent by 2055 (City of Vancouver, 2015a). Tree cover provides essential cooling, shade protection, and air quality improvement for city residents, increasing both physical and mental well-being. Vancouver is working toward the Action Plan's goal to increase residents' enjoyment of and access to green spaces. In addition to increasing the tree canopy, work is being done to create an environment in which all Vancouver residents live within a 5-minute walk of a park, greenway, or other green space.

Clean Water, Clean Air, and Local Food

The Action Plan strives for Vancouver to be a leader in drinking water quality, air quality, and urban food systems. It wants to meet or exceed the most stringent quality standards and guidelines for water and air quality. In terms of water use, it aims to reduce per capita water consumption by 33 percent from 2006 levels. It plans to increase the number of local food growing, processing, and distribution facilities by at least 50 percent over 2010 levels (City of Vancouver, 2015a).

Green Economy and Ecological Footprint

Building on its reputation as a city specializing in green businesses, the Action Plan calls for Vancouver to double the number of green jobs over 2010 levels and double the number of companies actively engaged in greening their operations over 2011 levels. For the city at large, it seeks to reduce Vancouver's ecological footprint by 33 percent over 2006 levels (City of Vancouver, 2015a).

OTHER SIGNIFICANT ACTIVITIES

Given its limited jurisdiction, Vancouver knew it could not achieve its 2020 targets on its own; therefore, city staff focused on forming and strengthening partnerships with the private sector, other levels of government, the nonprofit sector, academia, and the public to jointly deliver on their environmental mandate. An external steering committee was formed with representation across all sectors. A $2 million Greenest City Fund was established to provide funding for grassroots efforts to green Vancouver. A "CityStudio" was created in partnership with Vancouver's six postsecondary academic institutions to incubate and test out bright ideas in the academic setting. Students of these institutions can spend a semester at the Studio receiving course credit while working on projects to help build the Greenest City. In total, over 10,000 people are playing an active role in working toward Greenest City goals (City of Vancouver, 2015a).

Vancouver's success at achieving Greenest City outcomes and firmly placing itself on the path to true environmental sustainability can be attributed to several key success factors, some of which are recommended best practices for other cities. They are described below.

Socioeconomic Stability

Vancouver had the good fortune to receive an influx of federal investment to build infrastructure for the 2010 Winter Olympic Games during the last global economic downturn. According to a report by PricewaterhouseCoopers, "the midpoint for the range of real GDP impacts from 2003 to March 31, 2010 is estimated to be $2.3 billion dollars" (PricewaterhouseCoopers, 2010). This investment peaked in 2008, the same time at which the global economy reached the bottom of its lowest drop since the 1930s (PricewaterhouseCoopers, 2010). This provided Vancouver with a long period of socioeconomic stability, relative to other parts of North America, for the duration of the delivery of the Greenest City Action Plan.

Strong Public and Political Support

The home of Greenpeace and David Suzuki, Vancouver has a long history of strong public support for sustainability. In fact, the support is so strong that Vancouver citizens elected Mayor Robertson based on his campaign platform that focused on making Vancouver the Greenest City in the world, and have reelected him twice, based in part on the results achieved on this agenda.

BOX 4-5
British Columbia's Carbon Tax

The British Columbia (BC) Provincial Government passed a carbon tax in 2007. Carbon is taxed at a rate equivalent to $30 per metric ton by increasing the cost of greenhouse gas generating fuels by a relative equivalent amount. The carbon tax is working both environmentally and economically. Since the tax was implemented, fuel use in the province dropped 16 percent per capita while it rose 3 percent per capita in the rest of the country. Similarly, BC's real GDP grew 9.2 percent during the same period (more than the Canadian average). Because of this, in late 2015, the BC Government's Climate Leadership Team (a team of senior advisors appointed by the government) recommended that the government continue to strengthen the carbon tax.

Stable Funding

That same strong public support made it possible for the provincial government to pass a carbon tax in 2007 (Box 4-5). Carbon is taxed at a rate equivalent to $30 per metric ton by increasing the cost of GHG emissions generating fuels by a relative equivalent amount (British Columbia Ministry of Finance, 2012). Municipalities get the carbon tax they pay refunded to them on the condition that the funding is used to support sustainability programs. This provides a stable source of funding that is protected from competing internal priorities. Grant funding from utility demand-side management programs also contributes capital. On an annual basis, one-third to one-half of the city of Vancouver's Sustainability Department budget comes from outside sources, primarily provincial (City of Vancouver, 2015c).

Organizational Capacity and Good Governance

Stable funding creates the organizational capacity needed to implement the mayor's bold vision. The city has a properly resourced Sustainability Group that provides strategic oversight, technical expertise, and project delivery capacity to accountable owners across the organization, who are, in turn, responsible for delivering on plan objectives. A 2015 survey conducted by the Urban Sustainability Directors Network (USDN) concluded that, of the 12 other member municipalities with a population size similar to Vancouver (500,000 to 750,000), 72 percent had smaller sustainability budgets and 60 percent had fewer Sustainability Department staff than the City of Vancouver.

Strong Cross-sectoral Partnerships

Partnerships with the other levels of government, energy utilities, academia, not-for-profit organizations, and business help to mobilize resources and get results on the ground. For example, in 2010 the City of Vancouver partnered with the University of British Columbia to offer the Greenest City Scholars Program, which enables graduate students to work on sustainability projects with the city in support of the Greenest City Action Plan goals. The 80 projects completed to date have accelerated the implementation of the plan and several scholars have been hired by the city into full-time positions upon graduation.

Sharing of Knowledge Resources and Intellectual Property

The sharing of knowledge and intellectual property between cities and with academia is key to accelerating the rate of change. Vancouver's deputy city manager co-founded USDN, a North American member-based organization

150 cities strong—cities who share best practices and learnings toward advancing municipal sustainability. Since its inception in 2008, USDN has placed $6 million in collaborative municipal innovation projects and has disseminated this knowledge to other municipalities to encourage replication. Examples of USDN innovation products can be found on the USDN website: http://usdn.org/public/page/56/Innovation-Products.

Active Performance Management

Finally, active performance management ensures that progress toward the goals and targets is measured, tracked, and rewarded. Key sustainability metrics are embedded in the city's Corporate Scorecard. Key initiatives are embedded in the City of Vancouver's Corporate Business Plan (City of Vancouver, 2015d).

Vancouver's Greenest City story provides useful lessons to other municipalities, both at the micro level (through its successful delivery) and at the macro level. Vancouver's local success has given its politicians a license to operate, and advocate, internationally. Vancouver Mayor Gregor Robertson had an audience with the Pope at the Vatican in July 2015, met with senior climate change staff at the White House in Washington in October 2015, and attended the United Nations Framework on Climate Change Conference of Parties (COP 21) in Paris in December 2015. Vancouver's political leaders are supporting a growing movement of subnational governments globally who are changing the definition of successful urban development.

However, there is a caveat to Vancouver's success. The current municipal council and staff have made a lot of progress toward the Greenest City 2020 goals in a short period of time, but this has resulted in fatigue among residents about the amount and rate of change that they have been asked to absorb in pursuit of the sustainability goals. Traffic patterns have been changed when street lanes have been reallocated for bikes and when traffic-calming measures have been implemented to make neighborhoods more walkable. The frequency of garbage collection has been reduced from weekly to biweekly to support the introduction of weekly food scraps collection, changing residents' waste disposal habits. Ordinances have been passed that restrict the ease with which residents can cut down mature trees on their property. While each individual change was made to support residents' desire to live in a more sustainable city, the collective impact of all of these initiatives requires a significant amount of behavior change from residents and this has proved to be difficult for some. During the last municipal election, the mayor made a formal apology, acknowledging that some voters had become alienated by the city's ambitious pursuit of its green agenda. He was elected for a third term based, in part, on the commitment he made when making the apology to listen more carefully to residents' concerns about planned changes (Hutchinson, 2014; Lee, 2014). Other cities can learn from Vancouver's experience by carefully monitoring residents' response to change (both while planning and implementing green initiatives) and by course-correcting as needed.

SUMMARY OBSERVATIONS

The 15 targets described in Box 4-4 are measured and reported on annually. At the midpoint in the delivery of the plan, positive progress has been made in all areas, most notably the following:

- Citywide GHG emissions are down 7 percent over 2007 levels;
- Waste to landfill or incinerator is down 18 percent over 2008 levels;
- Water consumption per capita is down 16 percent over 2006 levels;
- Half of all trips in Vancouver are made by foot, bike, or transit;
- Vehicle kilometers traveled per resident is down 21 percent over 2007 levels;
- 37,000 new trees have been planted since 2010;
- Local food production, processing, and distribution capacity has increased by 36 percent since 2010;
- Zero water and air quality exceedences occurred over the past year; and
- Green jobs are up 19 percent over 2010 levels (City of Vancouver, 2015a).

Furthermore, the initiative has attracted significant international attention and accolades. The Economist Intelligence Unit placed Vancouver among the top five "greenest cities" in its Green Cities Index (The Economist,

TABLE 4-6 Example Highlighting Actions for Vancouver that Illustrate Steps in Urban Sustainability Roadmap (see Chapter 3, Figure 3-1).

City	Vancouver
Adopt Principles	P1, P2, P3, P4
Opportunities and Constraints	To make Vancouver the "greenest city in the world."
Prioritize Co-net Benefits	Prioritizes actions that can also advance the city's Social Sustainability and Green Economy strategies.
Partnerships	City staff focused on forming and strengthening partnerships with the private sector, other levels of government, the nonprofit sector, academia, and the public. An external steering committee was formed with representation across all sectors. The Sustainability Group provides strategic oversight, technical expertise, and project delivery capacity to accountable owners across the organization.
Goals	10 goal areas and 15 measurable targets.
Strategies	Greenest City 2020 Action Plan, approved in 2011. Passed a motion to be a city that runs completely on renewable energy by 2050.
Data Gaps	Active performance management ensures that progress toward the goals and targets is measured, tracked, and rewarded.
Implementation	125 related projects implemented by the city since 2011. Hundreds more in progress led by the city and the community.
Local to Global	Mayor worked with former New York Mayor Michael Bloomberg and other municipal leaders to create the Compact of Mayors, the world's largest coalition of city leaders addressing climate change.
Public Buy-in	During 2010 and the first half of 2011, over 35,000 members of the public were engaged to develop strategies.
Feedback	Active performance management ensures that progress toward the goals and targets is measured, tracked, and rewarded.

2011). It has also ranked Vancouver in the top three of its annual "Global Liveability Ranking" every year since 2010 (The Economist, 2015). Vancouver was named the greenest city in the world by the World Wildlife Fund in 2013 and National Champion in 2015 (World Wildlife Fund, 2015). The city was invited to join the C40, an elite international group of the most environmentally progressive cities, and to join the Carbon Neutral Cities Alliance (a cohort of 17 international cities with the most aggressive environmental goals).

Though much has been accomplished, the City of Vancouver recognizes that there is much work still to do, both to reach its 2020 goals and to be a truly sustainable city. In March 2015, the Vancouver Council upped the ante, unanimously passing a motion to be a city that runs completely on renewable energy by 2050. At the time of publication of this report, this Renewable City Strategy was under development.

PHILADELPHIA

Philadelphia is a city of U.S. firsts—the first capital, first public school, first public library, first university, first hospital, first paved turnpike, and first public parks (Richardson, 1982). Unfortunately, Philadelphia has had a series of major unwanted firsts. It is estimated to have experienced the largest population loss of any U.S. city over 1 million from 1950 to 2000 and the highest level of vacant properties of any U.S. city in 2000 (Bonham and Smith, 2008; Nasser, 2011). Philadelphia is also estimated to be the most economically segregated major city in the United States with many health and safety issues (Florida and Mellander, 2015). Many of the sustainability trends in Philadelphia, however, are headed in the right direction and the city appears to be in the midst of an emerging recovery.

BACKGROUND

Philadelphia is, in many ways, a prototype U.S. city. William Penn's efficient and orderly grid design of Philadelphia was a departure from European cities of his time and is still easily seen in today's Philadelphia and many other U.S. cities (Figure 4-7). In 1700, Philadelphia and New Orleans were the two key, urban commercial centers in the American colonies. Philadelphia's commercial dominance would later be overshadowed by Baltimore and New York as a result of several factors, including its more restricted waterways and greater distances to Atlantic shipping routes. Lesser waterways and commercial competition with these other cities would prompt Philadelphia to build the first paved turnpike in America, west to the fertile farmlands of Central Pennsylvania (Richardson, 1982).

Philadelphia had the near-unique advantage over all other early U.S. seaport cities, except Baltimore, of being on a fall line and thus able to use its internal streams as a natural source of water energy. This propelled the city into the industrial revolution as a key innovator and center of technology. The nation's leading expert on hydraulic engineering in the early 1800s was a Philadelphian who created a new water distribution system that included iron pipes and fire hydrants. This system was subsequently emulated by dozens of other U.S. and European cities.

Despite these auspicious accomplishments, the latter half of the 20th century was a difficult time for Philadelphia, which began to experience other, decidedly unwanted firsts. Driven by suburbanization, crime, and education

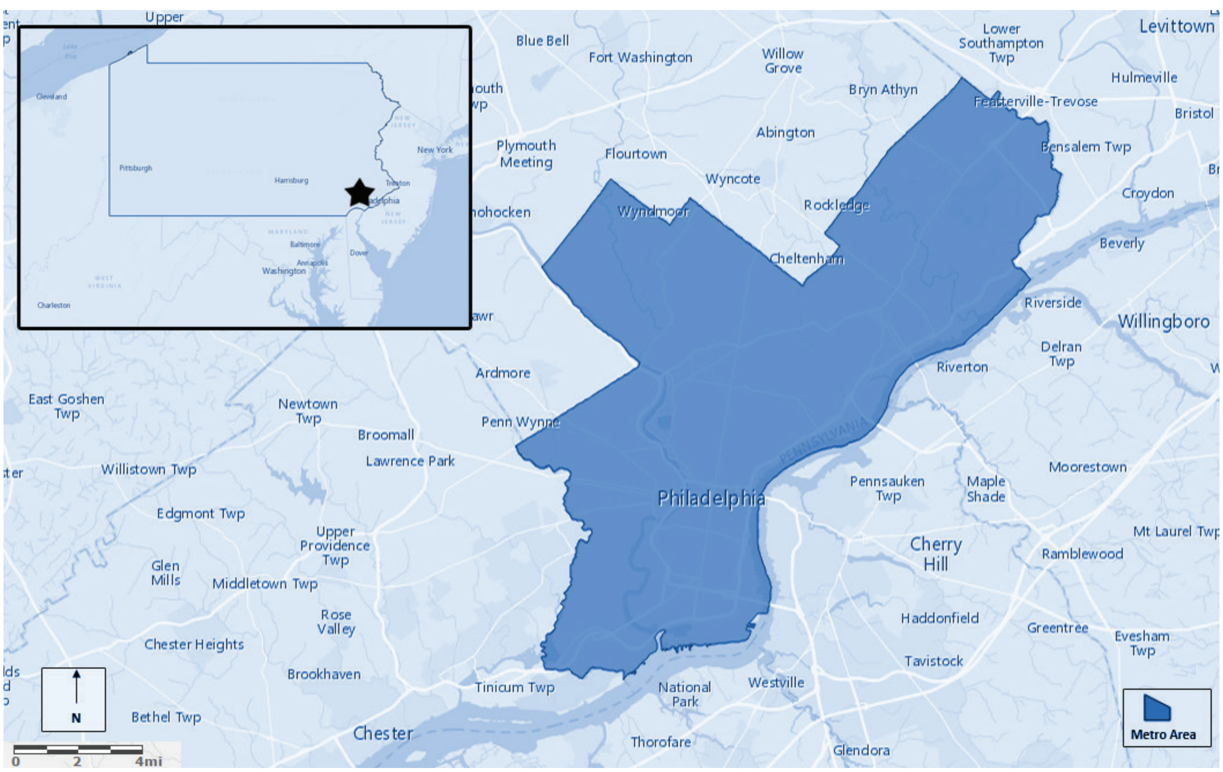

FIGURE 4-7 Map showing the city of Philadelphia boundary and location in Pennsylvania. SOURCE: Prepared by Brent Heard, Consultant to the STS Program.

system challenges, Philadelphia saw its population drop from over 2 million in 1950 to a little over 1.5 million in 2000, a loss of some 550,000 people. This 50-year, –26.8 percent loss of Philadelphia's urban population from 1950 to 2000 was the largest of any major U.S. city over 1 million people (Detroit's population fell to under 1 million) and in stark contrast to the +60 percent growth rate that the city experienced from 1900 to 1950. By 2000, Philadelphia had the highest level of vacant properties of any major U.S. city (Bonham and Smith, 2008). Although these were national trends, Philadelphia's story was more pronounced than other cities. Philadelphia's subsequent sustainability challenges—air quality, energy inefficiency, social inequity, poor health, and sluggish economy—are in many ways tied to this population loss and the accompanying disinvestment in its urban structures on a citywide scale (see Table 4-7).

The past decade has nonetheless been a time of urban revitalization and growth for Philadelphia. Fourteen of the 15 largest U.S. cities in 2000 lost population or slowed in growth by 2010. Philadelphia, on the other hand, was the only city in this list of 15 that did not, reversing over a half century of population loss (Nasser, 2011). Today, Philadelphia is a city of almost 70 unique and diverse neighborhoods and the fourth most walkable city in the nation (Panaritis, 2015; University of Pennsylvania, 2015). In a remarkable turnaround, the Center City District of Philadelphia has become the second-most densely populated downtown area in the United States, after Midtown Manhattan (Center City Philadelphia, 2015; Nasser, 2011).

Philadelphia City and Philadelphia County are coterminous and encompass 135 square miles of land bordered by the Delaware River to the east and bisected by the Schuylkill River in the west (Figure 4-7). Much of today's Philadelphia is commercial or industrial, a large and growing portion is residential, and some 16 square miles are parkland, including 63 neighborhood and regional parks.

TABLE 4-7 Key Characteristics for Philadelphia

Indicator	Philadelphia	United States
ENV Average Annual Precipitation (inches/year)	41.5	40.8
ENV Existing Tree Canopy (% of land cover)	20%	25%
ENV Roadway Fatalities (per 100 million annual vehicle miles traveled)	1.2	1.1
ENV Particulate Matter 2.5 (ppm)	11.6	10.2
ENV Residential Carbon Footprint (metric tons of CO_2 per capita from residential energy consumption)	1.8	3.4
ECON Financial Health	A+	AA+
ECON Average Residential Electricity Rate (cents/kWh)	12.9	11.9
SOCIAL Black or African American	44.1%	13.2%
SOCIAL Hispanic or Latino	13.6%	17.4%
SOCIAL Asian	7.2%	5.4%
SOCIAL Home Ownership (2009-2013)	53.3%	64.9%
SOCIAL High School Graduate (25 or older, 2009-2013)	81%	86%
SOCIAL Below Poverty Level	26.5%	15.4%
SOCIAL Violent Crimes (per 100,000 people)	1,190	191

NOTE: ENV, ECON, and SOCIAL refer to the three dimensions of sustainability: environmental, economic, and social, respectively. SOURCE: Appendix B.

MAJOR SUSTAINABILITY EFFORTS

In 2008, a new mayoral administration set five basic goals to make Philadelphia a "place of choice" for people to live and stay, and one of the safest cities in the United States, with improved education and health for its residents. Most noteworthy, the new mayor's goals also prominently included making Philadelphia "the greenest and most sustainable city in America" (Philadelphia Managing Director's Office, 2015). What followed was a highly ambitious citywide sustainability plan in five parts: environment, energy, equity, economy, and engagement. Five goals and 15 measurable targets were intended to be met by sometime in 2015 (NRC, 2013). By extension, numerous private local entities, perhaps because they were proximal or connected to city government in some way, also launched their own, related sustainability activities. In 2014, two-thirds of Philadelphia voters cast ballots to make the Mayor's Office of Sustainability a permanent part of city government. Since its inception, the Mayor's Office of Sustainability has always played the role of convener for city agencies, private institutions, and advocates (Office of the Mayor, 2015).[17]

Climate and Environment

For the foreseeable future, the Philadelphia Mayor's Office of Sustainability will primarily focus on the impact of climate change on energy, water, and agricultural, nonrenewable, and ecosystem services. The office is currently producing the city's first-ever climate adaptation report, which will focus on what efforts local government can undertake (or is already undertaking) to ensure that the city will continue to provide services and maintain assets as the climate changes. An example of this work in action is a set of experiments that the Philadelphia Department of Parks and Recreation is running in the Haddington Woods neighborhood of the city to understand forest restoration practices appropriate for the weather Philadelphia is expected to experience in the 21st century. Last year the Office of Sustainability published *Useful Climate Science for Philadelphia*, a document that provides local projections for the city as the climate changes (Office of the Mayor, 2015). As part of the process of compiling this report, climate scientists from around the region were convened to review early drafts for accuracy and to identify next steps for research. Philadelphia is also closely exploring further roles city government can play in reducing citywide GHG emissions, whether through improved energy efficiency or transition to clean energy sources.[18]

The 2015 Philadelphia sustainability plan has had other innovative activities in terms of the environment. Although it is unclear if this was directly due to its sustainability plan, the city has improved its air quality in moving toward the attainment of federal standards with a 70 percent reduction in unhealthy air quality index days (from 20 such days in 2008 to 6 such days in 2014). It has also exceeded its initial target by diverting 73 percent of its solid waste from landfills, and residential recycling rates have more tripled in the past 7 years with the advent of single-stream recycling. However, even though the city set a target 20 percent reduction in GHG emissions, it only managed to achieve a 1 percent citywide reduction from 1990 to 2012 (Office of the Mayor, 2015).

The Philadelphia Water Department has become a nationally recognized innovator in stormwater management (NRC, 2013). In 2007, the EPA signed a statement of intent supporting and encouraging the municipal use of Green Stormwater Infrastructure (GSI) to meet federal regulatory standards under the Clean Water Act. Based on this, Philadelphia began to plan for and implement GSI citywide. This GSI approach allowed stormwater to percolate through the soil wherever possible in the city, using installations of infrastructure such as basins, street bumpouts, tree trenches, pervious pavements, wetlands, planters, green roofs, swales, and rain gardens. The co-benefits of these GSI installations were numerous. Over the past 5 years, almost 600 acres of land have been greened to manage stormwater and meet federal standards, and over 120,000 new trees have been planted citywide. These newly greened spaces and tree canopy have provided park and recreation co-benefits, shade, and heat reduction and have been shown to even reduce certain crimes (Kondo et al., 2015; Office of the Mayor, 2015) (see Figure 4-8). EPA is also actively exploring tradeoffs among social, environmental, and economic objectives. In 2014, the agency provided about $5 million in grants to five universities to support research to examine the financial and social costs and benefits associated with green infrastructure as a stormwater and wet weather pollution management

[17] Freeh, R. 2015. Personal communication. Mayor's Office of Sustainability, City of Philadelphia. August 3.
[18] Freeh, R. 2015. Personal communication. Mayor's Office of Sustainability, City of Philadelphia. August 3.

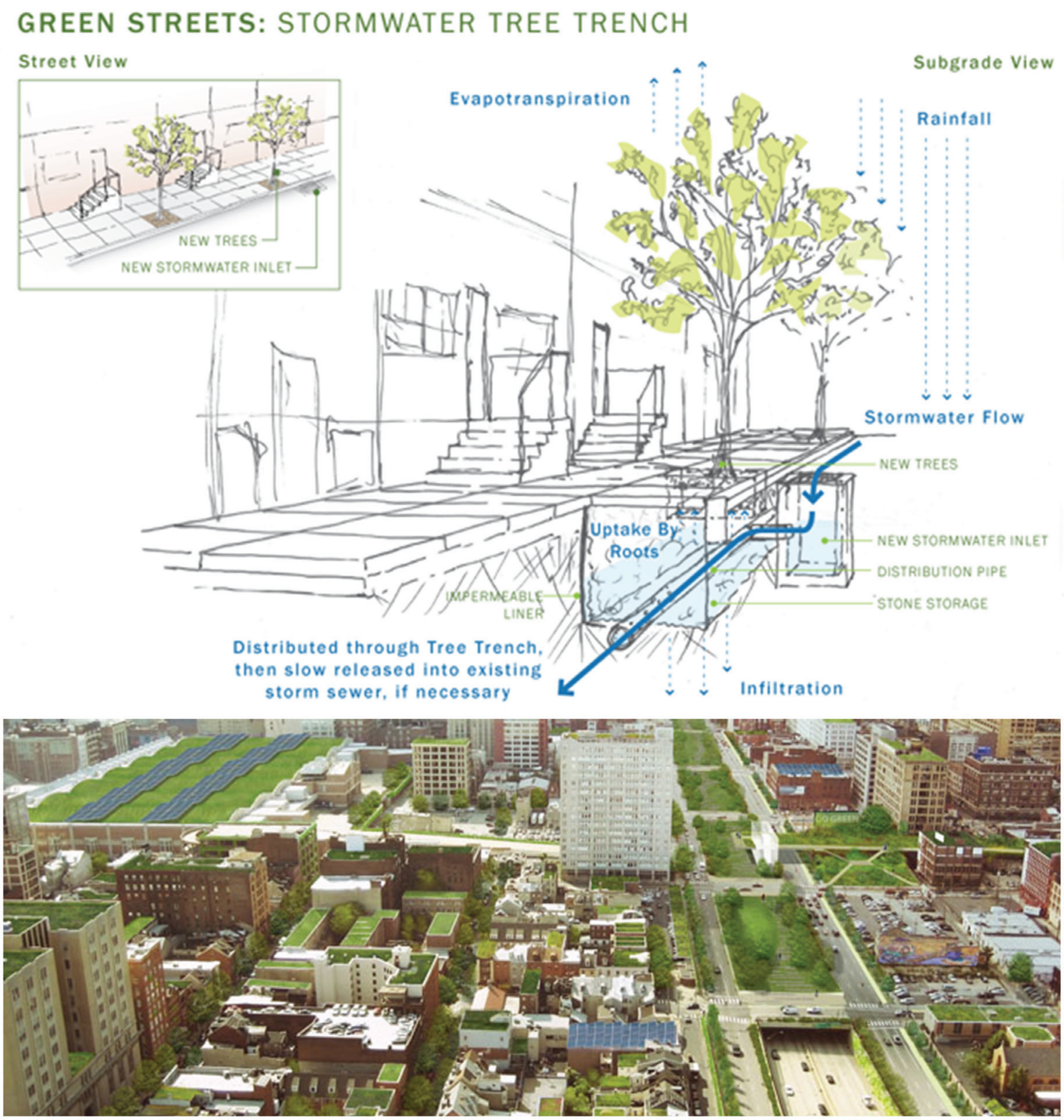

FIGURE 4-8 Philadelphia's "Park of a Thousand Pieces" benefits stormwater and flood management and has also been shown to result in health and safety co-benefits such as crime reduction. SOURCE: Philadelphia Water, 2016; Popp, 2011. Image courtesy of Philadelphia Water.

tool, including an adaptive management process to evaluate tradeoffs among different benefits (EPA, 2014b). This suggests that understanding how to manage tradeoffs in specific situations requires research.

Philadelphia has also undertaken numerous innovative initiatives for the reuse of abandoned land, which was held by both the city's municipal government itself and private owners. By 2010, a public-private partnership between the Philadelphia Office of Housing and Community Development and the Pennsylvania Horticultural

Society had successfully acquired and greened some 5,000 vacant lots representing over 200 acres of land in Philadelphia. This greening itself was a simple, inexpensive, and highly reproducible process that has promoted sustainability, maintenance, and positive community uses for years to come on the greened lots. An evaluation of this vacant lot greening program showed that residents welcomed the program in their neighborhoods (which were often the city's poorest and most challenged) and that health and safety problems such as stress, sedentary behavior, and gun violence were significantly reduced after the lots were greened (Branas et al., 2011; Garvin et al., 2012; South et al., 2015). These simple vacant lot greenings also had a positive effect on retail sales, as they provided visible proof of clean and safe environments that shoppers need in order to want to go to and mingle in commercial corridors (Econsult Corporation, 2009). The Mayor's Office of Sustainability also staffs the Food Policy Advisory Council, which brings together restaurant owners, farmers, local food advocates, and residents to work together to improve the local production and accessibility of healthful and sustainably grown food (Office of the Mayor, 2015) (see Figure 4-8).[19]

Energy and Housing

There are some ways that Philadelphia epitomizes urban sustainability just by way the city is laid out. Similar to the fact that its existing transit network and street grid lend themselves to forms of transportation other than personalized cars, so, too, do Philadelphia rowhouses trump detached homes from an energy sustainability standpoint. To further supplement this innate advantage in the area of energy, Philadelphia has retrofitted over 16,000 homes with insulation, air sealing, and cool roofs. The city has also purchased and generated 15 percent of the electricity it uses from alternative energy sources, including national wind renewable energy credits, a new biogas co-generation plant, and roof photovoltaic panels. These activities may be what has led an independent evaluation to conclude that, from 2001 to 2010, Philadelphia had the most improved building carbon footprint of the 100 largest cities in the United States (see Figure 4-9).

The Consortium for Building Energy Innovation at the Philadelphia Navy Yard is a U.S. Department of Energy entity, administered in partnership with Pennsylvania State University, that has produced a plethora of research highlighting technologies and best practices that can lead to substantial building energy savings in Philadelphia and other cities. These have included more efficient controls for heating, ventilation, and air conditioning systems; Internet-connected accessible thermostats and software; various building contractor regulatory strategies; and strategic energy retrofits. Despite these successes, however, citywide building energy consumption increased by 19 percent from 2006 to 2014 in Philadelphia, well outside of the reduction targets set by the city (Office of the Mayor, 2015).

Philadelphia has also pursued a number of standout and innovative housing policies over the past decade. Decades of growing housing abandonment and blight have taken their toll—Philadelphians cite these decaying urban structures, which they are forced to see each day on their way to work and school, as among the most detrimental factors to their health, safety, and quality of life (Garvin et al., 2012; South et al., 2015). One innovative Philadelphia program in response to this is the 2011 Doors and Windows ordinance that required property owners of abandoned buildings to remove plywood and other nonfunctional coverings, clean their façades, and install working doors and windows in all structural openings or face significant fines. Within a year of such repairs, the area around the remediated buildings saw as much as a 39 percent drop in crime, including serious crimes such as gun violence and assaults (Kondo et al., 2015). But despite the success of abandoned building development, residents are also wary of overdevelopment and gentrification. They remain concerned that wealthier newcomers to the city, while necessary for its revitalization, may ultimately erode working- and lower-middle-class residents' economic abilities to remain in neighborhoods where they have lived for generations. In response, one innovative Philadelphia ordinance passed in 2013 has seen some success in this regard by limiting property tax increases for longtime residents. The ultimate intent of this ordinance is preventing unwanted displacement of residents, although its effects have yet to be fully evaluated (Williams, 2014).

[19] Freeh, R. 2015. Personal communication. Mayor's Office of Sustainability, City of Philadelphia. August 3.

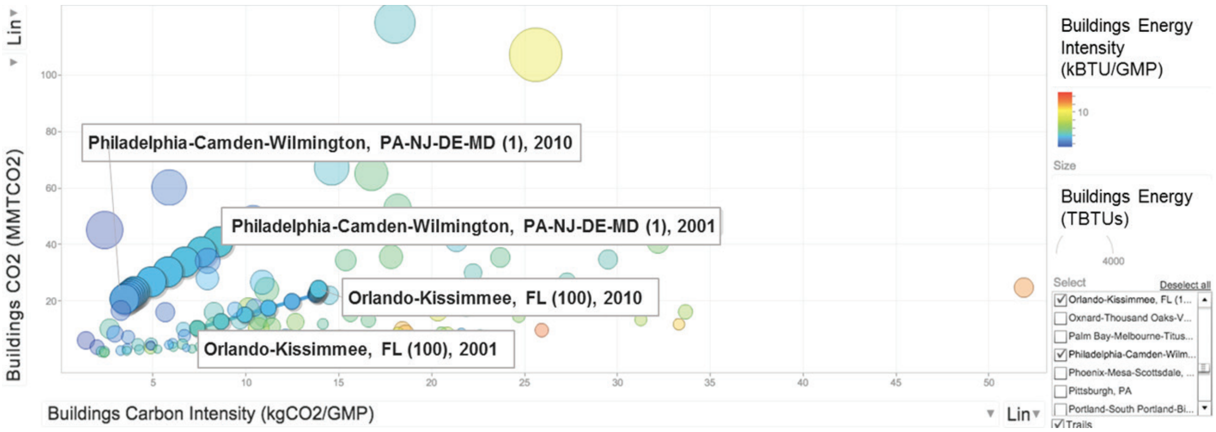

FIGURE 4-9 Metros with the least (Orlando) and most (Philadelphia) improved building carbon footprints. SOURCE: Brown and Cox, 2015; Renewable Energy Global Innovations, 2015. Online. Available at: https://reginnovations.org/key-scientific-articles/progress-energy-carbon-management-in-large-u-s-metropolitan-areas. Reprinted with permission from the Renewable Energy Global Innovations.

Economy, Health, and Safety

The economic assets that perhaps have had the biggest impact on sustainability in the Philadelphia region are its universities, colleges, and medical centers.[20] The city is home to over 450,000 college students (only New York City and Chicago have more) (Florida, 2012). Philadelphia's University City District was founded in 1997 via a partnership between anchor educational and medical institutions, such as those at the University of Pennsylvania and Drexel University. University City District has subsequently created a world-class, vibrant urban living experience through major investments in public space development, public maintenance, and public safety by connecting entrepreneurs and residents to economic opportunity and to numerous destination events (University City District Press, 2014). Of the 27 regional real estate submarkets in the Philadelphia area, the University City District has the highest office occupancy rate, a total of 96 percent. In 2014, 82 percent of all office construction in the entire Philadelphia region was happening within the University City District, on just 0.02 percent of the region's office market land mass. Over a 5-year period, 10 million square feet of real estate projects have been developed in Philadelphia's University City District—a $4.5 billion total investment supporting 73,000 jobs and $1 billion of research and development. The intensity and speed of economic activity created by Philadelphia's "eds and meds" is among the very highest in the nation (Bergheiser, 2014).

Historically, Philadelphia's academic institutions have not always acted as champions of their surrounding neighborhoods or their city (Puckett and Lloyd, 2015; Saffron, 2015). More recently though, the research and capacity building that Philadelphia's universities, colleges, and medical centers have provided to its residents, and the business ventures and spinoffs that are emerging from these anchor institutions, are making Philadelphia a center for sustainable innovations and industries (Office of the Mayor, 2014). Perhaps the biggest contribution of Philadelphia's medical centers to local health and sustainability is not their provision of medical care (which can be immensely inefficient with a minimal return on investment), but the jobs and urban revitalization they provide (Emanuel and Pearson, 2012; Schroeder, 2007). Moreover, clean, safe, and sustainable environments matter for shoppers, and not coincidentally, University City District's work on and patrol of commercial corridors have contributed to a boom in new stores and shopping activity (Econsult Corporation, 2009).

It is no surprise that the Philadelphia Mayor's Office of Sustainability sees scientists and its local university partners as an essential part of ensuring that the city better understands the impact of its sustainability policies, as

[20] Freeh, R. 2015. Personal communication. Mayor's Office of Sustainability, City of Philadelphia. August 3.

well as the efforts that are needed to appropriately expand these policies or, alternatively, retool or abandon policies that are not shown to have positive, sustainable impacts. The city has directly connected to scientists via local institutions such as the University of Pennsylvania Institute for Urban Research, from which multiple university faculty have been directly involved in or led activities in several of the city's sustainability efforts, and Drexel University, whose faculty have led the creation of a framework to understand how Philadelphia could reduce its citywide GHG emissions 80 percent by 2050, an emerging best practice target for cities around the world.

In terms of health and sustainability, Philadelphia has had many successes. Based on the U.S. Centers for Disease Control and Prevention's health impact pyramid and "making the healthy choice the easy choice" concepts, Philadelphia's Get Healthy Philly campaign was launched in 2010 and has evolved into an innovative and successful exemplar for other U.S. cities (Frieden, 2010). This campaign has brought together public health and city planning sectors, synergistically focusing them on environmental initiatives to change contextual circumstances and situations that have traditionally fostered poor health for many Philadelphians. These initiatives have included changing the policy environment by increasing local tobacco taxes, expanding smoke-free places, focusing on unhealthy tobacco advertising (Philadelphia has far outpaced other cities in tobacco ads in public spaces), and improving walkability and bikeability through infrastructure improvements (Hillier et al., 2009). Since 2007, key health improvements have included an 18 percent reduction in smoking among adults and a 30 percent reduction in smoking among youth, translating into over 60,000 fewer smokers in the city. In addition, a 6.3 percent reduction in childhood obesity and improvements in childhood asthma hospitalization rates were also recorded. However, it is unclear if the Get Healthy Philly campaign and its accompanying policies have directly led to these changes (Buehler, 2014; Philadelphia Department of Public Health, 2015a; Robbins et al., 2015).

Unfortunately, the benefits of rapid prosperity in many parts of Philadelphia have not been uniformly experienced by all its residents. In 2015, Philadelphia was the most economically segregated major city in the United States (Florida and Mellander, 2015). The Philadelphia School District spent less per pupil in 2015 than almost any other major U.S. city (Graham, 2015). Moreover, despite modest reductions in some metrics over the past 5 years, Philadelphia continues to have the highest rates and prevalence estimates of any major U.S. city in terms of a host of health problems—premature death, child mortality, smoking, obesity, hypertension, diabetes, infant mortality, and low birth weight (Philadelphia Department of Public Health, 2015b). Nearly 30 percent of adults were obese in 2015, an increase from 21 percent in 2000 (Public Health Management Corporation, 2015). And although crime in Philadelphia fell by over 23 percent in the prior decade (over 2 percent per year on average), in 2013, Philadelphia was found to be the least safe major city in the country, a statistic driven to some extent by violent crime but also by traffic crash deaths (City-Data.com, 2015; Florida and Mellander, 2015; Philadelphia Department of Public Health, 2015b).

Although the City of Philadelphia is thoroughly capitalizing on its economic assets, numerous barriers continue to hinder sustainable growth for the city and the Philadelphia region. These barriers include educational and environmental policy shortfalls at higher levels of government (Thompson, 2016), and the layering on of additional burdens, over and above state and federal requirements, that create additional, home-grown barriers to development and growth.

OTHER SIGNIFICANT ACTIVITIES

Transportation

Part of the reason cities are attractive for millennials, one of the fastest-growing populations in Philadelphia, is that locations that do not require cars speak to a sustainability ethos that young people want to live (Blumenberg et al., 2012; Delbosc and Currie, 2012; Myers et al., 2013; U.S. PIRG Education Fund & Frontier Group, 2012). Conversely, for generations past, the iconic ethos had to do with cars, whether getting one's first car or going for a drive on the open road. Philadelphia, with its multimodal transportation system and tight street grid, has particularly benefited from this shift in preference. The city has a large and varied public transportation network, the Southeastern Pennsylvania Transportation Authority (SEPTA), with buses, trains, rapid transit, trolleys, and trackless trolleys throughout the city as well as surrounding Pennsylvania counties. Further connections with southern

New Jersey exist via trains, buses, and ferries operated by private firms and the Delaware River Port Authority Transit Corporation. Despite rapid growth and reurbanization in Philadelphia's city center, the city remains well connected to its outlying neighborhoods and suburbs via public transportation, extensive roadways, and political alliances. Philadelphia is also a corporate home to Amtrak, the nation's passenger train system, and sees over 4 million passengers coming through its main station each year (Center City Philadelphia, 2015).

The city has been a lead adopter of select, innovative transportation initiatives such as promotion of "complete streets" programs, increased availability of walking and bicycling paths throughout the city, and better management of public transit programs and highways (NRC, 2013). The complete streets initiative has prompted local transportation entities in Philadelphia (Streets Department, SEPTA, Bicycle Coalition) to change their thinking and policies on community roads with a clear focus on safe access for all users—pedestrians, bicyclists, motorists, and public transit riders of all ages and abilities (Smart Growth America, 2015). A series of new bicycle lanes and walking corridors subsequently emerged. From 2005 to 2013, Philadelphia exceeded its target by reducing vehicle miles traveled by 12 percent and steadily growing the percentage of its residents that commuted by bike, foot, or transit. Moreover, the city is considering adoption of a Vision Zero approach to road safety and committing to the elimination of road deaths within the coming decades (Office of the Mayor, 2015).

SUMMARY OBSERVATIONS

In 2015, the Mayor's Office of Sustainability reported that "long-term sustainability work had just begun and that looking forward, the city will have to go well beyond low-hanging fruit and increasingly take actions that drive large-scale impacts" (Office of the Mayor, 2015). Perhaps this realistic, yet undeterred sense of optimism and desire for action are Philadelphia's greatest asset as it moves toward a more sustainable future. With that in mind, multiple ongoing major sustainability exemplars and challenges are evident.

Philadelphia is a prime example of a city that has overtly pursued and scientifically documented sustainability co-benefits and the triple-bottom line. Municipal leaders and nonprofit agencies have maximized their use of and connection to local scientific and university resources in testing whether they have actually achieved triple-bottom-line outcomes in select sustainability programs while considering tradeoffs among social, environmental, and economic objectives. Many of the city's greening initiatives (Table 4-8) have been scientifically evaluated and shown to be co-benefits affecting the city's triple-bottom-line sustainability goals. These initiatives have been shown to improve the city's environment in terms of stormwater recapture, its economy in terms of improved housing values, its social structures in terms of lower crimes, and its health outcomes in terms of reduced residential stress and sedentary behavior (Branas et al., 2011; Heckert and Mennis, 2012; Kondo et al., 2015; South et al., 2015).

Despite some very noteworthy progress, Philadelphia remains the most economically segregated major city in the United States and continues to have some of the lowest health and safety indicators of any major U.S. city, as measured by multiple citywide metrics and cross-city comparisons. Disparities in socioeconomic status, education, health, and safety are major challenges to the city's sustainability and directly undermine the overarching goal of making Philadelphia a "place of choice" for people to live and stay. These have been enormous, decades-long challenges, although the city is now poised to tackle them in various ways in achieving its overall sustainability goals. Philadelphia should take pride in the programs it has pioneered in this regard—especially its programs to reduce blight via vacant lot greening and abandoned housing remediation—and actively seek to export these to other cities as models of action toward making a city a place of choice for people to live and stay (Philadelphia Inquirer, 2013).

Philadelphia has had a few sustainability successes in the areas of energy and environment. However, the latest numbers show that citywide building energy consumption has significantly increased in stark contrast to reduction targets set by the city. In addition, Philadelphia remains far below its own GHG emission target, and it is scarcely on a path to reduce its citywide GHG emissions 80 percent by 2050, the suggested target for cities globally. The City of Philadelphia's consumption of energy may be tempered by the fact that the larger Philadelphia metro area may consume less over time as the overall region becomes more centralized in a more efficient city nucleus. Future energy targets could be reworked to focus as much on the Philadelphia metropolitan region itself

TABLE 4-8 Example Highlighting Actions for Philadelphia that Illustrate Steps in Urban Sustainability Roadmap (see Chapter 3, Figure 3-1).

City	Philadelphia
Adopt Principles	P1, P2, P3, P4
Opportunities and Constraints	Opportunities: An inherently compact street grid has contributed greatly to the city's walkability and renaissance, with a large reduction in unhealthy air days as well as tens of thousands fewer smokers and obese children. Energy inefficiency, economic segregation, and a severely underresourced school district continue to pose challenges. Constraints: There are many areas in which the city would like to have larger impact but is hindered by state and national policies.
Prioritize Co-net Benefits	Philadelphia has overtly pursued and scientifically documented sustainability co-benefits and the triple-bottom line. Municipal leaders and nonprofit agencies have maximized their use of and connection to local scientific and university resources in testing whether they have actually achieved triple-bottom-line outcomes in select sustainability programs. Many of the city's greening initiatives have been scientifically evaluated and shown to be co-benefits affecting the city's triple-bottom-line sustainability goals.
Partnerships	Philadelphia's Center City District has spurred a population influx reportedly making it the second-most densely populated U.S. downtown. The University City District, and maximal leveraging of local "eds and meds" institutional partnerships, has connected entrepreneurs and residents to economic opportunity. Multimodal and metropolitan management via SEPTA regional transit authority.
Goals	A realistic, yet undeterred sense of optimism and a desire for action are Philadelphia's greatest asset as it moves toward a more sustainable future. Although the Mayor's Office of Sustainability has been voted into perpetuity, it will be important for the next mayor to pick up the baton in terms of further casting the overall vision of sustainability for the city and providing leadership to ensure that the targets and the "how" of meeting these targets are realized.
Strategies	The Philadelphia Mayor's Office of Sustainability Greenworks Plans lays out important targets and over 100 separate initiatives in meeting these targets. However, the initiatives themselves may benefit from more explicit, quantitative goal setting if they are to fully contribute to meeting the broader set of 15 targets. Important, complementary plans, such as Green2015 (by PennPraxis and the Philadelphia Parks Department), have also been launched and outline specific goals as to how certain targets can be met "on the ground" through planning, implementation, and collaborative efforts. Other important strategies include a new biogas co-generation plant, newly insulated homes, and a pioneering abandoned housing remediation program.
Data Gaps	The city has made impressive strides in terms of large, distributed data systems that include some of the nation's first municipal GIS products both for use by city employees and publicly available. However, gaps in connecting a large variety of databases still exist, especially databases that contain traditionally disconnected information; e.g., housing and land use data are not centrally connected with public safety and public health data.
Implementation	Philadelphia has retrofitted over 16,000 homes with insulation, air sealing, and cool roofs. The city has also purchased and generated 15% of the electricity it uses from alternative energy sources.
Local to Global	Via university-government partnerships (both city government and federal agencies like the local U.S. Forest Service), Philadelphia has produced some of the nation's first clear evidence of triple-bottom-line successes. These sorts of studies have served as models for other cities, both in the United States and around the world, essentially positioning Philadelphia as an exporter of generalizable scientific methods and knowledge related to urban sustainability.
Public Buy-in	Numerous public forums are held on urban sustainability and the city's investment in this is a mayoral priority. This is expected to continue as the new mayor takes office in 2016.
Feedback	—

as they do on the City of Philadelphia alone, perhaps more consistently including per capita measures to better capture relative efficiencies.

The Philadelphia Mayor's Office of Sustainability Greenworks Plans lays out important targets and over 100 separate initiatives in meeting these targets. However, the initiatives themselves may benefit from more explicit, quantitative goal setting if they are to fully contribute to meeting the broader set of 15 targets. Important, complementary plans, such as Green2015 (by PennPraxis at the University of Pennsylvania and the Philadelphia Parks Department), have also been launched and outline specific goals as to how certain targets, such as adding 500 acres of new publicly accessible green space to the city by 2015, can be met "on the ground" through planning, implementation, and collaborative efforts among myriad partners, including neighbors, businesses, nonprofits, developers, and the city (PennPraxis, 2015). Although the Mayor's Office of Sustainability has been voted into perpetuity, it will be important for the next mayor to pick up the baton in terms of further casting the overall vision of sustainability for the city and providing the leadership to make sure that the targets and the "how" of meeting these targets happen in city government.

PITTSBURGH

Pittsburgh's success as an industrial center in the 19th century has created a legacy of sustainability issues to be addressed in the 21st century. Diversification of its economy, a shift to cleaner energy sources, and successful public-private partnerships have helped Pittsburgh improve the metrics of several sustainability indicators like air pollution and water quality, but the city needs to continue its efforts to reach its sustainability goals.

BACKGROUND

The Pittsburgh region has a remarkable history of industrial and socioeconomic change over time. Pittsburgh is located in western Pennsylvania at the confluence of the Allegheny and Monongahela Rivers that combine to form the Ohio River. The metropolitan area around Pittsburgh comprises six counties in Pennsylvania, while the broader region (the "Tri-state Region") includes counties in Ohio and West Virginia. Allegheny County is the central county and includes the city of Pittsburgh (Figure 4-10). Allegheny County's population peaked in the 1970s at 1.6 million and was 1.2 million in 2010 (Hoesly et al., 2012). The city of Pittsburgh in 2010 had 20 percent of the population of Allegheny County and 13 percent of the land area. Pittsburgh does not have the authority to unilaterally expand its boundaries; surrounding the city is a series of independent municipalities that resist incorporation into the central city.

Pittsburgh is in the humid continental climate zone with four distinct seasons. Average annual precipitation is 38 inches. The precipitation and rivers provide ample water resources for the region. From the middle of the 19th century to the middle of the 20th century, Pittsburgh was known as the Steel City, serving as the headquarters of the Carnegie Steel Company and, subsequently, the U.S. Steel Corporation (Tugwell et al., 1999). The steel industry took advantage of local coal and iron ore shipped in through the Great Lakes and railway connections. Immigration from Ireland, Eastern Europe, and the South occurred throughout this period with employment opportunities in the steel and service industries. During the 1970s, the regional steel industry went into a severe decline, with considerable steel production relocating overseas. More than 125,000 manufacturing jobs were lost in the Pittsburgh region in the 1970s (Tugwell et al., 1999).

In the early 20th century, Pittsburgh experienced severe environmental and health problems. In 1907, 622 people died of typhoid fever due to contaminated water. The riverfront was dominated by industrial plants and freight facilities for barge and rail shipping. Sewer systems were generally unavailable. Worker living conditions were termed "deplorable" (Tugwell et al., 1999).

Figure 4-11 shows estimates of the carbon dioxide emissions and energy consumption for various economic sectors in total and per capita for Allegheny County in the 20th century. Both overall and per capita carbon dioxide emissions peaked around 1980, but energy use per capita has continued to increase from 1930 onward. The emissions of carbon dioxide from industrial sources peaked in 1950 and have declined subsequently due to changes in fuel sources and shifts in the types of regional industries. In particular, coal has been generally replaced by natural

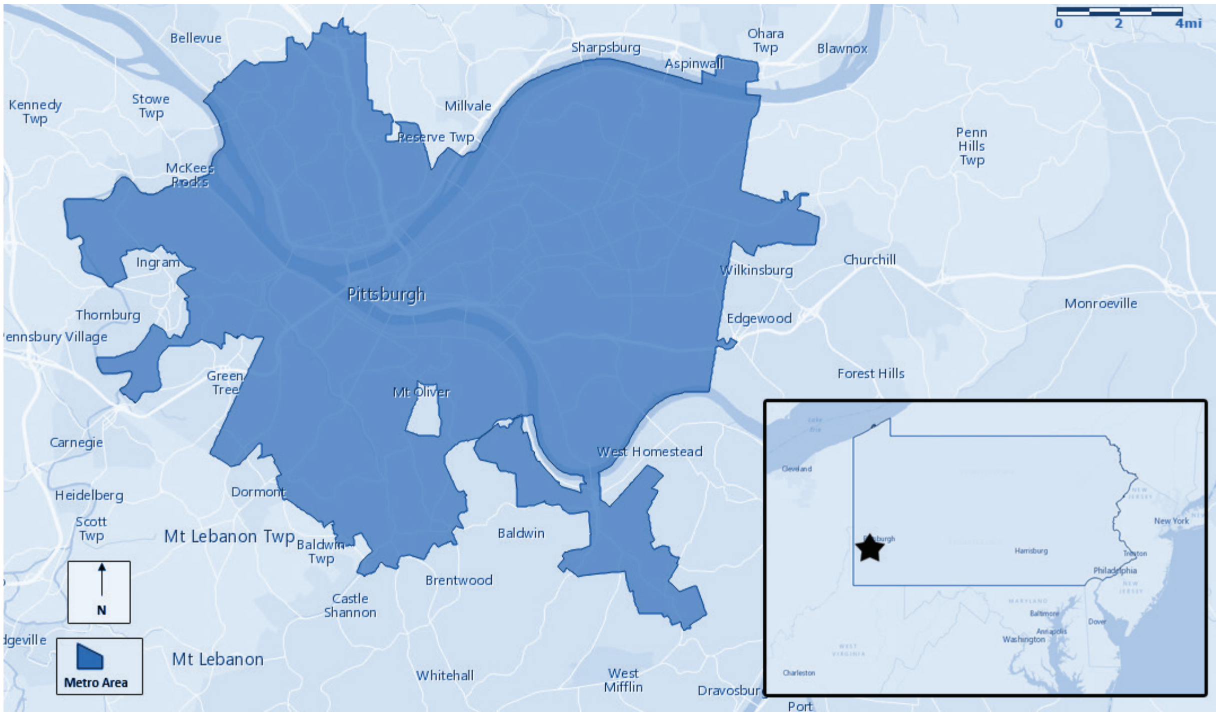

FIGURE 4-10 Map showing the city of Pittsburgh municipal boundary and location in Pennsylvania. SOURCE: Prepared by Brent Heard, Consultant to the STS Program.

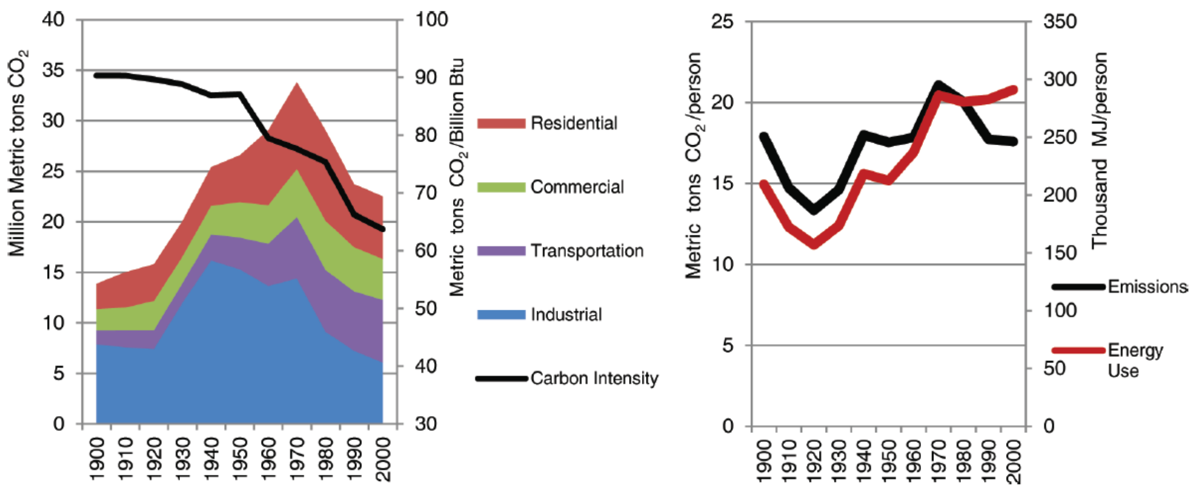

FIGURE 4-11 Energy consumption and CO_2 emission estimates for Allegheny County (1900-2000). SOURCE: Hoesly et al., 2012. Reprinted with permission from Hoesly, R., M. Blackhurst, H. S. Matthews, J. F. Miller, A. Maples, M. Pettit, C. Izard, and P. Fischbeck. 2012. Historical carbon foot printing and implications for sustainability planning: A case study of the Pittsburgh Region. Environmental Science & Technology 46:4283-4290. Copyright 2016 American Chemical Society.

TABLE 4-9 Key Characteristics for Pittsburgh

Indicator	Pittsburgh	United States
ENV Average Annual Precipitation (inches/year)	34.8	40.8
ENV Existing Tree Canopy (% of land cover)	42%	25%
ENV Roadway Fatalities (per hundred million annual vehicle miles traveled)	1.2	1.1
ENV Particulate Matter 2.5 (ppm)	14.0	10.2
ENV Residential Carbon Footprint (metric tons of CO_2 per capita from residential energy consumption)	2.7	3.4
ECON Financial Health	A+	AA+
ECON Average Residential Electricity Rate (cents/kWh)	11.4	11.9
SOCIAL Black or African American	13.4%	13.2%
SOCIAL Hispanic or Latino	1.9%	17.4%
SOCIAL Asian	3.4%	5.4%
SOCIAL Home Ownership (2009-2013)	65.5%	64.9%
SOCIAL High School Graduate (25 or older, 2009-2013)	93%	86%
SOCIAL Below Poverty Level	12.9%	15.4%
SOCIAL Violent Crimes (per 100,000 people)	421	191

NOTE: ENV, ECON, and SOCIAL refer to the three dimensions of sustainability: environmental, economic, and social, respectively. SOURCE: Appendix B.

gas for many heating uses. Emissions and energy use generally had similar trends during the 20th century, until emissions declined in the last two decades while energy use continued to increase. A combination of fuel changes and efficiency improvements led to this change.

MAJOR SUSTAINABILITY EFFORTS

Air Pollution

With abundant coal resources and considerable heavy industry, air and water pollution became major environmental concerns in the Pittsburgh region throughout the 20th century. Air pollution was so intense that streetlamps were turned on during the daytime, and office workers would have to change shirts midday. In 1948, roughly two dozen residents died and hundreds were hospitalized in Donora, Pennsylvania, due to pollution associated with a severe temperature inversion in the local area (Tugwell et al., 1999). Emission controls and a transition to medical and technology-based industries resulted in gradually improving air and water quality in the region during the 20th century, but Pittsburgh continues to struggle with air quality. With more stringent recent air quality standards, the region is out of attainment with federal air quality standards for 8-hour ozone and 2.5-micron particulate matter. However, the region is in attainment with federal standards for all other criteria air species. The trend is good, with exceedance of 19 days in 2012 dropping to 2 days at one site in 2014 (Allegheny County Health Department, 2014). An indoor air quality metric is being piloted in the city as part of the Pittsburgh 2030 Initiative (Green Building Alliance, 2014). In addition, the Pittsburgh Climate Action Plan Version 2.0, released in 2012, has outlined the creation of an air quality action plan for Allegheny County and the City of Pittsburgh as one of its medium-term recommendations, aiming to raise awareness of the importance of urban air quality issues (Pittsburgh Climate Initiative, 2012).

Water Quality

As with air quality, Pittsburgh also continues to have degraded water quality. A particular problem has been combined sewer overflows, in which large precipitation events overwhelm the combined wastewater sewer and treatment capacity, resulting in overflows of sewage into local rivers. In 2010, 28 percent of days during the recreation season had water quality advisories issued (Pittsburgh TODAY, 2015). A second longstanding concern is acid drainage from legacy coal mines. A long-term program of investment in wastewater infrastructure is still under development, and many miles of rivers and streams have already been reclaimed.

In terms of water consumption, a district water baseline for downtown Pittsburgh was established using historic water consumption information by the Pittsburgh 2030 District Initiative and the Pittsburgh Water and Sewer Authority. Existing building targets for water consumption are a 50 percent reduction by the year 2030, and an interim target of a 10 percent reduction by 2015. In 2014, water performance from 80 percent of downtown square footage was reported, with results indicating a 10 percent reduction from the baseline (Green Building Alliance, 2014).

Regarding the water industry more generally, southwestern Pennsylvania is uniquely positioned to be a leader in various dimensions of water infrastructure innovation. In 2011, Sustainable Pittsburgh facilitated the release of Pittsburgh's H2Opportunity–An Assessment of Southwestern Pennsylvania's Water Sector, the region's first ever economic analysis of the water industry sector, which provided key recommendations on the assessment, organization, and advancement of regional opportunities related to water, the support of innovation and commercialization in water technology, and the promotion of green water management infrastructure, among others (Pittsburgh World Environment Day Partnership, 2011). In 2012, the Water Innovation Consortia Planning Committee released the Sustainable Water Innovation Initiative for Southwestern Pennsylvania, which identified eight projects relating to either energy development and water management; navigation infrastructure, monitoring, and water security; stormwater and green infrastructure; or regional watershed and drinking water interactions to leverage the development of innovative solutions in the water sector (Water Innovation Consortia Planning Committee, 2012). This example presents how various stakeholders have integrated research, science, and technology into the support of sustainability initiatives.

Climate Action Plan

As shown in Figure 4-11, GHG emissions declined in Allegheny County from 1900 to 2000, generally due to a switch of fuel sources away from coal and a reduction in heavy industry. This trend is likely to continue, largely due to requirements imposed by the federal and state governments. In particular, the Commonwealth of Pennsylvania has regulated provision of renewable energy, with a requirement for 8 percent of renewable energy by 2020 in the state (Rabe, 2006). Corporate Average Fuel Economy Standards should reduce emissions for transportation services.

Local efforts for GHG emission reductions also exist. In 2008, the city of Pittsburgh adopted its first Pittsburgh Climate Action and established a goal of reducing GHG emissions to 20 percent below 2003 levels by 2023. GHG emissions in the county are shown in Figure 4-11. Figure 4-12 shows more recent emissions amounts, as reported in the 2008 Pittsburgh Greenhouse Gas Emissions Inventory (Pittsburgh Climate Initiative, 2008). In 2012, the Pittsburgh Climate Action Plan Version 2.0 was released, which provides an update on the progress of initial recommendations, as well as outlines new measures aimed toward meeting the 2023 target. As of 2014, more than 23 of the 35 community action items have been completed or are under way.

Energy Production and Use

Pittsburgh historically has had a heavy reliance on energy from coal reserves, although natural gas and nuclear power are also major sources of energy. Figure 4-13 shows energy consumption estimates from the Energy Information Administration for the Commonwealth of Pennsylvania. Pittsburgh is generally similar in energy consumption to the entire state. Pennsylvania as a whole is a net exporter of electricity. Natural gas has become the predominant means of heating buildings, whereas coal filled this role in the early 20th century.

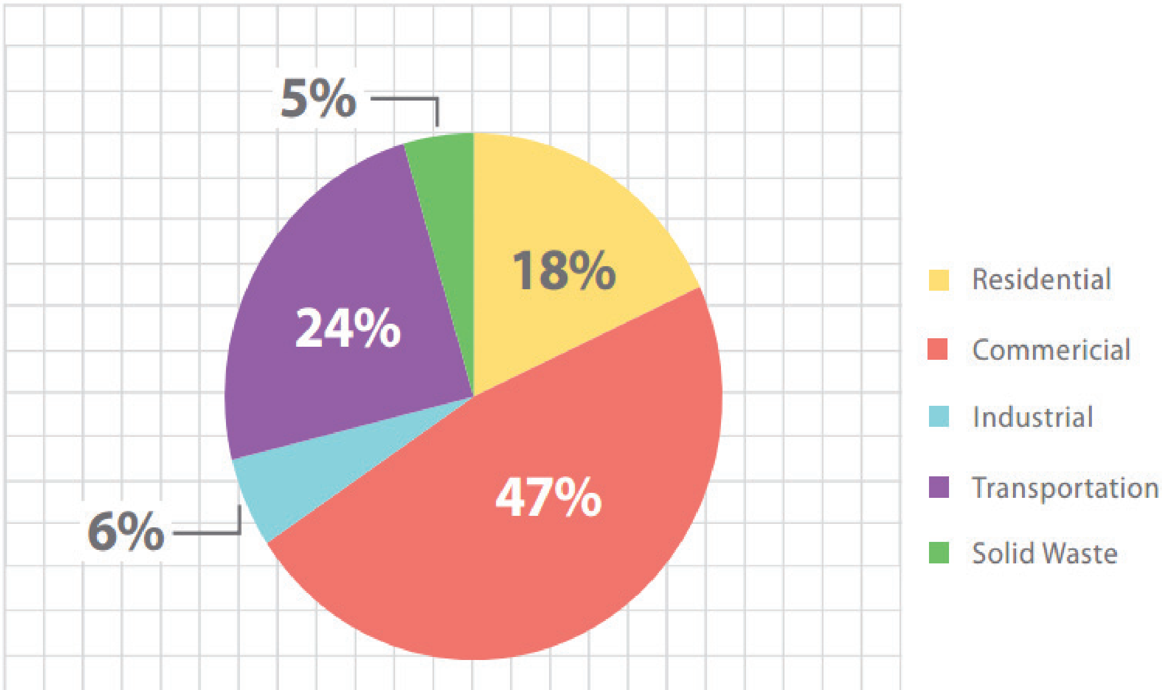

FIGURE 4-12 Pittsburgh greenhouse gas emissions by sector. SOURCE: Pittsburgh Climate Initiative, 2008. Reprinted with permission from the Pittsburgh Climate Initiative.

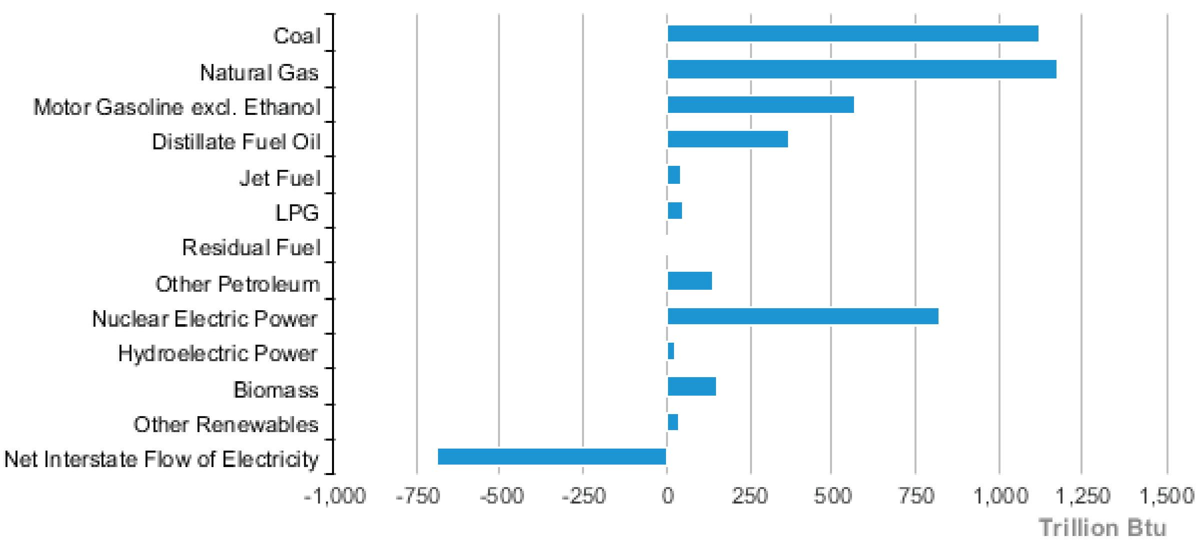

FIGURE 4-13 Pennsylvania energy consumption estimates by energy source. SOURCE: EIA, 2015b.

Another sustainability challenge facing the Pittsburgh region is managing the impact of the Marcellus Shale Natural Gas development. Production and proven reserves in the Marcellus Shale area of northern Pennsylvania have both increased in the past 10 years (Figure 4-14). The well development has affected local ecosystems, required water for hydraulic fracking operations, increased regional conventional and GHG emissions, and increased roadway traffic, including roadway wear and tear (EIA, 2014).

The Pittsburgh Climate Action Plan Version 1.0 provides a number of recommendations which focus on energy use and efficiency as relating to emissions. Version 2.0 of the plan provides a number of updated recommendations which primarily focus on reductions in energy demand, water demand, waste generation, transportation fuel combustion, and strategies to strengthen regional capacity (Pittsburgh Climate Initiative, 2012). Examples include

- Reducing energy use in city-owned buildings by 20 percent over 5 years, and
- Adopting a goal of 10 MW of renewable energy capacity installed in Pittsburgh by 2020 (Pittsburgh Climate Initiative, 2012).

Moreover, the Pittsburgh 2030 District initiative has reported a 6.3 percent reduction in energy use below the baseline. The initiative has established goals of a 10 percent reduction by 2015, and a 50 percent reduction by 2030 (Green Building Alliance, 2014). In addition, the city government purchases 15 percent of its electricity from renewable energy and utilizes solar energy on its facilities (Pittsburgh Climate Initiative, 2012).

Transportation

Pittsburgh has been a transportation hub throughout its history. The rivers have been major corridors for freight movement, especially with development of lock and dam systems in the region. With the development of the steel industry in Pittsburgh, railroads provided connections throughout the United States. Many of the neighborhoods of Pittsburgh developed as streetcar suburbs in the late 19th and early 20th centuries (Brunn et al., 2003).

The topography of the Pittsburgh region provides challenges for transportation investment and operations. The three major rivers and related streams require use of numerous bridges and restrict the extent of the roadway

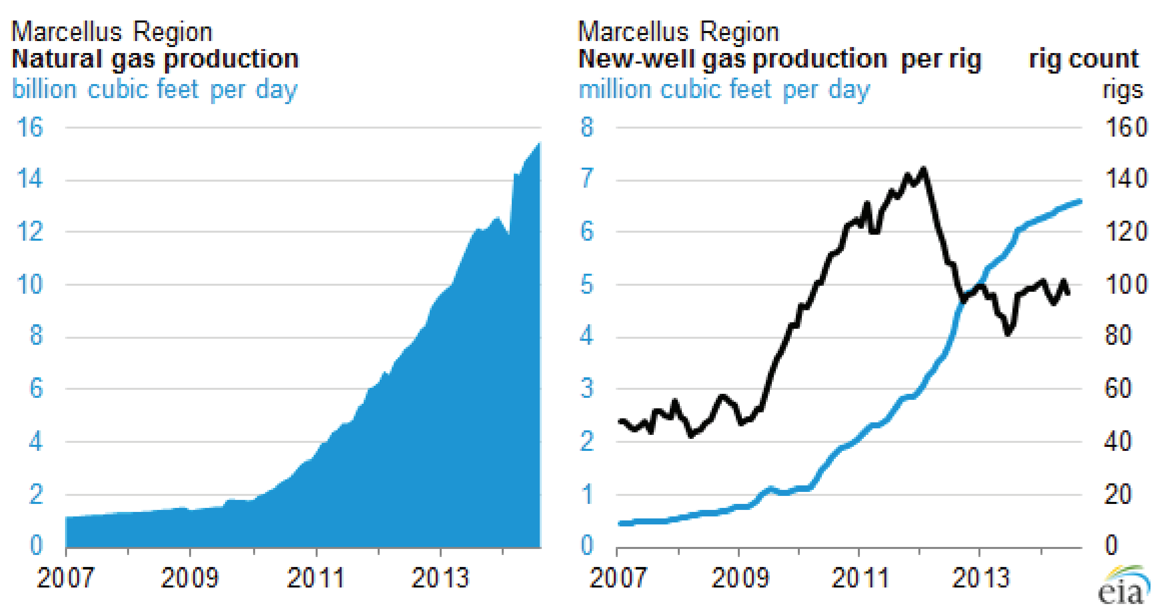

FIGURE 4-14 Production and proven reserves in the Marcellus Shale area of northern Pennsylvania. SOURCE: EIA, 2014.

network. Recently, the City of Pittsburgh has developed a network of bicycle lanes throughout the city to encourage nonmotorized transportation (Fraser, 2014).

Transportation also features as a prominent issue area in the Pittsburgh Climate Action Plan, with recommendations focusing on reducing the number of single-occupancy vehicles commuting to Pittsburgh, encouraging public transit use and bicycle commuting, and reducing commuter and travel footprints (Pittsburgh Climate Initiative, 2012). As part of the Pittsburgh 2030 District Initiative, a 50 percent reduction in transportation emissions goal was established, as well as an emissions baseline (from mid-2015) which was established as an average of the percentage share of different transportation modes of commuters and associated air emissions from commuter transportation to and from downtown Pittsburgh (Green Building Alliance, 2014). The city is also involved in a number of other transportation initiatives, including alternative fuels and waste hauler retrofits—the city uses B20 biodiesel (20 percent biodiesel, 80 percent petroleum diesel blend) in all diesel equipment and is retrofitting its diesel waste hauling vehicles with equipment to reduce diesel particulate emissions. Diesel particulate filters have been installed on 13 waste haulers and the rest of the fleet is planned to be retrofitted from a $443,100 grant awarded by the state of Pennsylvania (City of Pittsburgh, 2016).

Poverty and Workforce Development

With the drop in steel industry employment, Pittsburgh has had problems with concentrated pockets of poverty and unemployment, particularly in the towns surrounding steel mill closures. For 2009-2013, persons below the federal poverty level were 23 percent, compared with a statewide average of 14 percent (U.S. Census Bureau, 2015b). Retraining steel workers for employment at comparable wage levels to those in the steel industry is very difficult.

In recent years, the Pittsburgh region has seen growth in software, robotics, and medical technology enterprises. These industries have attracted recent graduates (especially from the local universities) and immigrants. In June 2015, the unemployment rate in the region was 5.5 percent (Pittsburgh TODAY, 2015).

City of Pittsburgh Sustainability Planning

Since 2008, the City of Pittsburgh has had an Office of Sustainability that works in partnership with private groups (such as the Green Building Alliance and Sustainable Pittsburgh) and with other government agencies (such as Allegheny County and the Commonwealth of Pennsylvania). Objectives for the city's sustainability program are (City of Pittsburgh, 2015a)

- Improving the internal operations of municipal government, to reduce the fiscal and environmental impact related to the local government's services;
- Fostering innovative and collaborative solutions that overcome barriers to ecological responsible behavior;
- Ensuring that the city provides clean air, water, and livable communities for residents and businesses;
- Being a leader locally, nationally, and globally in the collective effort to reduce the impacts of climate change while growing the local economy; and
- Encouraging economic opportunities for all communities.

A wide range of activities are performed by the Office of Sustainability, generally in the following programmatic areas:

- Benchmarking and Recognition,
- Innovation and Process Improvement,
- Coordination and Facilitation,
- Funding and Resource Development,
- Sustainability and Resilience Planning, and
- Communication and Education.

Figure 4-15 shows 2014 key performance indicators for the Office of Sustainability for its city improvement activities.

Indicator	Description	Data Source	Baseline
Baseline measurement of City Employee Commute Mode Share established by Q4 2014	**Transportation mode share** for City employees	Employee Transportation Survey	Of those surveyed, 55% drive alone to work, 27% bus, 6% bike, 8% carpool and 4% walk.
Employee Sustainability Awareness baseline established by Q4 of 2014	Education baseline for **employee awareness of sustainability activities**	Employee Sustainability Awareness Survey	Of those surveyed, 36% did not know Pittsburgh had an Office of Sustainability, and of those who know the Office existed, 25% do not know what the Office of Sustainability does.
Water Meter Installation in CCB and (other 2030 Buildings) completed by Q2 of 2015 + Conductivity Measurement initiated on 6th Floor by Q4 of 2014	**Water quality and consumption** to guide conservation and improvement efforts	CCB water meter/ CATTfish water conductivity meter	Installation of water meters. Water within normal potable range
Install CMU Speck monitors and collect data by Q4 of 2014	**Indoor air quality monitoring**	CMU Create Lab – Speck monitor	Speck monitors deployed on two floors in City County Building
Complete CCB waste audit and waste stream analysis by Q4 of 2015	Establish data-derived foundation for **internal waste diversion** improvements	CCB Waste Audit Results	Preliminary waste audit completed. Result: creation and adoption of a new Citywide waste policy.
Reduce Energy Consumption by 20% by 2020 from 2010 levels (5% Reduction is achieved by Q4 2015)	Electricity consumption based on kilowatt hours (kWh) and Energy Use Intensity (EUI) - or energy per square foot.	Portfolio Manager Energy Consumption Reporting	We currently stand at a 3% improvement (2013=153) from our 2010 EUI(energy use intensity) baseline of 158

FIGURE 4-15 2014 key performance indicators. SOURCE: City of Pittsburgh, 2015b. Reprinted with permission from the City of Pittsburgh.

OTHER SIGNIFICANT ACTIVITIES

Public-Private Partnerships

Beginning in 1945 and extending through the 1950s, Pittsburgh experienced Renaissance I, which focused on air pollution control and redevelopment of the downtown area. Renaissance I plans were formed by a partnership between business (organized in the Allegheny Conference for Community Development) and the City of Pittsburgh under the leadership of Mayor David Lawrence. A second Renaissance began in the 1970s with a focus on cultural district expansion and renewal. Again, this activity was a result of private-public partnership, but the public agencies and private foundations tended to take on leadership roles (Tarr, 2002). During the 1990s, the region realized that economic revitalization was critical to its future sustainability. Again, a public-private partnership was formed, called the Regional Economic Revitalization Initiative. Some environment actions were pursued within this initiative, such as redevelopment of riverfronts for parkland, but the bulk of the activity was intended to foster economic and workforce development. Finally, beginning around 2010, the local government, businesses, foundations, and university communities coalesced around an agenda to overcome continuing environmental problems and to promote sustainable development. Deployment of new technologies developed locally is a feature of this new set of partnerships.

More recently, the Pittsburgh Climate Action Plan Version 2.0 outlines a number of recommendations which focus on community and business partnerships (Pittsburgh Climate Initiative, 2012). Sustainable Pittsburgh provides an example of an organization which promotes sustainability through a focus on partnerships and collaboration, and facilitates a number of initiatives such as the Pittsburgh Green Workplace Challenge, the Sustainable Pennsylvania Community Certification, and Sustainable Pittsburgh Restaurants (Sustainable Pittsburgh, 2016).

Role of Science and Innovative Technology

From the 1800s to the early 1900s, the Pittsburgh region was notable for innovation in developing world-class steel production and manufacturing processes. Pittsburgh steel was exported for buildings and transportation facilities throughout the world. More recently, innovation has been promoted to achieve the sustainability goals outlined above. For example, in conjunction with researchers at Carnegie Mellon University, the city is investing in indoor air quality monitors and new adaptive traffic signal controllers. It has formal agreements with local universities and was a founding member of the MetroLAB city-university consortium intended to promote “smart cities” as part of the White House Smart Cities Initiative (Carnegie Mellon University, 2015). The MetroLAB Network aims to advance collaboration among university researchers and city policy makers to undertake research and development projects that improve infrastructure, public services, and environmental sustainability. Finally, the Phipps Center for Sustainable Landscapes in Pittsburgh is one of the first buildings in the world to achieve the Living Building Challenge.[21]

Brownfield Redevelopment

With a significant industrial history, the Pittsburgh region has over 10,000 brownfield sites that can be redeveloped, although most require some form of environmental remediation. Nevertheless, numerous successful brownfield redevelopments have been accomplished while considering developmental, ecological, and socioeconomic tradeoffs (Haller, 2005). For example, the former LTV plant of 48 acres along the Monongahela River was successfully developed for office and research space use. The site now has over 1,000 employees and returns roughly $1 million per year in property taxes (Western Pennsylvania Brownfields Center, 2015). Brownfield developments are associated with lower overall travel times for residents and industries. Moreover, they can take advantage of existing infrastructure developed for the original industrial users.

SUMMARY OBSERVATIONS

Pittsburgh has a history of unbridled industrial development in the 19th century, with recurring problems of air and water quality as well as waste disposal. It received the description “Hell with the lid off” for good reason. While Pittsburgh has retained considerable primary production, the development of the software, robotics, and medical technology enterprises has begun to change the city significantly.

Several lessons can be drawn from the evolution of Pittsburgh’s economy and activities over the past 150 years. First, public-private partnerships can be effective in implementing changes to improve the overall quality of life. Pittsburgh’s three renaissance periods all featured such partnerships, although the more recent developments included a greater presence of the private sector, nonprofit groups (particularly charitable foundations), and

[21] The Living Building Challenge™ is the built environment’s most rigorous performance standard. It calls for the creation of building projects at all scales that operate as cleanly, beautifully, and efficiently as nature’s architecture. To be certified under the Challenge, projects must meet a series of ambitious performance requirements over a minimum of 12 months of continuous occupancy. See http://living-future.org/lbc.

TABLE 4-10 Example Highlighting Actions for Pittsburgh that Illustrate Steps in Urban Sustainability Roadmap (see Chapter 3, Figure 3-1)

City	Pittsburgh
Adopt Principles	P1, P2, P3, P4
Opportunities and Constraints	Opportunities: Growth of renewable energy generation and green infrastructure. Constraints: Air and water pollution and aging infrastructure.
Prioritize Co-net Benefits	Brownfield development, improved job access, improved street lighting and traffic management. Green infrastructure projects could simultaneously help with issues of air pollution, water pollution, GHG emissions, and urban heat islands.
Partnerships	Numerous partnerships with private sector, nonprofit organizations, corporations, universities, and other government agencies. Example partners: Allegheny Conference for Community Development, Green Building Alliance, Pittsburgh Higher Education Council, Pittsburgh Cultural Trust, Sustainable Pittsburgh.
Goals	Adopted by the Mayor and City Council and used by the city's Office of Sustainability. GHG reduction target of 20% below 2003 levels by 2023.
Strategies	Street light improvements; building energy efficiency improvement; transportation mode shift; pollution reduction; green infrastructure for stormwater management.
Data Gaps	Indirect emissions (Tier 3 emissions) are not tracked locally. Emissions within the region but outside the city limits.
Implementation	City of Pittsburgh Office of Sustainability
Local to Global	Close cooperation between agencies at different levels.
Public Buy-in	Mayor roundtables. Public forums on issues such as the city's Climate Change Adaptation Plan
Feedback	—

universities. Second, reusing old industrial sites can have significant benefits for travel time and urban liveliness. Generally, the benefits outweigh the costs of environmental remediation. Brownfield redevelopment benefits include travel cost savings and employment opportunities. Finally, the Pittsburgh region was overly reliant upon a single industry for its economic driver during much of the 20th century. With the contraction of the local steel industry in the 1970s, the region has struggled to find other industries to provide growth and employment. Diversity of industrial activity is an important lesson learned. Nonetheless, Pittsburgh has made progress in environmental stewardship efforts, with a targeted focus on GHG emissions reduction and climate protection (Table 4-10).

CHATTANOOGA

Chattanooga is the fourth largest city in the state of Tennessee, located near the Tennessee-Georgia border (Figure 4-16). The mountains that surround Chattanooga and provide its scenic backdrop also trap air pollutants in the Chattanooga valley, so that in 1969, the federal government declared Chattanooga's air the dirtiest in the nation. In the time since, substantial private and public resources have been invested in transforming the city to what is considered today as one of the most revitalized cities in the Southeast.

BACKGROUND

Chattanooga was first settled by Europeans in 1816. By the mid-1800s, Chattanooga was seen as "the gateway to the deep south," a vital trading stop for steamboats and trains (Eichenthal and Windeknecht, 2008). The resources of Chattanooga made it a strategic city during the Civil War, with the second deadliest battle of the war occurring just miles from the city at Chickamauga (Civil War Trust, 2015). A new industrialized Chattanooga rose out of the rubble, one that was considered the “dynamo of Dixie.” However, less than a century later, Chattanooga was hit hard by the Great Depression. Although the Tennessee Valley Authority (TVA) revolutionized the region by generating cheap hydroelectricity that attracted manufacturing and jobs, the industrialization of Chattanooga had its costs. In 1960, Chattanooga had a higher percentage of manufacturing jobs than any other city in the South, which contributed in 1969 to EPA finding that Chattanooga had the dirtiest air in the nation (Parr, 1997). As pollutants hovered over the city, Chattanoogans moved to the suburbs and the downtown district emptied out (Eichenthal and Windeknecht, 2008).

In the 1970s and 1980s, a vision of “bringing the country to the city” was introduced to Chattanooga largely by city councilman David Crockett who studied inner-city redevelopment initiatives across the United States. At the same time, civic leaders like Eleanor McCallie Cooper (Director of the Chattanooga Venture) invited the whole community to bring their ideas to the discussion about the future of Chattanooga, to ensure that decisions about the city were not made by a small elite (Lerner, 1998).

Chattanooga spans about 140 square miles of Hamilton County and is encircled by mountains and rivers. Overlooking Chattanooga, Lookout Mountain provides a picturesque view of the city and the Tennessee River (Phillips, 2013). The modified Köppen classification system defines the climate of Chattanooga as humid subtropical with an average temperature of 60.3 degrees (Chattanooga Area Chamber of Commerce, 2011; Pidwirny, 2011) and 52.4 inches of annual rainfall (Table 4-11).

In 2010, the City of Chattanooga had a population of about 170,000, and the metro area had a population of about 528,000. Based on these data, Chattanooga is the fourth largest city in Tennessee, and one of the largest 150 cities in the country. While the majority of Chattanoogans are white, the City of Chattanooga has a diverse racial composition: 19.8 percent are black or African American, 5.1 percent are Hispanic or Latino, and 2.1 percent are Asian (Table 4-11).

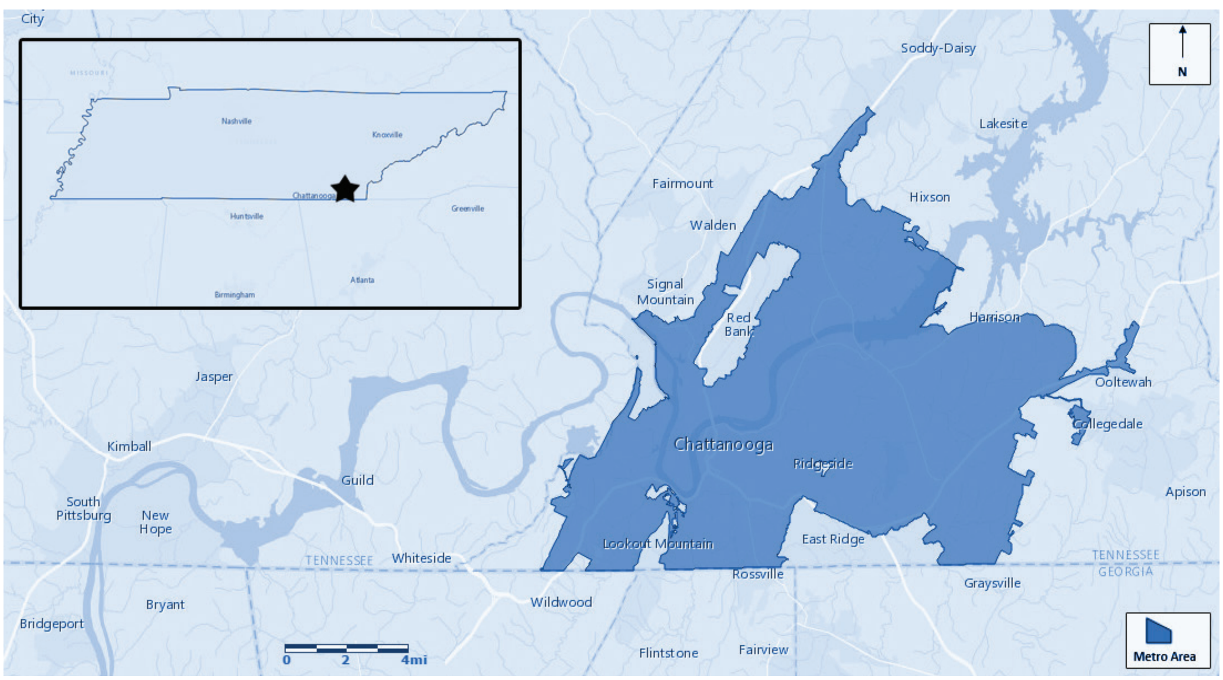

FIGURE 4-16 Map showing the City of Chattanooga municipal boundary and location in Tennessee. SOURCE: Prepared by Brent Heard, Consultant to the STS Program.

There are a number of notable statistics related to Chattanooga. Violent crimes occur at a rate that is more than three times higher than that of the United States. Although this rate is alarming, the violent crime rate has been declining, potentially as the result of an increase in the city's police force. Examining the crime statistics of Chattanooga also interestingly reveals that close to one-half of assaults and homicides occur in a house where both the perpetrator and victim live (Brogdon, 2013).

Similarly, Chattanooga suffers from a poverty level that is above the national average. Within the city limits, the poverty levels nearly double to 30 percent. Manufacturing had once been the largest employer in Chattanooga, but job opportunities disappeared with the factories. As a result, Chattanooga's unemployment rate is higher than the national average (7.9 versus 7.6 percent). More than 40 percent of children in Chattanooga live in poverty, and close to 70 percent of impoverished households are headed by women (Greenhouse, 2014). Chattanooga's progression toward sustainability has been achieved despite ongoing problems of poverty and crime.

Like most southern cities, Chattanooga grappled with racial tensions in the 1950s and 1960s. However, Chattanooga was unique in hiring black police officers beginning in 1948 and busing out-of-district students into white school districts before most other southern cities (Eichenthal and Windeknecht, 2008). Despite this, a 2009 National Association for the Advancement of Colored People (NAACP) study said, "Chattanooga has a major race problem." The study found a general perception among black residents of Hamilton County that they had limited career paths, feared retaliation for accusing authority figures of racist behavior, and were 19.5 times more likely to go to jail than white residents of Hamilton County. Unemployment is much higher among African Americans and especially black youths (NAACP, 2011).

By the end of the 1960s, nearly one-third of Chattanooga jobs were in manufacturing, and the effects of manufacturing had perverse impacts on the city's air quality. By merely walking outside, Chattanoogans risked covering their clothing in soot. The beautiful view of the mountains was obscured behind a haze of air pollution, and drivers had to use their headlights in daylight in order to see. Today 12.6 percent of Chattanoogans are employed in manufacturing; while much less than 50 years ago, this is still higher than most U.S. cities (U.S. Census Bureau,

TABLE 4-11 Key Characteristics for Chattanooga

Indicator	Chattanooga	United States
ENV: Average Annual Precipitation (inches/year)	52.44	40.8
ENV: Existing Tree Canopy (% of land cover)	23	25
ENV: Roadway Fatalities (per hundred million annual vehicle miles traveled)	1.40	1.10
ENV: Particulate Matter 2.5 (ppm)	13.5	10.2
ENV: Residential Carbon Footprint (metric tons of CO_2 per capita from residential energy consumption)	3.1	3.4
ECON: Financial Health	AAA	AA+
ECON: Average Residential Electricity Rate (cents/kWh)	10.13	11.88
SOCIAL: Black or African American	19.8%	13.2%
SOCIAL: Hispanic or Latino	5.1%	17.4%
SOCIAL: Asian	2.1%	5.4%
SOCIAL: Home Ownership (2009-2013)	64.9%	64.9%
SOCIAL: High School Graduate (25 or older, 2009-2013)	86.3%	86%
SOCIAL: Below Poverty Level	16.6%	15.4%
SOCIAL: Rate of Violent Crimes (Type 1 Violent Crime Offenses Reported/100,000 people)	636	191

NOTE: ENV, ECON, and SOCIAL refer to the three dimensions of sustainability: environmental, economic, and social, respectively. SOURCE: Appendix B.

2015a). Along with the region's declining but still relatively high reliance on coal for electricity generation, the city's strong manufacturing base contributes to its noncompliance with fine particulate matter. TVA's shrinking reliance on coal power contributes to the city's smaller-than-average residential carbon footprint. Reflecting its strong business and industrial base, Chattanooga enjoys a higher financial rating (AAA) than the U.S. government (AA+) (Tables 4-11 and Appendix B).

Figure 4-22 compares the performance of Chattanooga and the United States on seven sustainability indicators. The spider chart was created using the metrics data supplied in Table 4-11. The chart shows that Chattanooga today falls far short of the nation in terms of public safety and air quality, but excels in financial health.

MAJOR SUSTAINABILITY EFFORTS

Today's postindustrial Chattanooga economy and environment are in stark contrast to the city it was half a century ago, with clean air, new investments in high-tech businesses and clean manufacturing, and an emphasis on sustainability. The "Chattanooga way" (see Box 4-6)—combining strong and sustained community and business leadership with a commitment to participatory democracy—has produced an environmentally based urban recovery movement that has transformed the city.

Air Pollution

As the industrial and railroad sector thrived in Chattanooga, so did unregulated air particle emissions in the late 1960s. Residents, governmental officials, and industrial leaders united to clean the air over the city they called home. In 1969, Chattanooga passed an Air Pollution Control Ordinance (after being declared the city with the dirtiest air in the country). The ordinance created the Air Pollution Control Board and Bureau, and placed significant limits on stationary and mobile emissions. Despite a compliance cost of over $40 million a year, all major contributors to Chattanooga emissions were in line with the new standards within 3 years (Chattanooga-Hamilton County Air Pollution Control Bureau, 2015). A large contributing factor to reducing emissions in the 1970s was the loss of foundries and factories in Chattanooga. However, it would take 20 years for the Chattanooga skies to meet federal standards. When Chattanooga did acquire attainment, it was one of the first eastern cities to succeed for 1-hour ozone levels (Hundt et al., 2009).

BOX 4-6
The Chattanooga Way

With the creation of the Chattanooga Venture in 1983, the "Chattanooga way" was born. It draws on the broad engagement of Chattanoogans of diverse backgrounds and occupations in a public discourse about the future of their city. Assisted by the creation of public-private partnerships, public meetings periodically tap the opinions and views of residents, to ensure that goals and plans are achievable and reflect the preferences of the public. During one 20-week series of visioning sessions in the early 1990s, 1,700 people participated in meetings that generated thousands of ideas and produced a consensus for a cleaner, greener, safer city with rehabilitated housing and nonpolluting jobs (Lerner, 1998). Election reform helped Chattanooga better represent and engage a broader range of residents. A downtown plaza was built to serve as a place for Chattanoogans to gather and discuss civic affairs. Finally, the "Chattanooga way" has benefited from strong political, community, and business leaders who have endorsed sustained community engagement, made residents realize that they must do much of the heavy lifting, and broadly shared credit for the city's successes.

The EPA created more stringent air quality regulation in 1997; to achieve these stricter federal standards as soon as possible, Chattanooga formed an Early Action Compact. As Chattanooga continued its efforts to clean the air, so did the EPA nationwide by again setting new stricter levels of air quality (Chattanooga-Hamilton County Air Pollution Control Bureau, 2015). After failing to meet the standard in 2004, Hamilton County initiated motor vehicle emission testing (EPA, 2014d). Other aggressive measures taken by the city and county to meet these new standards included a burning ban from October to April, lowering the speed limits for trucks, retrofitting school buses to be emission neutral through the use of diesel oxidation catalysts, and installing vapor recovery systems at gas stations (Chattanooga-Hamilton County Air Pollution Control Bureau, 2015).

Land Use and Transportation

Revitalization efforts to create a sustainable city began in the 1980s. Moccasin Bend, 600 acres of land that straddle the Tennessee River across from downtown Chattanooga, was the initial target. The Lyndhurst Foundation, which attained its fortune from an heir of the Coca-Cola bottling rights, funded an Urban Land Institute evaluation of Moccasin Bend. The task force concluded that efforts to revitalize the city must be focused on reconnecting the city with the Tennessee River. A plan for a 22-mile Tennessee River Park was conceptualized in hopes of creating community pride and inviting new investments and tourists (Eichenthal and Windeknecht, 2008).

With the election of Mayor Gene Roberts in 1983, and continued revitalization efforts by the Lyndhurst Foundation, plans were initialized for the Miller Park District. Located in the center of downtown, the plan called for a Tennessee State Aquarium and the construction of additional housing. The Lyndhurst Foundation further funded "Chattanooga in Motion" to allow Chattanooga leaders to visit other cities also hoping to revitalize their downtown areas. Following these visits, the Chattanooga Venture was created in 1983 to host a series of public meetings discussing what the ideal Chattanooga would look like in 2000. These meetings resulted in Vision 2000. Among the goals detailed in Vision 2000 were the preservation of the Walnut Street Bridge and additional downtown affordable housing (Eichenthal and Windeknecht, 2008).

After receiving funding from the Lyndhurst and Tonya Foundations, the Miller Plaza opened in downtown Chattanooga in 1988. For more than 20 years, the plaza has served as a place for Chattanoogans to gather. Also in 1988, ground was broken along the banks of the Tennessee River for the Tennessee State Aquarium. Funded exclusively by private donations, including $10 million from the Lyndhurst Foundation, the largest freshwater aquarium in the world opened in 1992. In less than half a year, more than one million people had visited the aquarium, and it had brought in more than $130 million to Chattanooga in its first year. Chattanoogans had participated in civic engagement to accomplish a large-scale goal, and thus the "Chattanooga way" had worked.

Also in 1992, Chattanooga became one of the first cities to launch a free electric shuttle, in this case connecting the largest hotel in Chattanooga to the aquarium (Eichenthal and Windeknecht, 2015). In 2012, the Chattanooga electric shuttle celebrated its 20th anniversary and ridership of nearly 17 million since opening (Pare, 2012). In 1993, the Walnut Street Bridge reopened and connected downtown Chattanooga to North Chattanooga (Eichenthal and Windeknecht, 2015). Today, the Walnut Street Bridge is one of the longest pedestrian bridges in the world and is seen as a symbol of Chattanooga (Wade, 2014). In 1994, the first multifamily apartment complex opened in downtown in 20 years. The citizens of Chattanooga and their leaders again joined forces to complete Coolidge Park along the river. This 10-acre park replaced a Coast Guard reserve station and now boasts a carousel and rock climbing wall. By the beginning of the new millennium, downtown Chattanooga had transformed into a thriving center for nightlife complete with hotels, entertainment, restaurants, and a minor-league baseball stadium (Eichenthal and Windeknecht, 2008).

Additional steps were taken by the local government in the waning years of the 20th century to prepare Chattanooga for the 21st century. In 1996, citizens approved a referendum to raise taxes with an understanding that half of revenues would go toward enhancing economic development. An environmentally friendly building was constructed to house city and county offices in part as a result of this tax. Further conversion and reconstruction projects continued throughout the downtown area (Eichenthal and Windeknecht, 2008).

Sustaining Chattanooga for a Changing Climate

In 2006, Chattanooga Mayor Ron Littlefield was among the first 500 mayors to sign the Climate Protection Agreement (Garcia, 2007). This committed Chattanooga to record its current emissions levels and set goals to reduce emissions. As is the "Chattanooga way," the residents were asked for their opinions and views. More than 500 attended "Chattanooga Green," a meeting to gauge what Chattanoogans wanted from a sustainable city. After receiving input from Chattanoogans, the Chattanooga Green Community analyzed ways to turn these hopes into reality. In 2009, Chattanooga unveiled its climate action plan that detailed 47 action items (Hundt et al., 2009).

The Chattanooga Climate Action Plan focuses on four areas: energy efficiency, education and policy, healthy communities, and natural resources. The Chattanooga Green Committee—14 individuals appointed by the mayor—hoped through this plan Chattanooga could achieve its goals while improving the quality of life and ensuring Chattanooga remains economically competitive. In order to implement this plan, the committee recommended an Office of Sustainability (Hundt et al., 2009). After opening, this office merged with the Chattanooga-Hamilton County Regional Planning Agency to reduce costs (Hightower and Sohn, 2012). The committee research found that electricity and transportation were the largest contributors to emissions in Chattanooga. With this in mind, the committee set the following three goals: (1) 7 percent reduction in GHG emissions by 2012 compared to 1990, (2) 20 percent reduction in GHG emissions by 2020 compared to 1990, and (3) 80 percent reduction in GHG emissions by 2050 compared to 1990 (Hundt et al., 2009).

First, the committee recommended focusing on energy efficiency and increasing alternative energy use. Alstom, a wind turbine manufacturer, opened a plant in Chattanooga in 2010. The plant is partially funded by a Department of Energy clean-energy tax credit worth $63 million (Micheli, 2013). The Chattanooga Airport is now also 85 percent powered by a 7.5-acre solar farm located at the airport that generates 2.1 MW (Pare, 2013). Furthermore, the mayor of Chattanooga issued an executive order in 2012 mandating a 25 percent reduction in energy usage by city departments and offices by 2020, a move that will annually save nearly $3 million by conservative estimates (Hightower and Sohn, 2012). Following the recommendation of the committee, the city's municipal utility—the Electric Power Board (EPB)—became a TVA Generation Partner through generating energy that TVA can buy back. Consumers are incentivized to invest in green power by as much as $1,000 to offset initial costs. TVA then buys this entire green power output at a premium (EPB Electric Power, 2015).

Additionally, the committee recommended constructing LEED-certified buildings (Hundt et al., 2009). The first and still only LEED Platinum certified auto plant on the planet is now in Chattanooga following the opening of the Chattanooga Volkswagen Plant (Volkswagen Group of America, 2014). The committee also endorsed more green buildings in Chattanooga (Hundt et al., 2009). Today, Chattanooga's green buildings are enabled by green|spaces, a store dedicated to providing materials necessary for green building, and a Green Building Council on the Home Builders Association of Greater Chattanooga (green|spaces, 2015; Home Builders Association of Greater Chattanooga, 2015; Malek, 2015). Since the committee recommendation to increase recycling, Chattanooga has made it easier for its residents to recycle by offering recycling bins (City of Chattanooga, 2015).

The committee also voiced that city officials were already acting properly by continuing to focus on ensuring that Chattanooga's downtown offers affordable housing so Chattanoogans can live, work, and play in a focused area. This coupled with further alternative transportation options will further reduce emissions (Hundt et al., 2009). In 2013, Chattanooga launched "GreenTrips," a program that rewards commuters for opting to bike, walk, carpool, or use public transportation (GreenTrips, 2015). Chattanoogans are able to register "green trips" they have taken and receive points. These points can then be redeemed to buy prizes or enter contests. Today, biking is particularly attractive to Chattanoogans thanks to "Bike Chattanooga," a program that allows members to pick up and drop off bikes at their convenience from dozens of stations across the city (Chattanooga Bicycle Transit System, 2015). Chattanooga has also been named a top 40 American bike-friendly city (Bicycling, 2014).

The committee also urged the city to continue expansion of greenways, protection of biodiversity, and further planting of trees (Hundt et al., 2009). As would be expected from a city focused on manufacturing, trees had been replaced with pavement and factories. Since undertaking sustainable efforts, the tree canopy of Chattanooga has grown (Figure 4-17). It should continue to expand with the "Citizen Forrester" program, in which participants of the program discover where to best plant different types of trees in the city (Barnett, 2011). In terms of city green

FIGURE 4-17 Chattanooga in 1970 (above) and 2015 (below). SOURCE: Benic ("Bruz") Clark, Vice President and Treasurer, Lyndhurst Foundation, presentation to Committee on July 28, 2015. Reprinted with permission from the River City Company.

space, Main Terrain Art Park, a 1.72-acre park, opened in 2013. The park hosts on-site detention ponds that store 1.5 million gallons of water annually. This water is then recycled to irrigate the park (National Endowment for the Arts, 2015). In the coming decades, climate is not the only expected change for Chattanooga. The population of the Greater Chattanooga area is expected to surge from 1 million to 1.4 million by 2055. Once again the community of Chattanooga is engaging in conversations of how to sustain their scenic city through Thrive 2055 (Omarzu, 2014).

OTHER SIGNIFICANT ACTIVITIES

Over the past several years, Chattanooga has continued to apply innovative approaches to promote sustainability. Of particular note are its unique fiber optic and smart grid networks. In 2011, EPB completed the installation of 8,000 miles of fiber optic cables, making it the first "gigabit city" offering gigabit speeds as a standard residential fiber optic option. High-speed fiber optic networks send data as instant pulses of light rather than signals over a metal cable. This fiber optic network delivers television, phone, and broadband services to every residence and company in EPB's 600-square-mile territory. Unlike most systems, its high-end services are not just an option for the affluent, but are standard service for all (Chattanooga Area Chamber of Commerce, 2015).

With a grant from the U.S. Department of Energy, Chattanooga was able to add intelligent devices to its electricity distribution system, supported by its fiber optic backbone, to achieve more reliable and efficient services. Its distribution automation is served by 1,200 "IntelliRupter Pulse Closers" producing real-time telemetry that is sent to EPB's SCADA (Supervisory Control and Data Acquisition) system every 4 seconds (see Figure 4-18) (Wade, 2014). This system avoids electric outages by detecting potential faults and rerouting power. In addition, EPB's automated meter infrastructure allows customers to manage their usage more effectively with real-time

FIGURE 4-18 Installation of an IntelliRupter Pulse Closer. SOURCE: McCarthy, 2015. Image courtesy of POWERGRID International.

TABLE 4-12 Example Highlighting Actions for Chattanooga that Illustrate Steps in Urban Sustainability Roadmap (see Chapter 3, Figure 3-1)

City	Chattanooga
Adopt Principles	P1, P2, P3, P4
Opportunities and Constraints	Scenic location with access to the Tennessee River; gigabit city. Historically "dirtiest air in the nation"; race and crime issues; unemployment.
Prioritize Co-net Benefits	Improve air quality: City becomes a community again. Become greener: Invites tourists to visit and new companies move in. Prepare for a changing climate: Ensures Chattanooga is a sustainable city.
Partnerships	Chattanooga formed an Early Action Compact. Partnerships induced by a leading foundation, the Lyndhurst Foundation. Chattanooga Venture was created in 1983 to host a series of public meetings discussing what the ideal Chattanooga would look like in 2000. These meetings resulted in Vision 2000.
Goals	Achieve a cleaner, greener, safer city with rehabilitated housing and nonpolluting jobs: Achieved. Comply with EPA air quality standards: Achieved. Bring the community and jobs back into the city: Achieved. Reconnect the city with the Tennessee River: Achieved. 80% reduction of GHGs by 2050 compared to 1990: In progress.
Strategies	Vision 2000: public-private partnerships and strong public engagement. The climate action plan: Creation of a Chattanooga Office of Sustainability.
Data Gaps	
Implementation	Chattanooga passed an Air Pollution Control Ordinance. Creation of the gigabit city with a smart grid and infrastructure to enable the growth of IT-driven businesses.
Local to Global	—
Public Buy-in	The "Chattanooga way" (see Box 4-6).
Feedback	—

consumption data and time-of-use rates. With these features and more, Chattanooga has become arguably the smartest municipal electric grid in the country.

With these infrastructure assets, Chattanooga has developed business accelerator programs to launch businesses based on ultrabroadband applications. This has drawn entrepreneurs from across the globe to Chattanooga, including HomeServe USA and Engage 3D, that have chosen to relocate to the city because of its smart grid and fiber optic capabilities (Chattanooga Area Chamber of Commerce, 2015).

Chattanooga has also achieved greater "procedural" equity with respect to its governance. The government of Chattanooga was commission style until 1990. This meant the five city commissioners were elected through at-large elections rather than through elections that were based on district representation. A recommendation of Vision 2000 was for Chattanooga to adopt a mayor/council model that would provide greater government representation for all residents. Following a lawsuit, the commission style was ruled illegal under the Voting Rights Act since it did not allow fair representation from the minority population of Chattanooga (Table 4-12). Chattanooga adopted the recommended revised form of government that now has nine city council members elected through nine district elections. This innovation led to the inaugural council comprised of nine members who had never served in city government before. While the council had only ever had one nonwhite commissioner before 1990, the council of today is now racially diverse (City Council of Chattanoga, 2015; Eichenthal and Windeknecht, 2008).

SUMMARY OBSERVATIONS

Chattanooga's designation as the "dirtiest city in America" in 1969 became a catalyst for a sea of change. EPA's air quality benchmarking motivated the city to go beyond incremental improvements to dramatically turn itself around. Without such a "wake-up" call, it is not clear that Chattanooga would have become the hub of sustainable growth that it is today. Other observations include the following:

1. Chattanooga benefited greatly from the involvement of strong business and civic leaders, along with substantial resources made available from local foundations to fund the transformation planning and the reconstruction projects that accelerated change.
2. Despite being plagued by numerous challenging issues, Chattanoogans were able to participate in civic engagement by laying out attainable goals for a cleaner environment, and pursuing them until they became a reality.
3. The city's land use planning fostered healthy urban ecosystems by capitalizing on Chattanooga's unique assets, including the beauty of Moccasin Bend along the Tennessee River that had been rundown and lost as a focal point during the decades when heavy industry occupied this prime real estate.
4. Its recent innovations in fiber optic and smart grid infrastructures have created new partnerships and enabled Chattanooga to attract clean high-tech development.
5. Chattanooga has achieved further success by ensuring greater procedural equity in its governance by reforming the city government to be more inclusive.
6. Despite the progress Chattanooga has made over the past five decades, not all Chattanoogans have benefited. Crime, poverty, and unemployment rates remain high.

Looking to the future, the sustainability efforts of Chattanooga will likely attract further economic development. Chattanooga should continue to build phoenix industries from the assets that previously existed in its historic manufacturing days. However, it is clear that sustainability initiatives alone cannot resolve enduring poverty and racial issues that continue to challenge Chattanooga. For this city to achieve world-class status, its less prosperous residents need to benefit more substantially from the creation of a greener city.

GRAND RAPIDS

The experience of Grand Rapids demonstrates three main lessons: (1) sustainability plans do more than set targets—they inform stakeholders of both the current conditions and plans for action; (2) measurable targets joined with scientific threshold impact statements encourage support and build local buy-in—they illustrate the importance of action and the consequences of inaction; and (3) triple-bottom-line indicators create a framework for sustainability that illustrates the co-benefits of multitargeted goals—they allow for broader and interrelated work plans.

BACKGROUND

A historic manufacturing city 30 miles due east of Lake Michigan, Grand Rapids is the second largest city in Michigan with a city population of 193,792. It is the seat of Kent County and the largest city in an eight-county area in western Michigan that includes 1.5 million people (Figure 4-19). The population is steady, gaining almost 4 percent of its population since 2000. However, social and economic issues challenge the city with more than one-quarter of its population living below the poverty rate, income at almost 20 percent less than the state of Michigan median, and a home ownership rate 15 percent less than the state's average. A significant percentage of families pay more than 35 percent of their monthly income in housing costs (see Table 4-13) (U.S. Census Bureau, 2015b).

Grand Rapids is a city of innovation. Its history has included one of the nation's first hydroelectric plants, it was the first city to introduce fluoride to its drinking water, and it had the first publicly funded art installation (Western Michigan Environmental Action Council, 2013). Today, local corporations have created a collaborative model for innovation with GRid70, a multicorporate research and development design hub that uses intersectoral

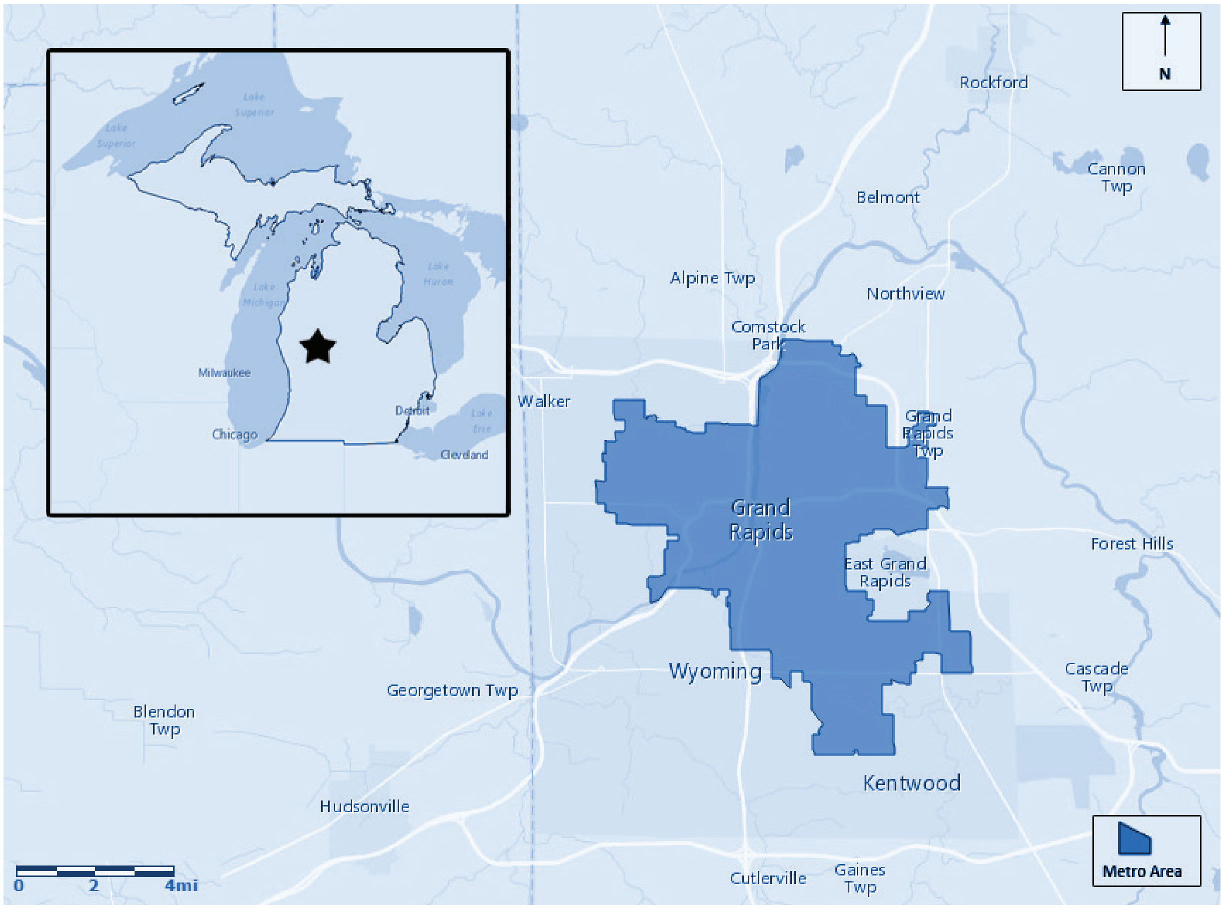

FIGURE 4-19 Map showing the city of Grand Rapids municipal boundary and location in Michigan. Source: Prepared by Brent Heard, Consultant to the STS Program.

and interdisciplinary approaches to new product and process development in noncompeting companies in the region. Companies located in GRid70 include Meijer Stores, Amway, Mercy Health, and Wolverine Shoes (Knape, 2010). In addition, a new $15 million venture capital fund, Start Garden, invested in two new ideas a week in 2012. Those initial investments have grown with more capital being invested. From 2012 to 2016, Start Garden has invested in 190 ideas, 70 next stage projects, and 22 startups (Dishman, 2012; Sanchez, 2015).

Once known as the “Furniture City,” Grand Rapids experienced decline in traditional manufacturing in the 1960s and 1970s. The resulting job loss made diversifying the economy a priority. While 15 percent of the local workforce is still in manufacturing compared to a national average of 9 percent, the current economic profile includes furniture and office equipment, aviation, automotive, retail, manufacturing, sales, publishing, multisector service industries, and health care. Spectrum Health is the largest employer in western Michigan with over 23,000 employees. Grand Rapids is the fourth largest cluster of medical device suppliers in the Midwest and the eighth in biopharmaceuticals (Longworth, 2014).

With these growth industries, educational attainment, workforce preparation, and sectoral diversification are critical to support the regional economy. Grand Rapids was one of the first cities to receive a Department of Labor WIRED (Workforce Innovation in Regional Economic Development) grant through the West Michigan Strategic

TABLE 4-13 Key Characteristics for Grand Rapids

Indicator	Grand Rapids	United States
ENV Average Annual Precipitation (inches/year)	38.3	40.8
ENV Existing Tree Canopy (% of land cover)	34%	25%
ENV Roadway Fatalities (per 100 million annual vehicle miles traveled)	1.0	1.1
ENV Particulate Matter 2.5 (ppm)	12.2	10.2
ENV Residential Carbon Footprint (metric tons of CO_2 per capita from residential energy consumption)	4.7	3.4
ECON Financial Health	AA-	AA+
ECON Average Residential Electricity Rate (cents/kWh)	13.71	11.88
SOCIAL Black or African American	10.4%	13.2%
SOCIAL Hispanic or Latino	10.1%	17.4%
SOCIAL Asian	2.8%	5.4%
SOCIAL Home Ownership (2009-2013)	70.1%	64.9%
SOCIAL High School Graduate (25 or older, 2009-2013)	84%	86%
SOCIAL Below Poverty Level	26.8%	15.4%
SOCIAL Violent Crimes (per 100,000 people)	409	191

NOTE: ENV, ECON, and SOCIAL refer to the three dimensions of sustainability: environmental, economic, and social, respectively. SOURCE: Appendix B.

Alliance. A focus of the $15 million grant was on workforce development to improve the number and qualifications of the local workforce referred to as the "talent supply chain" (Longworth, 2014). The area's number of high school graduates (83.9 percent) is less than both the state (88.9 percent) and national averages (86.0 percent). However, its population with a bachelor's degree from 2009-2013 exceeds both at 29.9 percent (U.S. Census Bureau, 2015b). This effort is complemented by the area's 2-year, 4-year, and graduate institutions, including Grand Valley State University and a branch of the Michigan State College of Human Medicine (Longworth, 2014).

MAJOR SUSTAINABILITY EFFORTS

Because of its strong corporate history, business leadership has been a prominent component of Grand Rapids' civic culture working with local government and citizen groups to improve the quality of life in the city and invest in areas of promise. These strong partnerships allowed the city to identify problems and then create inclusive engagement processes for solutions. For example, in the 1980s deficiencies in storm and wastewater treatment triggered new approaches in infrastructure planning and investment (Western Michigan Environmental Action Council, 2013). In the mid-1990s, at the urging of a local business leader, the city began a process to use quality management principles to address local social issues (City of Grand Rapids, 2008). This study process lasted 18 months and resulted in the application and introduction of high-impact management practices across city departments.

According to former Mayor George Heartwell, this early work extended to the adoption of the triple-bottom-line (social, environmental, and economic) approach to sustainable development in 2005. The existing sustainability planning process was replaced with the formation of the Grand Rapids Area Community Sustainability Partnership (CSP). The partnership, which has grown from the original five members to over 200, includes community leaders from academia, government, business, and environmental organizations. The partnership's work began by

BOX 4-7
Water Conservation

Grand Rapids is fortunate to have abundant water access. While working on a number of sustainability fronts, the city wants to ensure that this important natural resource is available to future generations. In 2015 Grand Rapids received the Water Conservation Award from the Great Lakes and Saint Lawrence Cities Initiative for water conservation efforts that reduced water usage by 100 gallons per day per meter (30.62 percent) over its 2000 average water usage baseline of 400 gallons per meter per day. Through a combination of improved infrastructure, new technology, and natural filters Grand Rapids has had success in water protection and conservation. Initiatives include a water management system that measures usage and pinpoints potential issues, early completion of a combined sewer overflow elimination project, installation of a variable speed water pump, construction of an underground stormwater storage facility, and the planting of 2,800 trees to intercept stormwater and filter out pollutants before they reach the Grand River. The co-benefits of the water conservation effort are improved water quality, less wastewater to burden surface water levels, more efficient technology on water pumping that decreases GHG emissions, more manageable stream flows, which reduce the chance of neighborhood flooding, and more recreation and commerce related to the Grand River (City of Grand Rapids, 2015b).

providing guidance for improving the city's services to residents and businesses and has since evolved to a more comprehensive sustainability initiative focused on triple-bottom-line indicators. In 2006 the city developed its first sustainability plan with a vision of improving the environment, economy, and social equity using indicators and specific targets guided by research, data, and implementation strategies. In 2008 the city worked in partnership with the Community Research Institute at Grand Valley State University to collect data on sustainability measures and to establish a baseline for the future assessment of outcomes.[22] In addition, according to Dr. Haris Alibašić, director of the Office of Energy and Sustainability, the city established sustainability requirements for city buildings around materials, energy use, and water conservation for construction, renovation, and management. Sustainability has been a priority for the City of Grand Rapids for more than a decade (Box 4-7).[23]

A key component of the sustainability plan is its accountability. The Office of Energy and Sustainability and the CSP revised the 2006 plan in 2010 to cover fiscal years (FY) 2011-2015 with updates and specific data targets and indicator research included. This plan was adopted by the city and was updated in October 2015 with revised targets for FY2016-FY2020.

THE FOCUS OF THE SUSTAINABILITY PLAN

Grand Rapids has been quite successful in identifying indicators and targets in its triple-bottom-line approach to improve environmental, economic, and equity outcomes on a range of issues and also in highlighting co-benefits of the outcomes while managing tradeoffs. The Sustainability Plan for FY2011-FY2015 contains 232 targets organized around economic, social equity, and environmental outcomes (Alibašić, 2013; City of Grand Rapids, 2013b). In the fifth year of the FY2011-FY2015 plan, 188 of the targets are completed, 42 are in process, and 2 have had no change. Using the triple-bottom-line frame, 68 percent of the economic targets, 61 percent of the social outcomes, and 71 percent of the environmental targets have been met. The 32 resiliency recommendations of the Climate Resiliency Report are being incorporated into the Sustainability Plan and have measurable targets as well (City of Grand Rapids, 2015b).

[22] G. Heartwell, interview with S. Morse Moomaw, July 2015.
[23] H. Alibašić, interview with S. Morse Moomaw, July 2015.

While the plan covers a broad range of specific actions, the following is a summary of the priorities:

- On economic well-being, Grand Rapids emphasizes growing and encouraging small to mid-sized companies, a more diverse supplier base, worker skills and career readiness, and enhanced downtown and neighborhood business districts that capitalize on the Grand River area.
- In the social equity area, the focus is on improving the quality and quantity of housing, increasing educational attainment and workforce participation, expanding civic involvement, reducing crime, and improving the quality of life through access to the arts, food sources, and recreation.
- In the environmental area, the plan focuses on reducing greenhouse gas emissions and the impact on climate change, protecting the quality of natural systems including stormwater management, and implementing sustainable design and land use.

Within these three areas, four initiatives are particularly strong: reduction of greenhouse gas emissions, stormwater management, stakeholder engagement, and green infrastructure (City of Grand Rapids, 2013b).

Reduction of Greenhouse Gas Emissions

In 2009 as part of an initiative by ICLEI, the international association of local and metropolitan governments dedicated to sustainable development, the City of Grand Rapids joined with the U.S. Conference of Mayors Climate Change Protection Agreement to reduce greenhouse gas emissions. Using the six major sources of GHGs developed by the Kyoto Protocol—carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride—Grand Rapids developed a data set that provides a baseline against which progress can be evaluated. Based on the data from the inventory, the city has identified very specific targets for reducing GHG emissions with the overall goal of meeting the obligations of the U.S. Mayors Climate Protection Agreement (City of Grand Rapids, 2009). The city has reduced direct and indirect CO_2 emissions by 4,440 metric tons since 2012 (City of Grand Rapids, 2015b).

The Office of Energy and Sustainability has had a strong focus on the renewable energy sector. Renewable energy sources account for more than 30 percent of the city's energy supply. Grand Rapids has committed to energy reduction and use in two major ways: (1) reduction of greenhouse gas emissions and reduction of energy demand and (2) reduction of fossil fuel consumption. These targets center on reducing time in cars and increasing sustainable, multimodal transportation alternatives (City of Grand Rapids, 2015b). The Intergovernmental Panel on Climate Change estimates that transportation is responsible for almost one-quarter of all energy-related GHG emissions (Ribeiro et al., 2007; Sims et al., 2014). Research from the CEO for Cities organization suggests that reducing 1 mile per day in vehicle miles traveled per vehicle in the region would generate $141 million in annual savings in fuel, maintenance, and automobile purchases (Cortright, 2008). Grand Rapids is continuing to expand its alternative transportation systems and increase use of alternative fuels. The city had reduced its GHG emissions by an average of 2.6 percent annually since 2013 due to efficiency improvements, waste reduction, and renewable products (City of Grand Rapids, 2015b).

Stormwater Management

Stormwater management is important to the long-term growth and stability of all cities but particularly those who depend on a natural water source. In the 1980s, the city realized that the lack of a strong stormwater management process left it vulnerable to weather events, particularly the flooding of the Grand River, which intersects the city. As a result, several major initiatives were launched, including the Stormwater Asset Management Plan to provide a system inventory, the implementation of the Asset-Management Optimization Software system to locate any major breaches in the system, and the improvement of its stormwater ordinance, which is considered a model for other cities. The ordinance encourages 100 percent stormwater retention on new development sites and offers "greenspace" credits to encourage developers to incorporate innovative practices (Western Michigan Environmental Action Council, 2013). In addition, Grand Rapids' sustainability plan calls for a 100 percent compliance rate for three permit programs: the Stormwater Pollution Prevention Initiative, the Public Education Program, and the Illicit Discharge Elimination program. As of 2008, the city had spent more than $350 million to separate combined sewers and to eliminate overflows into the Grand River. The city completed the initiative to eliminate all its combined sewer discharges into the Grand River in 2015 (City of Grand Rapids, 2013b, 2015a,b).

Stakeholder Engagement

Stakeholder engagement has been critical in the development and implementation of the Grand Rapids sustainability plan and is an important lesson for other cities. The mayor's office, local leaders, and city employees view sustainability in the context of a multigoal approach and are encouraged to contribute to the "bottom line" of the goal results. The plan process subscribes to the Plan-Do-Check-Act method to achieve results, to be flexible and adaptable to a changing environment, and to plan budget and initiatives accordingly.

Sustainability is integrated horizontally and vertically with regional, state, and national partnerships and across neighboring communities (Price, 2011). These partnerships are guided by strategic initiatives that are cross-cutting and comprehensive. A current example of this vertical integration is the work the Office of Energy and Sustainability is doing with a number of western Michigan organizations and businesses to create the Grand Rapids 2030 Energy District to encourage high-performance buildings, which is positioned to encourage innovation, further education, and promote creative strategies across the built environment sector (Walton, 2015). Grand Rapids has the largest number of LEED buildings per capita in the United States with 83 buildings certified; of those, 24 are classified either platinum or gold (City of Grand Rapids, 2015a; The Right Place, 2016). Vertical integration and partnerships are key to implementation and impact.

Integrity of Green Infrastructure

The integrity of green infrastructure is a cross-cutting theme in the Grand Rapids Sustainability Plan and in the city's Master Plan. The co-benefits of improvements in both the built and natural environments support a long-term response to climate change through the protection and maintenance of healthy ecosystems and habitats by increasing the tree canopy and the diversity of trees and planting low-maintenance grasses and native plants in parks and public spaces. Part of the Green Grand Rapids initiative, the current tree canopy covers 34 percent of the land area. The sustainability target is to increase the urban tree canopy to 40 percent (City of Grand Rapids, 2011c, 2015b).

In the built environment, the city aims to reduce the carbon footprint through 100 percent compliance with zoning regulations and land-use permits, by increasing the number of sustainable buildings through new construction and adaptive reuse, by instituting more areas of parkland and green space using low-impact design, and by increasing the accessibility of parks to community members. Sustainability targets to support these goals include increasing the number of acres of city-owned parks and open space, increasing the number of people who live within one-quarter of a mile of a park or open space, and making all parks and green spaces 100 percent compliant with the Americans with Disabilities Act. The Green Grand Rapids process used to engage community members around quality of life and green infrastructure issues in updating the Master Plan has engaged thousands of citizens with its user-friendly "Green Pursuits" board game that allows citizens to visualize the desired changes on a map of the city and then report back at "Green Gathering" sessions (City of Grand Rapids, 2011c, 2015b).

Finally, Grand Rapids, like many cities, was designed for automobiles. However, as the city is considering ways to improve multimodal options, citizens have advocated for a bicycle-friendly environment supported by Complete Streets. The goal is 100 additional miles of on-street bicycle lanes by the end of 2017 from the 72.5 miles in 2011 (City of Grand Rapids, 2011a,b). The League of American Bicyclists already considers Grand Rapids one of the nation's most bike-friendly communities, rating it a bronze in its system of classifying communities (League of American Bicyclists, 2014). However, with a score of 55 out of 100, the community is quick to admit that improvement is needed to reach their goals.

OTHER SIGNIFICANT ACTIVITIES

In 2010 Grand Rapids joined with the ICLEI to launch the Climate Resilient Community Initiative with seven other inaugural partners to support research and action toward increasing local resilience. A partnership with the West Michigan Environmental Action Council in 2012 led to the documentation of climate change resiliency at the local level using the triple-bottom-line framework. The Grand Rapids Climate Resiliency Report (Western Michigan Environmental Action Council, 2013) included climate science, research and analysis, and the results from 25 local interviews. The interviewees represented a wide range of sectors impacted by climate change. Using the software Model for the Assessment of Greenhouse-Gas Induced Climate Change with the Regional SCENario GENerator v. 5.3.3, coordinates were marked for the City of Grand Rapids and projected to an area of 175 by 175 miles (Liobimtseva, 2013; Western Michigan Environmental Action Council, 2013).

The Great Lakes region, of which Grand Rapids is a part, can expect more variable and volatile weather from year to year and from season to season. This could lead to more extreme weather events, such as storms that produce more than 1 inch of rain in a 24-hour period, increased frequency of days above 90 degrees and 90 percent humidity, and more freeze-thaw cycles in winter and spring (Kling et al., 2003; Liobimtseva, 2013; Winkler et al., 2012). Additionally, data show that winter ice coverage on the Great Lakes decreased by 71 percent between 1973 and 2011 (Wang et al., 2012). Climate change variables of temperature and precipitation were projected for 2022 and 2042 using baseline data from 1961 to 1990. Projections for 2022 showed that temperatures will increase by 1.1 degrees and 2.6 percent, respectively (City of Grand Rapid, 2013a). The largest increases in temperature are projected to occur during the winter. Climate change impacts were assessed in terms of how they would affect residents' quality of life and the ability of key sectors to provide services and benefits. While climate change impacts an individual sector in isolation, it also affects the interaction of the sectors and the function of the system as a whole. Therefore, understanding the needs of the community, major relationships between sectors, and the ability of the sectors to meet those needs in a changing climate are key to building resiliency.

The Office of Energy and Sustainability is now integrating resiliency and sustainability into emergency preparedness. This illustrates the kind of integrative thinking that has allowed Grand Rapids to continue to build synergy around sustainability and strive for a balanced community portfolio.

SUMMARY OBSERVATIONS

Grand Rapids illustrates how a mid-sized city can use planning, collaboration, and research to build a sustainability strategy. The city is developing a multifrontal approach to environmental security that identifies and measures sustainability indicators and their impact. The goal of the sustainability agenda is to reach beyond city government to corporations, small businesses, government agencies, nonprofit organizations, and the public at large. While this kind of integrated sustainability effort lies beyond the scope of a local government planning agency, continued and consistent municipal leadership provides an important foundation for sustainability efforts. Several key findings emerged from the work in Grand Rapids that can be helpful as other mid-sized cities consider sustainability planning:

1. Actions related to climate change, resiliency, and sustainability can be considered concurrently in developing both targets and responses.
2. A range of historic discriminatory practices around financial inequities, housing availability, and placement of at-risk neighborhoods causes vulnerable populations to be disproportionately affected by extreme weather events.
3. Targets, words, and specificity matter. Sustainability planning must include benchmarks, targets, and implementation plans. Clarity on the definition and application of sustainability is critical.
4. Broad-based community support, consistent community leadership, and collaboration across sectors are critical to changes in behavior and policy. Environmental issues must have champions.
5. The triple-bottom-line (economics, social equity, and environmental) approach to sustainability provides a transparency that can engender a more inclusive set of stakeholders and actions.

Recognized by the U.S Conference of Mayors in 2012 for efforts to confront global climate change, in 2010 as the "Nation's Most Sustainable City" by the U.S. Chamber of Commerce, and in 2009 as a Regional Centre of Expertise on Education for Sustainable Development by the United Nations, Grand Rapids is reaching its goals by setting sustainability as a priority early on, recognizing the co-benefits between issues, and being intentional in its approach (City of Grand Rapids, 2015b). See Table 4-14.

TABLE 4-14 Example Highlighting Actions for Grand Rapids that Illustrate Steps in Urban Sustainability Roadmap (see Chapter 3, Figure 3-1)

City	Grand Rapids
Adopt Principles	P1, P2, P3, P4
Opportunities and Constraints	Opportunities: Reduction of carbon footprint, water protection and conservation, stakeholder engagement, green infrastructure, and expanding economic opportunities through health care and tourism. Constraints: Fiscal limitations to implement strategies, transportation infrastructure, and poverty.
Prioritize Co-net Benefits	The City of Grand Rapids Sustainability Plans have approached the challenge of sustainability through the triple bottom line—economics, equity, and environment—and their related co-benefits. The goals set respond to each of these areas separately but are intentional about identifying and enhancing the intersections of the three.
Partnerships	The Grand Rapids Area Community Sustainability Partnership (CSP). has grown from the original five members to over 200 and includes community leaders from academia, government, business, and environmental organizations. GRid70, a multicorporate research and development design hub, uses intersectoral and interdisciplinary approaches to new product and process development in noncompeting companies in the region. Community Research Institute at Grand Valley State University assists the Sustainability Office with data and data collection to support the target indicators. An example of vertical integration is the work the Office of Energy and Sustainability is doing with a number of western Michigan organizations and businesses to create the Grand Rapids 2030 Energy District to encourage high-performance buildings.
Goals	To approach sustainability from a triple-bottom-line perspective in order to ensure economic vitality, social equity of all residents, and protection the natural and built environment.
Strategies	To build a strong economy by expanding sectors, investing in workforce development, supporting small business development, and strengthening the quality of life. To create social equity by increasing housing choices, improving educational outcomes, making community services and opportunities more accessible, and reducing crime. To secure the environment by reducing energy use and dependence on fossil fuels, reduction, managing stormwater more efficiently, expanding the amount and accessibility of green space and the tree canopy, conserving and protecting water, and developing mobility options.
Data Gaps	Data to support implementation strategies, to update and verify outcomes, and to determine interrelationship and connectedness with region, state, and world.
Implementation	Targeted investments in technology, natural systems, human capital, the built environment, and social capital.
Local to Global	A founding city in the ICLEI network, Grand Rapids has a commitment to the U.S. Mayor's Climate Change Agreement and the use of available science and protocols to contain local and regional footprint.

TABLE 4-14 Continued

City	Grand Rapids
Public Buy-in	The growth of the Community Sustainability Partnership is evidence of strong support for the concept. In addition, the city uses traditional media, social media, and neighborhood dialogues to communicate plans and progress and to solicit input from a broad range of stakeholders. The Green Grand Rapids process to update the Master Plan around quality of life and green infrastructure issues has engaged hundreds of community members with its user-friendly "Green Pursuits" that allows citizens to visualize the desired changes in a board-game map process and then report back at "Green Gathering" sessions.
Feedback	Since the city adopted its first Sustainability Plan in 2006, there have been five target updates as well as a Climate Resiliency Report published.

CEDAR RAPIDS

Cedar Rapids has followed the path of many small cities in the Midwest. The population of urban areas has increased as farming has become more mechanized, but the city economy is still dominated by the agricultural economy. Cedar Rapids is an example of many small to moderate-sized cities spread across the landscape in resource-rich areas with sufficient rainfall that are, or could be, producers of the stuff (food, timber, minerals, energy) that supplies staples to the rest of society (Day et al., 2016). The megatrends of the 21st century, especially that of energy scarcity, will likely result in agriculture becoming more labor intensive with a higher diversity of crops than is common now. Farm communities will also likely become more robust with the re-invigoration of rural institutions.

BACKGROUND

Cedar Rapids is in the center of a region that supplies an enormous amount of grain and other foods both to U.S. consumers and to export markets. Cedar Rapids is the second largest city in Iowa after the state capital, Des Moines (Figure 4-20). It is the only urban area among those considered in this report that is not part of a mega-region as described in the section on settlement patterns and population distribution (see Figure C-1 in Appendix C) (Hagler, 2009). It is one of many small cities established in the rich agricultural region of the Midwest in the 19th century, and where many counties are classified as underperforming (see Figure C-2 in Appendix C) (Hagler, 2009). Counties in underperforming regions are those that have not kept up with national trends in population, employment, and wages (Hagler, 2009).

The fertility of soils in the United States is highly variable and the Midwest "breadbasket" has some of the richest soils in the world. Figure C-3 in Appendix C shows the soil fertility index derived by Schaetzl et al. (2012). The dominant soil order as defined by the U.S. Department of Agriculture in much of the Midwestern Great Plains heart of U.S. agriculture is Mollisol, typically found where grassland ecosystems have flourished. The long-term addition of organic materials derived from grassland plants creates a thick, dark, fertile surface soil. This in turn enables incredibly productive agriculture. Around the world, Mollisols are used extensively for growing food (Brady and Weil, 2007). Much of the rest of the Midwest is characterized by Alfisols, highly fertile soils mainly formed under forest cover. Although Mollisols and Alfisols are widespread in the United States (together they make up more than one-third of U.S. land area), other soil types found around the country, especially in the east and west of the Great Plains, are not as favorable for growing food unless significant resources are used to boost productivity (Day et al., 2016). Inevitably, utilizing soils for agriculture causes changes in soil properties and can enhance the risk of erosion (Powlson et al., 2011). The richest soils are in the Midwestern breadbasket and the upper Great Plains.

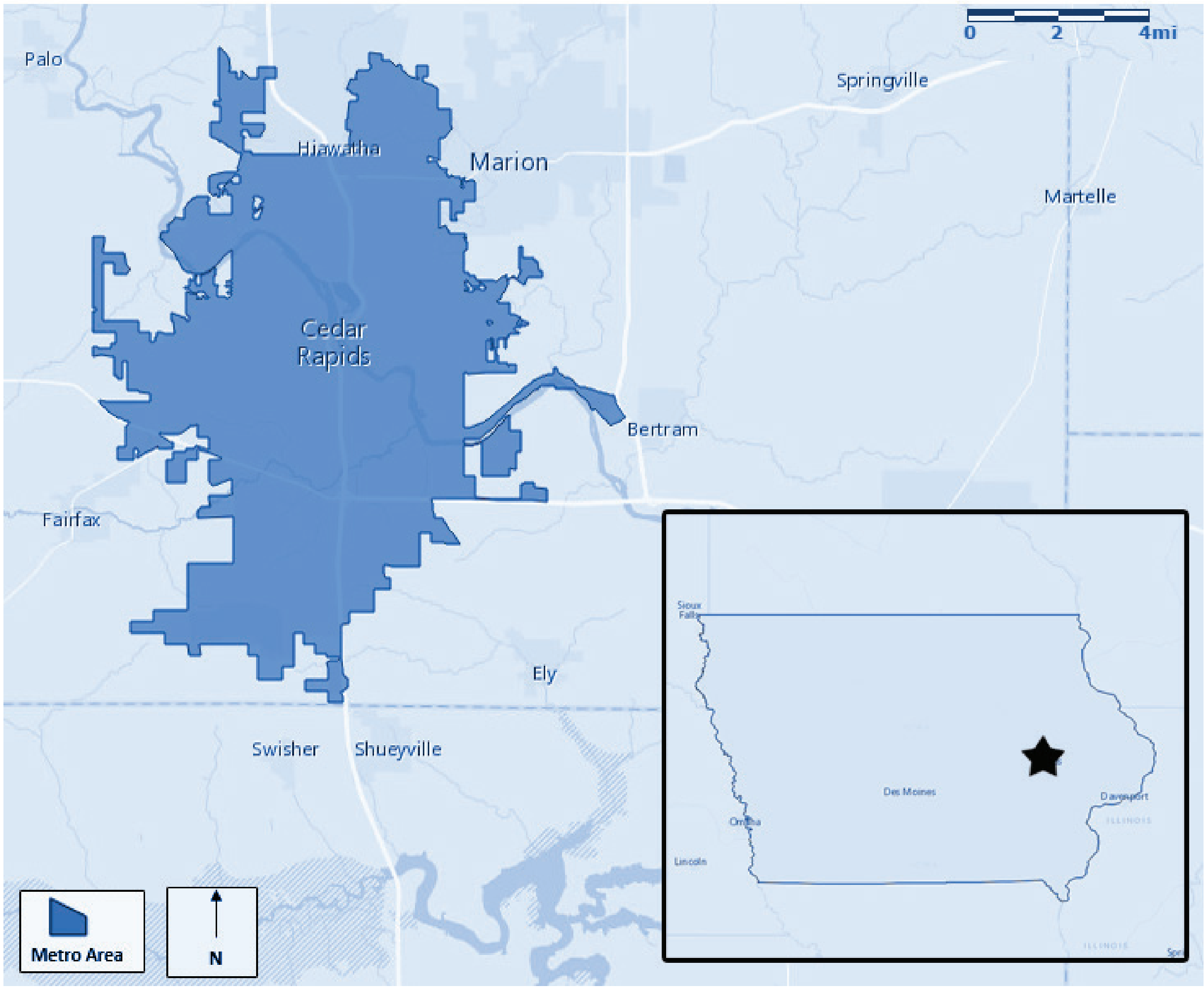

FIGURE 4-20 Map showing the city of Cedar Rapids administrative boundary and location in Iowa. Source: Prepared by Brent Heard, Consultant to the STS Program.

The city is situated on both banks of the Cedar River. The city's population was 1,830 in 1860 and increased to 25,656 by 1900. It surpassed 100,000 by 1970. The population remained relatively stable during the 1980s and 1990s. In 2010, the population of the city was just over 125,000, while that of the three-county metropolitan area was 255,452 (Day et al., 2016).

Given the fertility of the surrounding agricultural land and its location on a tributary to the nearby Mississippi River, it is unsurprising that grain processing forms the basis of Cedar Rapids' economy. Large agricultural companies that have offices in Cedar Rapids include Quaker Oats, Archer Daniels Midland, Cargill, and General Mills. Early in the 21st century, the value of agriculture products in east central Iowa was $600 million from crops and $300 million from livestock. Other important employers are the defense and commercial avionics company Rockwell Collins and the insurance company Aegon. Partly because of Rockwell Collins, Cedar Rapids has more engineers per capita than any other city in the United States. The city also has a higher percentage of exported products, per capita, than any other in the country, mainly reflecting the agricultural and avionics industries (Day et al., 2016).

TABLE 4-15 Key Characteristics for Cedar Rapids

Indicator	Cedar Rapids	United States
ENV Average Annual Precipitation (inches/year)	37.6	40.8
ENV Existing Tree Canopy (% of land cover)	13	25
ENV Roadway Fatalities (per 100 million annual vehicle miles traveled)	1.0	1.1
ENV Particulate Matter 2.5 (ppm)	11.1	10.2
ENV Residential Carbon Footprint (metric tons of CO_2 per capita from residential energy consumption)	not available	3.4
ECON Financial Health	Aa1	AA+
ECON Average Residential Electricity Rate (cents/kWh)	13.0	11.9
SOCIAL Black or African American	4.5%	13.2%
SOCIAL Hispanic or Latino	2.9%	17.4%
SOCIAL Asian	2.2%	5.4%
SOCIAL Home Ownership (2009-2013)	73.0%	64.9%
SOCIAL High School Graduate (25 or older, 2009-2013)	94%	86%
SOCIAL Below Poverty Level	9.7%	15.4%
SOCIAL Violent Crimes (per 100,000 people)	212	191

NOTE: ENV, ECON, and SOCIAL refer to the three dimensions of sustainability: environmental, economic, and social, respectively. SOURCE: Appendix B.

Before colonization, the area was inhabited by tribes belonging to the Prairie-Plains Indian culture whose members lived both migratory and settled lifestyles. The Sauk and Meskwaki tribes dominated eastern Iowa. These tribes sold their lands to the federal government and were relocated to Kansas. Cedar Rapids was settled, like much of Iowa, by European immigrants in the mid-1800s. The city was established in 1838 and incorporated in 1849. By 1870, farms and small towns covered much of the state, ending the frontier era.

From its founding, the economy of Cedar Rapids, like many towns and cities in the Midwest farm belt, has been tied to agriculture due in large part to the fertility of the area's soils. However, agriculture and infrastructure in the area have changed over time. Prior to the Civil War, wheat, oats, barley, hay, and sorghum were important crops. Crops were first shipped to markets on the Mississippi River, but in the 1850s, rail transport began. Following the Civil War and the completion of an east-west rail line across Iowa in 1867, the main agricultural crops changed to corn and hogs. For the most part, corn was fed to hogs that were then sold on the market. Iowa also became an important egg producer. It remains a top-producing state of corn, hogs, and eggs today.

In the first part of the 20th century, farms produced much of the food they consumed typically from large flocks of chickens, large gardens, small dairy herds, and fruit trees. After World War II, farms became less diversified and most farm families bought their food rather than produce it. Agricultural productivity increased and substituted mechanization and inputs, such as pesticides and fertilizers, for labor. As a result, farm sizes grew larger, and Iowa farms began to specialize in corn, soybean, and hog production (Day et al., 2016).

MAJOR SUSTAINABILITY EFFORTS

The vision of Cedar Rapids to create a more sustainable community is incorporated into its iGreenCR Team report. The City of Cedar Rapids contributes to this team by investing in more sustainable practices and working toward goals set for city operations to reach by the year 2020. The iGreenCR vision is built around five central principles:

1. Community—Building a community that embraces its diversity and history;
2. Growth—Advancing opportunities for businesses, individuals, and the community as a whole to thrive;
3. Environmental Stewardship—Promoting economic and social growth while restoring the relationship between the city and its natural environment;
4. Affordability—Creating a city that is affordable and accessible to all members of the community; and
5. Innovation—Serving as a leader in creative, successful strategies to lead the progression toward a sustainable future.

Elements of this vision include options for biking and mass transit; energy efficiency; a focus on environmental amenities such as parks, gardens, and urban and nearby water bodies; urban forestry; efficient use of water; and attention to place and history. Energy efficiency initiatives include tracking of reduced greenhouse gas emissions. There are no specific plans for meeting the energy needs of the city from renewables (Ambrosy et al., 2014).

Climate change impacts to the Cedar Rapids region will be moderate compared to other regions of the country such as the Southwest and coastal areas. There will be some temperature increase but rainfall should remain adequate for agriculture. The National Climate Assessment (NCA) reported that annual precipitation in Iowa increased by 5 to 15 percent from 1992 to 2012 compared to the 1901-1960 period (Melillo et al., 2014). The NCA also projected that precipitation in Iowa would increase by about 10 percent in the spring, decrease by less than 10 percent in the summer, and increase by less than 10 percent in the fall by the period 2071-2099 compared to the period 1970-1999. These climate projections indicate that Iowa will remain very suitable for agriculture without the necessity of any significant irrigation.

Cedar Rapids could easily feed itself from its local foodshed, as well as provide a surplus for other regions if a greater diversity of crops were grown. It has been reported that it takes about 1.25 acres per capita to provide a typical American diet (Peters et al., 2007; Pimentel and Pimentel, 2003). The population of metropolitan Cedar Rapids is about 255,000 so it would require about 320,000 acres to feed the city based on 1.25 acres per person, or an area within less than 20 miles from the city.

OTHER SIGNIFICANT ACTIVITIES

An analysis of the sustainability indicators indicates that Cedar Rapids fares well compared to the other cities in this analysis. Particulate matter is in the midrange for the case-study cities while the air quality index is one of the best. It has the best water quality index of all the cities. The flat topography of the land means landslide vulnerability is nil. Natural hazard vulnerability is high perhaps due to flooding potential.

Economic indicators are in the midrange to positive for Cedar Rapids. The city has the lowest unemployment of the cities analyzed. It scores low for percent use of public transit and walk score and is in the midrange of water usage.

Social indicators are also generally positive for Cedar Rapids. It is a relatively small metropolitan area with a largely white population. Compared to other case-study cities, it has the highest median household income, the lowest poverty rate, the lowest income inequality ratio, the lowest rate of violent crime, and the best health indicators. Cedar Rapids has a very high population of college-educated people. Despite its low population density and high percentage of licensed drivers per driving-age population, the city has the lowest mean travel time to work and, by far, the lowest yearly delay in hours per commuter of all the case-study cities; both of these indicators reflect the size of the Cedar Rapids urban area relative to other cities described in this chapter.

SUMMARY OBSERVATIONS

The most significant message for urban sustainability to come from this analysis of Cedar Rapids is the importance of the current status and setting of a city. It has a highly educated and affluent population without the extremes of income and wealth inequality that exist in cities like New York and Los Angeles. Cedar Rapids has a relatively benign climate and will be less affected by climate change than other cities because it is not vulnerable to sea-level rise and intense storms that originate in the oceans (hurricanes, west coast storms). There is a net

TABLE 4-16 Example Highlighting Actions for Cedar Rapids that Illustrate Steps in Urban Sustainability Roadmap (see Chapter 3, Figure 3-1)

City	Cedar Rapids
Adopt Principles	P1, P2, P3, P4
Opportunities and Constraints	Opportunities: Cedar Rapids is a producer city that produces agricultural products that are not dependent on discretionary spending. Climate impacts will be relatively benign. Highly educated workforce. Constraints: Agriculture will have to adapt to 21st-century megatrends but it has a clear preindustrial model.
Prioritize Co-net Benefits	Cedar Rapids scores relatively high on most metrics of sustainability. The focus for sustainability is on community, growth, environmental stewardship, affordability, and innovation.
Partnerships	The community was engaged in developing the iGreenCR report.
Goals	Sustainability is built around five principles: community, growth, environmental stewardship, affordability, and innovation.
Strategies	iGreenCR Team report.
Data Gaps	As yet, there are few specific plans for meeting the energy needs of the city from renewables.
Implementation	Plans for implementations include biking and mass transit; energy efficiency; a focus on environmental amenities such as parks, gardens, and urban and nearby water bodies; urban forestry; efficient use of water; and attention to place and history. Energy efficiency initiatives include tracking of reduced greenhouse gas emissions.
Local to Global	Cedar Rapids will be subject to the same national laws and regulations that impact all cities. The main connection of the city to national and global levels is the enormous food production that flows to national and global markets.
Public Buy-in	The public has been involved in the development of sustainability plans for the city.
Feedback	As yet, there are no specific metrics for meeting the energy needs of the city from renewables and for achieving sustainability goals.

precipitation surplus, and the city is on a permanently flowing river. Cedar Rapids will experience droughts from time to time, but sporadic flooding is the hazard more likely to occur. The relatively small size of the city means that it does not have the huge demands for energy and materials of mega-cities like New York and Los Angeles. The city is in an area of low regional population density with some of the richest soils in the world. As a locus of the food-processing industry, Cedar Rapids' economy is based on a nondiscretionary commodity—food—which provides economic stability. Furthermore, if needed, food could be supplied to the city's population from an area within about 20 miles from the city if agricultural production were more diversified.

Cedar Rapids' focus on community, growth, environmental stewardship, affordability, and innovation builds on a strong base that will make long-term sustainability easier to attain than most of the other cities considered in this report. These conclusions are supported by the Industrial Cities Initiative published by the Federal Reserve Bank of Chicago (Engel and Longworth, 2012). They classified Cedar Rapids, along with Grand Rapids, as resurgent cities. These are cities that have relatively smaller declines in manufacturing employment with relatively larger increases in well-being.

FLINT

Flint, Michigan, is an example of a postindustrial, depopulating city that is common across the Northeast and Midwest in an area that is termed the "Rust Belt." Its depressed economy and high poverty rate are substantial challenges to meeting its sustainability goals. However, its geographic location provides it with assets, such as insulation from the effects of climate change and fertile farmland, that could be used to improve its sustainability (Figure 4-21).

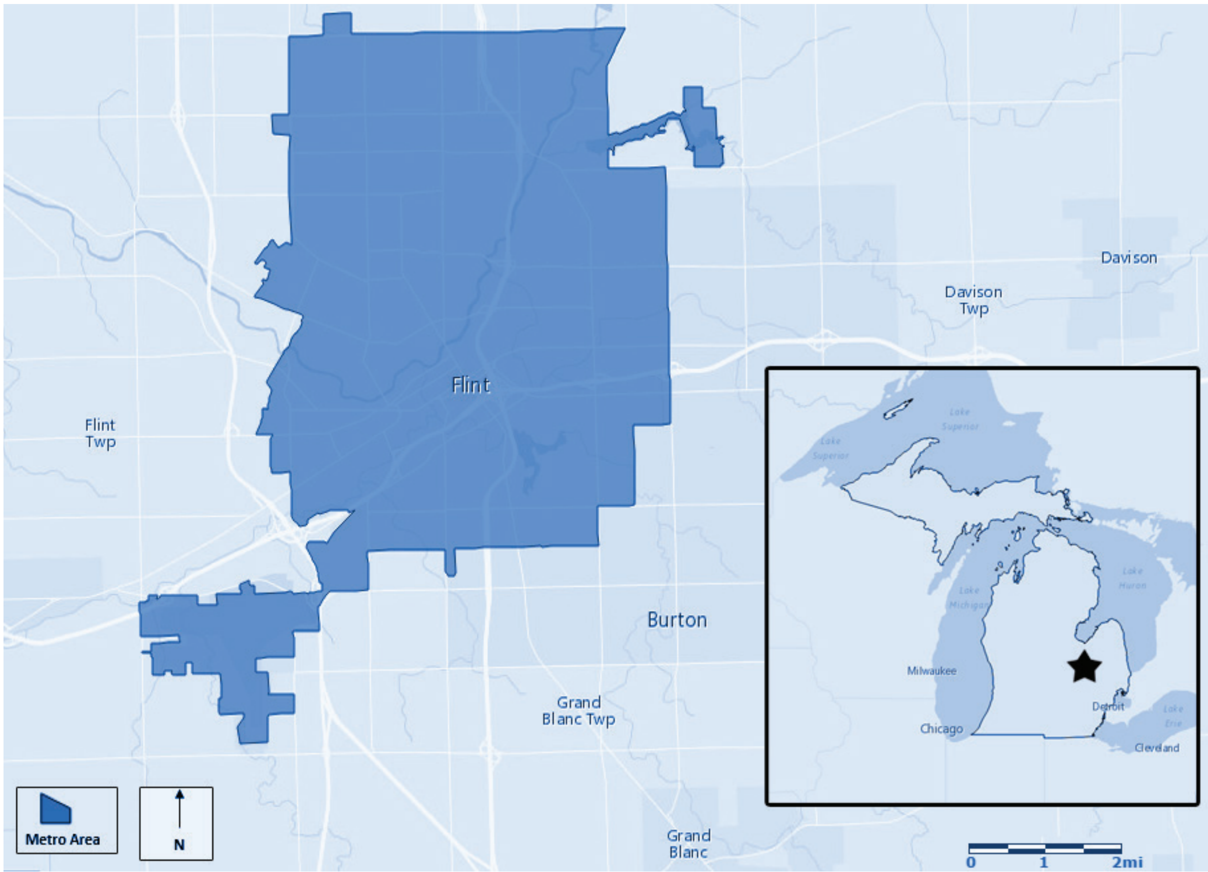

FIGURE 4-21 Map showing the city of Flint administrative boundary and location in Michigan. SOURCE: Prepared by Brent Heard, Consultant to the STS Program.

BACKGROUND

Flint was founded in 1819 as an outpost for fur trading with the local Ojibwa tribes. The town was also a stopover on the land route between Detroit and Saginaw. The village was incorporated in 1855. Flint and other towns in southern Michigan, such as Detroit, were originally prosperous agricultural communities based on the rich soils of the area. In the second half of the 19th century, exploitation of extensive old-growth forests of the region caused the lumber industry to grow in Flint, which in turn resulted in the development of a carriage-making industry. When horse-drawn transport gave way to vehicles powered by the internal combustion engine, Flint emerged as one of the most important locations for the growing auto industry. It was the birthplace of General Motors, and the founding of the United Auto Workers union grew out of the Flint Sit-Down Strike in 1936. During World War II, the city prospered as tanks and other war machines were manufactured. Up until the mid-20th century, Flint's prosperity paralleled the explosive growth of the auto industry as the United States transformed into an automobile-dominated society. Flint's economy benefited from a regional supply base that included steel mills in Pennsylvania, coal mines in Kentucky and West Virginia, and iron ore from Minnesota (Day et al., 2016).

Flint's fortunes reversed after the 1960s as a result of a number of major social and economic trends. Central to these was increasing prices of oil and the development of more fuel-efficient vehicles by the Japanese. The collapse of the U.S. auto industry and the general deindustrialization of the northeast and Midwest led to the dramatic loss of population and urban decay of the city. Employment by General Motors fell from about 80,000 in the late

TABLE 4-17 Key Characteristics for Flint

Indicator	Flint	United States
ENV Average Annual Precipitation (inches/year)	31.4	40.8
ENV Existing Tree Canopy (% of land cover)	13	25
ENV Roadway Fatalities (per 100 million annual vehicle miles traveled)	1.0	1.1
ENV Particulate Matter 2.5 (ppm)	12.2	11.9
ENV Residential Carbon Footprint (metric tons of CO_2 per capita from residential energy consumption)	not available	3.4
ECON Financial Health	no rating	AA+
ECON Average Residential Electricity Rate (cents/kWh)	13.7	11.9
SOCIAL Black or African American	20.6%	13.2%
SOCIAL Hispanic or Latino	3.2%	17.4%
SOCIAL Asian	1.1%	5.4%
SOCIAL Home Ownership (2009-2013)	70.3%	64.9%
SOCIAL High School Graduate (25 or older, 2009-2013)	89%	86%
SOCIAL Below Poverty Level	21.0%	15.4%
SOCIAL Violent Crimes (per 100,000 people)	854	191

NOTE: ENV, ECON, and SOCIAL refer to the three dimensions of sustainability: environmental, economic, and social, respectively. SOURCE: Appendix B.

1970s to less than 8,000 by 2010. Though Flint's population had exploded between 1900 and 1960—growing from 13,000 to nearly 197,000—by 2010 the population had shrunk to 102,000 (Day et al., 2016).

The economic crisis led to a series of financial emergencies and political upheavals as the city continued to decline and resulted in the state of Michigan taking over much of the city government operations. Flint now stands as a city fundamentally changed from its heyday of the 1960s. Vacant land is common because properties in residential neighborhoods have been abandoned, and blighted housing is widespread. In 2002, the Genesee County Land Bank was founded by the county treasurer Dan Kildee. The purpose of the land bank was to take charge of dilapidated and abandoned properties, making the properties available for resale or demolition. In 2009, the land bank owned 14 percent of property parcels in the city, much of which is open space (Day et al., 2016).

MAJOR SUSTAINABILITY EFFORTS

A number of the trends taking place in Flint can be viewed as movement toward sustainability, given the emerging constraints. Some of these have not been cast in the context of sustainability, but still there are lessons to be learned.

There are active plans in both Flint and Detroit to develop urban agriculture on vacant land. "Urban farms" from a few acres to several hundred acres have sprung up in both cities with vegetables, fruit trees, chickens, and eggs (Day et al., 2016). Soils in the region of Flint are characterized as Alfisols, highly fertile soils mainly formed under forest cover (Schaetzl et al., 2012). Like Cedar Rapids, Flint could feed itself from within a radius of 20 miles surrounding the city. Thus, in the face of pervasive urban decay and collapse, Rust Belt cities may be able to go a long way toward feeding themselves. This is potentially important if industrial agriculture begins to falter because of high energy prices and climate change.

Flint, as well as Detroit and other similar cities, serve as examples of both the perils and possibilities of postindustrial cities in the Midwest and elsewhere. In many ways, Flint and similar cities are on the leading edge of change that will come to most urban areas as the megatrends of the 21st century sweep across the landscape.

The City of Flint has outlined its vision of the future in *Imagine Flint—Master Plan for a Sustainable Flint* (www.imagineflint.com). The plan states that "Flint is a city poised and ready for transformation." It aims to transform Flint into a community that is economically, environmentally, and socially vibrant. It seeks to accomplish this objective by investing in the human capital of Flint's residents, improving the efficiency of the city's infrastructure, providing more support services to families, and empowering residents to improve their neighborhoods. The plan calls for civic engagement with the community, including with its youth, and says that decisions are to be based on active public participation.

The city hopes that *Imagine Flint* will result in walkable neighborhoods with green spaces and mixed-income housing; a diversified economy that encourages youth to stay in Flint and attracts new residents; and increased public safety and a reduction in crime and gun violence. The city's carbon footprint should be lowered through improved mass transit, investment in energy-efficient buildings, and attention to natural systems in the Flint River watershed. The plan also calls for developing a local food system, which is feasible because Flint is surrounded by fertile land. There are already urban farms operating on many of Flint's vacant lots, producing vegetables, fruit, eggs, and poultry meat. The vision of the program states in part: "Green, Sustainable, and Healthy are synonymous with Flint, as the City has fully embraced the notion of pioneering best practices in green industry and infrastructure, becoming a 21st Century Sustainable Community." *Imagine Flint* addresses social equity and sustainability, reshaping the economy, quality of life, and adapting to change, youth, and civic life. It includes emphases on mixed neighborhoods and neighborhood centers, energy-efficient buildings, encouraging walking and bike use, mass transit, enhance natural systems through responsible planning and development (Flint River watershed, parks and open space), reducing the city's carbon footprint, safe neighborhoods, reducing energy costs, strengthening education, reducing the number of residents with low skills, diversifying the economy, improving public safety and reducing crime, reducing gun violence, developing a local food system, expanding arts and cultural activities, and preparing a 5-year strategic plan (City of Flint, 2013).

OTHER SIGNIFICANT ACTIVITIES

Sustainability indicators for Flint are largely negative. Flint has higher particulate matter than the national average and poorer water quality. In addition and more recently, its water quality was of particular concern at the time this report was written. In order to save money, in April 2014, a temporary change in the source of the city's water supply, from Detroit-routed Lake Huron water to the Flint River, led to the leaching of lead into the water supply from the highly corrosive Flint River. This was compounded by an aging local water distribution system with a high percentage of preexisting lead pipes and plumbing. Following resident complaints, significantly elevated water lead levels and child blood lead levels were found to constitute a Safe Drinking Water Act violation. This is especially concerning given the long-term negative consequences of even low-level lead exposure for children—biologically, educationally, and psychologically—that could disadvantage any city for generations (CDC, 2012; Edwards et al., 2015; Hanna-Attisha et al., 2016).

This water crisis resulting in high lead levels is one of the most important sustainability issues facing Flint and likely many other cities with aging infrastructure. The Office of Michigan Governor Rick Snyder's Flint Water Advisory Task Force's 2016 Final Report found: "The Flint water crisis is a story of government failure, intransigence, unpreparedness, delay, inaction, and environmental injustice" (Flint Water Advisory Task Force, 2016, p. 1). The Task Force's finding, noting the role of "environmental injustice," is also reflected in a varied and growing number of other literature sources—from the *American Journal of Public Health* and the *New England Journal of Medicine* to the United Nations and beyond. For example, Hanna-Attisha et al. (2016) note, "Greater Flint's struggles have been amplified by a history of racial discrimination," while Ryder (2016) states, "the [Flint] crisis highlights the extent to which disparate vulnerabilities to risk and disproportionate impacts of hazards can become issues of environmental injustice." Similarly, a statement to the media by the United Nations Working Group of Experts on People of African Descent, on the conclusion of its official 2016 visit to the United States, noted "communities are calling for environmental justice as they are concerned that they are disproportionately exposed to environmental hazards impacting their health and standard of living" (UN Working Group of Experts on People of African Descent, 2016).

Additionally, the crisis illustrates how the legacy of Flint's governance problems, in the context of a city with very limited access to appropriate expertise, exacerbated the failure of government oversight to respond quickly to the water crisis (Rosner, 2016). Underprivileged communities have fewer resources to deal with infrastructure issues, and that impedes efforts toward urban sustainability (Flint Water Advisory Task Force, 2016). The confluence of environmental injustice and persistent governance deficiencies also compromised the deployment of engineering solutions in Flint. As Bellinger (2016) notes,"the corrosion-control treatments required by the Environmental Protection Agency's Lead and Copper Rule were, for some reason, discontinued. To make matters worse, the addition of ferric chloride to reduce the formation of trihalomethanes from organic matter increased the corrosivity of the Flint River water."[24] Scully (2016) also states, "when the City of Flint switched from Lake Huron to Flint River water, corrosion control with orthophosphate was discontinued despite the river's greater known corrosivity." Political, economic, and social conflicts are common for most of the cities treated in this report and across the nation. Neglecting these problems will impede sustainability efforts. All cities must realize the risks that they face by not prioritizing clean and reliable resources, and transparency of government actions (Konisky, 2016; UN, 2016a). There should have been close interaction among all levels of government rather than the finger pointing and attempts to assign blame. The central lesson here is that the health of city citizens is essential to sustainability as well as to the city's ability to compete for residents, businesses, and federal monies.

Flint also has high unemployment, a high crime rate, and the lowest level of college-educated persons of the cities examined in this report. The percentage of the population below the poverty line is above the national average. The income inequality ratio for city residents is low, but that may be because of the overall depressed state of the city's economy. Flint's indicators for health are low, as are its scores for public transit use and walking, but it has higher than average total good days in terms of the air quality index, scoring 178 compared to 33 for Los Angeles. Despite a high level of licensed drivers per 1,000 driving age population, Flint has a low mean travel time to work and an average yearly commuting delay in terms of hours per commuter. (Flint scores 25 hours compared to 7 for Cedar Rapids and 85 for Los Angeles.) Thus, the sustainability indicators show mixed results for Flint. They are measures of a city in transition. As discussed below, this could be the beginnings of a transition to sustainability in ways that other cities have not begun.

SUMMARY OBSERVATIONS

Flint and similar cities are widely viewed as failed urban areas in comparison with the currently more successful cities of the east coast and elsewhere. However, there are a number of factors that have the potential to make Flint a sustainable city. Climate change will be relatively benign compared to many other U.S. cities. Flint is in an area that will not suffer extreme droughts as in much of the western United States or the effects of sea-level rise and storms in coastal areas. The relatively low population means that providing for the needs of the city is less challenging than for urban areas with 10 to 100 times the population. If it developed a diversified agricultural economy, Flint would be able to easily feed itself within its local foodshed because the city exists in an ecosystem with adequate water and rich soils.

Flint's strong focus on the human capital element in the *Imagine Flint* program should help its population adjust to the changes of the 21st century. The plan's emphasis on engaging youth and supporting families may help it achieve its goals of retaining residents, improving the quality of life in the community, and reducing crime and gun violence. If it is able to repurpose and redevelop vacant spaces and increase the skill of its workforce, Flint may become an example of a postindustrial city that has put itself on a pathway to sustainability.

The Industrial Cities Initiative published by the Federal Reserve Bank of Chicago (Engle and Longworth, 2012) classified Pontiac, Michigan, as an overwhelmed city. These are cities that have relatively larger declines in manufacturing employment and relatively larger decreases in measures of well-being. In many ways, Flint is

[24] Also see Mann (2016).

like Pontiac in that it has suffered declines in manufacturing and population. How Flint and other similar "failing" cities manage the coming transition may provide examples for other cities that have not yet suffered as Flint has. A number of authors have looked at small to medium-sized cities as examples of a promising urban future. Catherine Tumber in her book *Small, Gritty, and Green* sees promise in smaller industrial cities in a resource-scarce future (Tumber, 2011). She writes about Rust Belt cities in the Northeast and Midwest (cities like Syracuse, Akron, Worcester, Buffalo, Peoria, and Youngstown), their deterioration, and growing invisibility as cities. But her book could just as well be about similar cities in other parts of the country. These cities, like many others, once had vibrant downtowns. But the forces of deindustrialization, outsourcing, and globalization led to loss of jobs, demographic changes, and poor school systems. These trends are expected to be reversed as the 21st century progresses because of emerging trends that include energy scarcity, climate change, food insecurity, and ecosystem degradation (Day et al., 2014). In terms of population, Tumber wrote about small cities in the range of 50,000 to 500,000 persons, which includes Flint (Tumber, 2011). Thus, Flint has potential to transition in sustainable directions, and a vision for such a transition has been partially articulated in the *Imagine Flint* program. Relatively benign climate impacts, a rich regional natural environment, and a low population will make achieving long-term sustainability less challenging than for much larger urban areas or cities in resource-poor regions such as arid areas.

TABLE 4-18 Example Highlighting Actions for Flint that Illustrate Steps in Urban Sustainability Roadmap (see Chapter 3, Figure 3-1)

City	Flint
Adopt Principles	P1, P2, P3, P4
Opportunities and Constraints	Opportunities: Urban farming on vacant land in the city, rich local food shed; climate change will be relatively benign. Constraints: Oil price rise in 1970 led to shifting of small car production to other area; deindustrializing Rust Belt city; high poverty and unemployment.
Prioritize Co-net Benefits	Sustainability indicators indicate both positive and negative aspects of city life in Flint. In terms of environmental indicators, Flint has higher than average particulate matter, poorer than average water quality, but has higher than average total good days in terms of the air quality index. Income inequality ratio is low.
Partnerships	The local community has been strongly involved in the development of the *Imagine Flint* plan; county land bank.
Goals	Social equity and sustainability, reshaping the economy, quality of life, adapting to change, youth, civic life.
Strategies	*Imagine Flint* (Master Plan for a Sustainable City). Flint has focused strongly on the human element in the *Imagine Flint* program.
Data Gaps	As yet, there are few specific plans for meeting the energy needs of the city from renewables.
Implementation	County land bank; urban agriculture on vacant land; open space and green neighborhoods. Mixed neighborhoods and neighborhood centers, energy efficient buildings, encourage walking and bike use, mass transit, enhance natural systems through responsible planning and development (Flint River watershed, parks, and open space), reduce the city's carbon footprint, safe neighborhoods, reduce energy costs, strengthen education, reduce number of residents with low skills, diversify the economy, improve public safety and reduce crime, reduce gun violence, develop a local food system, expand arts and cultural activities, prepare a 5-year strategic plan.
Local to Global	Flint and similar cities may be a harbinger and example of how cities can survive through the 21st century. It has already begun a transition that many other cities will likely have to go through. An example of how small cities can adapt.
Public Buy-in	The public has been involved in the development of sustainability plans for the city.
Feedback	—

SYNTHESIS

The sustainability actions undertaken in the metropolitan regions the committee selected exemplify, in specific urban contexts, the four urban sustainability principles and illustrate committee's urban sustainability "roadmap" (see Figures S-1 and 3-1). The selected urban areas cover a broad spectrum of population size, population density, geographical location, availability of local resources, and historic conditions that play a key role in the sustainability challenges and opportunity solutions faced by each one of them. Nine cities were selected—Los Angeles, California; New York City, New York; Cedar Rapids, Iowa; Flint, Michigan; Pittsburgh, Pennsylvania; Grand Rapids, Michigan; Vancouver, Canada; Chattanooga, Tennessee; and Philadelphia, Pennsylvania—to represent a variety of urban regions, with consideration given to city size, proximity to coastal and other waterways, susceptibility to hazards, primary industry, water scarcity, energy intensity and reliability, vertical density, transportation systems, and social equity issues.

Each of the nine cities incorporates urban sustainability metrics and indicators through its approaches to unique and shared sustainability challenges. The set of indicators chosen by this committee is, in varying degrees and contexts, highlighted in most of the major sustainability efforts undertaken by each city, most visibly reflected in local climate, energy, and water plans.

The varied sustainability challenges, opportunities, and solutions experienced by each of these urban areas concretely illustrate the four guiding principles outlined in Chapter 3. Many challenges, most visibly those associated with resource use, capacity, degradation, energy, climate change impacts, and so forth, embody Principle 1, which states that the planet has biophysical limits. Moreover, sustainability challenges are, by nature, highly interconnected, spanning all three dimensions of sustainability, thus requiring interconnected, multifrontal solutions. All of the cities examined have developed comprehensive sustainability plans and initiatives that reflect their diverse urban contexts and challenges, thus delineating the core tenets of Principle 2: human and natural systems are tightly intertwined and come together in cities. In addition, many of these cities experience and continue to struggle with social issues of poverty and inequity, reflective of Principle 3: urban inequality undermines sustainability efforts. Furthermore, the numerous examples of associated challenges, solutions, similarities, their connectivity to their regions and broader geographic areas, and lessons both shared and unique to these cities and urban areas exemplify the principle that all cities are highly interconnected (Principle 4). Moreover, a summary table provided at the end of each of the nine city profiles links the city's specific urban contexts to each step in the aforementioned urban sustainability "roadmap" (see Figures S-1 and 3-1).

The cities with the largest and most diverse populations, New York City and Los Angeles, demonstrated the longest history of implementing sustainability measures in the face of a large reliance on imported resources and big challenges in reducing social inequities and eradicating poverty. These challenges have driven both cities to develop aggressive sustainability plans, with specific targets and outcomes that rely on fruitful collaborations across municipal departments and institutions rather than top-down approaches. Though both cities have tried to heavily invest in public transportation infrastructure, the fundamental differences in the physical layout have driven the cities into distinctly different investment strategies: highways in Los Angeles versus trains and subways in New York. While both cities have made significant progress through a combination of regulation, technological advancement, cross-cutting collaboration, and aggressive policy changes, Los Angeles and New York face continual challenges in meeting their resource needs and the targets they have set for clean water, renewable energy resources, waste management, and GHG emissions reductions. For example, both cities rely on remote water sourcing strategies to supply water to their populations; however, New York City's innovative ecosystem services–based strategy and land stewardship approach in the Catskills starkly contrasts the importation approach, and associated issues of water rights, used by Los Angeles in the Owens River Valley. Organizations within the cities and their regions, in many cases, have formed working groups among the responsible organizations to target these problems. However, neither one has fully factored into its sustainability plan the substantial impact that the demand of resources needed to run a large city has on the regions that supply those resources.

The city of Vancouver has seen a very unique progress in sustainability. In part an outcome of its location, history, and government, Vancouver has enjoyed a convergence of efforts and results over many years so that the Economist Intelligence Unit placed Vancouver among the top five "greenest cities" in its Green Cities Index. It has also ranked Vancouver in the top three of its annual "Global Liveability Ranking" every year since 2010, among other similar distinctions. Vancouver's Greenest City story provides useful lessons to other municipalities, both at the micro level (through its successful delivery) and at the macro level. It is a success story that is transferable across international borders. Though much has been accomplished, the City of Vancouver recognizes that there is much work still to do to be a truly sustainable city. In March 2015, the Vancouver Council upped the ante, unanimously passing a motion to be a city that runs completely on renewable energy by 2050, with the objective of reducing GHG emissions as well as dependence on imported energy.

While such progress is positive and exciting, it also brings reason for caution. Vancouver's residents are challenged by the amount and rate of change that they have been asked to absorb in pursuit of the Greenest City Goals. While each individual change was made to support residents' desire to live in a more sustainable city, the collective impact of all of these initiatives requires a significant amount of behavior change from residents and this has proved to be difficult for some. Other cities can learn from Vancouver's experience by carefully monitoring residents' response to change (both while planning and implementing green initiatives) and by course-correcting as needed.

Philadelphia and Pittsburgh are prime examples of cities that have aggressively pursued diversification of their economies, with variable success. They both pursued innovative collaborations with municipalities, nonprofits, and various public-private partnerships. Although both cities thoroughly capitalize on their economic assets, continued efforts are needed to further sustainable growth for the cities and their regions. In terms of barriers, there are many areas in which the cities would like to make a bigger impact, but their efforts are hindered by policies at the state and national levels.

Each of the smaller cities in population size and density—Chattanooga, Grand Rapids, Cedar Rapids, and Flint—has experienced a different path to sustainability and at present has succeeded differentially toward its intended goals. Among them, Chattanooga is an example of a city that had to work very hard to succeed. Its designation as the "dirtiest city in America" in 1969 became a catalyst for a sea of change. The air quality benchmarking by the EPA motivated the city to go beyond incremental improvements to dramatically turn itself around. Without such a "wake-up" call, it is not clear that Chattanooga would have become the hub of sustainable growth that it is today. Grand Rapids started on the path to sustainability later and is now developing a multifrontal approach to economic, social, and environmental resilience. Grand Rapids is fortunate to have abundant water access with the Grand River. While working on a number of sustainability fronts, the city wants to ensure that this important natural resource is available to future generations.

The most significant message for urban sustainability to come from this analysis of Cedar Rapids is the importance of the current status and setting of a city. It has a highly educated and affluent population without the extremes of income and wealth inequality that exist in cities like New York and Los Angeles. Cedar Rapids seems to have a strong work ethic and a high level of tolerance to adverse developments as well as a low level of crime compared to other cities, so public safety is an important element of sustainability. At the same time, the city is not as diverse as the large metropolitan areas, and it has a limited built-in resilience. The megatrends of the 21st century will pose challenges for all cities, but Cedar Rapids will have a less difficult time meeting these challenges than many other cities due to its unique economic, social, and environmental construct. The city of Cedar Rapids is a phenomenon difficult to reproduce in a world characterized by massive urbanization. However, in the longer term, as the megatrends of the 21st century roll over society, an important recommendation is that cities develop and enhance basic economic activities that are nondiscretionary such as food production and processing—activities that could boost economic growth and improve regional wealth, which are important characteristics of urban sustainability.

Flint is widely viewed as a failed urban area in comparison with the currently more successful cities of the East Coast and elsewhere. Flint has lost about half of its population since 1960. However, there is a considerable amount of green space within the city that could be devoted to urban agriculture. There is also abundant farmland with fertile soils in the part of the state north of Flint where population density is low, so Flint could feed itself largely from its local foodshed. How Flint and other similar "failing" cities manage the coming transition may provide examples for other cities that have not yet suffered as Flint has. While Flint cannot do much to affect climate change or the larger energy supply system, it can work with the local population to adjust to the changes of the 21st century.

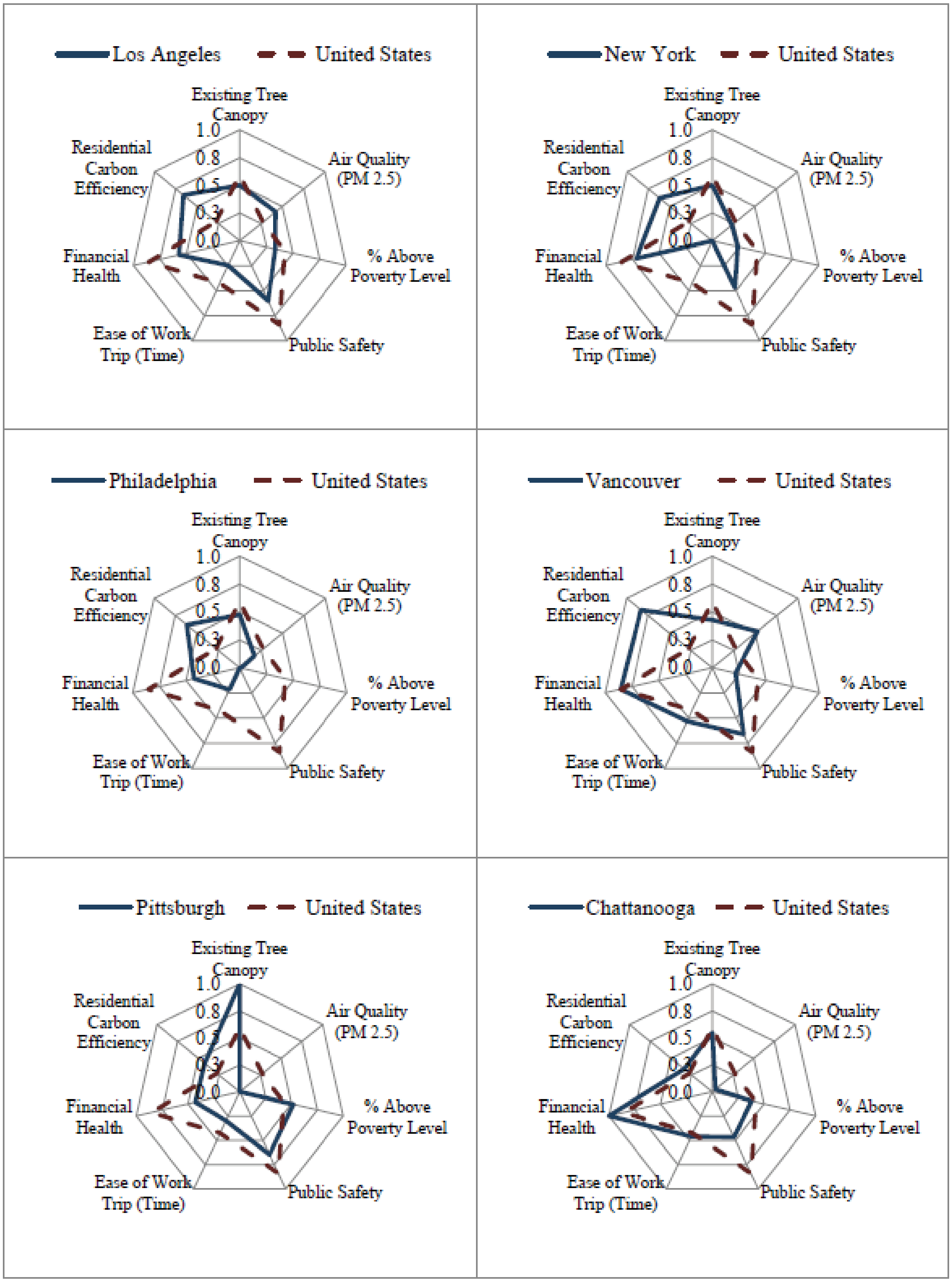

FIGURE 4-22 Spider charts comparing the nine profile cities across various metrics. SOURCE: Committee generated.

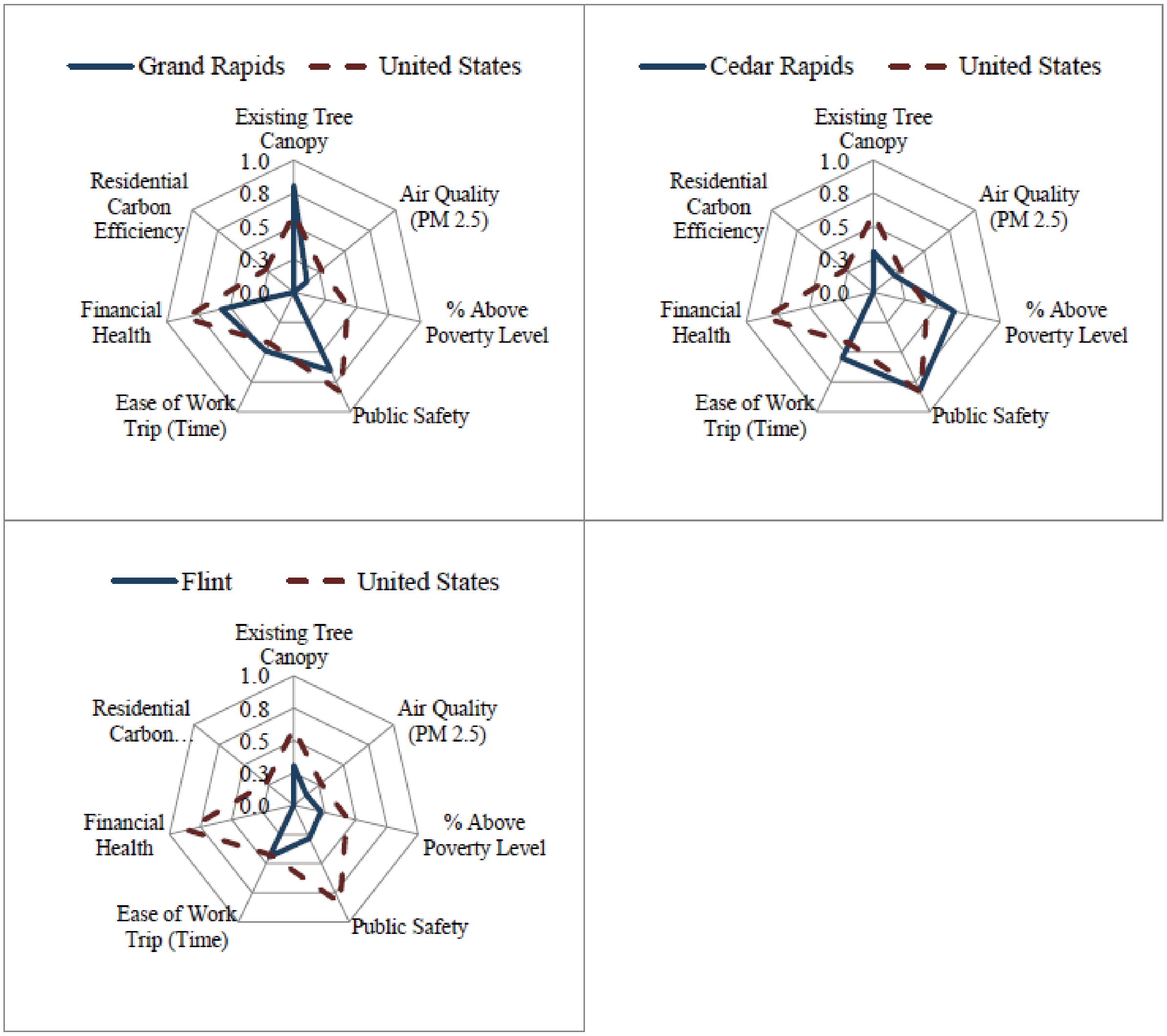

FIGURE 4-22 Continued.

To provide a comparative snapshot of the nine cities assessed in the study, the spider charts (Figure 4-22) were created using the metrics data supplied in Tables 4-1, 4-3, 4-5, 4-7, 4-9, 4-11, 4-13, 4-15, and 4-17, with the convention being the larger the spider web, the more sustainable the city. These charts are not meant to provide a definitive determination as to whether a city qualifies as sustainable, but rather to provide an illustration as to how metropolitan areas varied as compared to the national average. In the event that a high value for a metric was contradictory to sustainability (e.g., high $PM_{2.5}$, percentage below poverty, violent crime rate, average commute time to work, and residential carbon footprint), then the additive inverse was used for that value. For example, the value for percentage below poverty for Los Angeles is 17.8 percent, with the national average being 15.4 percent; since a high percentage below poverty value implies a negative correlation with sustainability, the calculated value for the chart is [1 – (17.8/15.4)] to obtain a measurement that would correspond positively to sustainability. Such measures were also renamed in the charts to reflect this positive correlation (air quality, % above poverty, public safety, ease of work trip, and residential carbon efficiency). For each of the seven metrics selected, the highest value across the cities and the United States was chosen as the maximum value in the range. Therefore, the values of the cities were divided by the U.S. average to create the numbers shown on the chart. The result is an overall maximum value of 1.00 and a minimum value of 0.00; thus, the axis measurements of the spider charts range from 0.0 to 1.0 to best illustrate this range of values. Inasmuch as the spider charts below represent static snapshots, the report does not overly rely on statistical methods. A temporal analysis of urban sustainability trends might ultimately strengthen the findings herein, but given the committee's resource and time constraints, this too must be subject to future inquiry and research.

5

A Path Forward: Findings and Recommendations

The committee has developed the following set of findings and recommendations based on its review and synthesis of the information gathered during the course of this study. This set of findings and recommendations has been drawn from specific city profiles, which can be found in Chapter 4, and is meant to encompass the nature of both the urban sustainability principles and the committee's urban sustainability roadmap. These findings and recommendations can guide academics, practitioners, policy makers, civil society, corporate leaders, and other stakeholders engaged in metropolitan regions to achieve greater sustainability and, by extension, greater global sustainability. The committee recognizes that local governments vary in their configurations, leadership structures, and offices; thus, for the purposes of this report, the following text addresses cities generally and sustainability coordinators in particular as the actors for these recommendations.

FINDINGS AND RECOMMENDATIONS

Global Constraints and Co-dependencies

***Finding 1*: The sustainable city exists within the larger contexts of the planet's finite resources and the city's linkages with other cities and regions, in addition to the region within which it exists.**

Achieving urban sustainability requires recognizing interconnections among places and the associated impacts of actions. Each of the cities investigated for this report is located within or adjacent to regions upon which they depend for resources and, in turn, provide resources. Los Angeles obtains water several hundred miles away with almost two-thirds of its supply originating from outside of its region. Similarly, air pollutants originating in the City of Los Angeles impact cities and counties downwind such as Riverside and San Bernardino; thus, air quality issues in Los Angeles are best considered at the basin scale rather than only the city or county. Alternatively, other cities such as Cedar Rapids, located in landscapes rich in water and other resources, supply food staples to other regions and communities. In Vancouver, Canada, residents' recognition of the value of Vancouver's natural surroundings prompted actions by the city to protect these valuable assets, such as designating local wild spaces as parks and encouraging extractive industries to move elsewhere.

In order to put local sustainability plans into a global context, understanding must be developed about the extent to which local sustainability programs can contribute to—or might in fact impede—global solutions (see Day et al., 2014; Liu et al., 2015; UNEP, 2012). This will require deeper comprehension of the nature and functioning of linkages among cities and of the positive and negative impacts of interplace interactions on the places of origin and destination for the flows of goods, services, and information. Also required is a complete and honest accounting of the urban metabolism—stocks and flows of materials, energy, and information—of cities. Cities such as Los Angeles, where sustainability policy making has a local to national orientation; Cedar Rapids, where policies are oriented toward supporting sustainability beyond its environs; and Vancouver, where municipal planning has made the city a model for the practice in other metropolitan areas globally provide valuable examples of linking urban footprints beyond the confines of administrative or municipal boundaries.

***Recommendation 1*: Actions in support of sustainability in one geographic area should not be taken at the expense of the sustainability of another. Cities should implement local sustainability plans and decision making that have a larger scope than the confines of the city or region.**

Importance of Incorporating Cross-scale Processes

***Finding 2*: Strategies implemented at a single scale or sector are often ineffective because they are not coupled to other relevant scales and sectors.**

The biophysical, economic, and social processes that define urban sustainability take place at multiple geographic scales ranging from the housing unit to the globe. Sustainability planning actions targeted at one spatial scale are likely to have impacts at other scales; urban planners and policy makers need to identify the linkages among the different spatial scales relevant to particular sustainability processes and integrate planning and strategies across scales to ensure policy effectiveness.

Linkages among the worldwide network of cities, as well as linkages through the vertical cooperation among partners in specific places, are salient. These linkages can provide needed connections to translate local engagement into state or national actions. Sustainability actions are likely to be most effective when they integrate across different geographical and governance scales and across the social, environmental, and economic dimensions of sustainability. In Chattanooga, the genesis of sustainability planning came from "[inviting] the whole community to bring their ideas to the discussion about the future of [the city]," resulting in increased recognition of these important cross-scale processes (Lerner, 1998). For example, the climate action strategies aimed at greenhouse gas (GHG) emissions reduction included coal-to-gas conversion through partnerships at the regional level between the municipal power utility and the regional power utility, and at the local level, incentivized residents to invest in green electric power, achieving economic, environmental, and social benefits across all scales. In addition, municipal sustainability planners and urban leaders in Vancouver have been recognized for successfully integrating their activities across geographic scales (EIU, 2011). A number of initiatives under the city's Greenest City Action Plan span spatial and administrative scales, from the block and community levels to district and regional levels.

***Recommendation 2*: Urban leaders and planners should integrate sustainability policies and strategies across spatial and administrative scales, from block and neighborhood to city, region, state, and nation, to ensure the effectiveness of urban sustainability actions.**

Cross-cutting Challenges, Solutions, and Co-benefits

***Finding 3*: Many urban sustainability challenges cut across more than one dimension of sustainability. Sustainability policies, designed to simultaneously address problems along different dimensions, can yield co-benefits for two or all three sustainability dimensions while considering tradeoffs.**

As illustrated in the Chattanooga example of GHG emissions reduction strategies, policies and actions that support one dimension of sustainability can also enhance other dimensions. For example, increased safety in a neighborhood typically leads to increased commerce. These types of co-benefits can justify expenditures in one area because of the value or return on investment across multiple dimensions. However, if improvements are repeatedly confined to the same two dimensions, they may not have the longer-term durability needed. Environmental and economic performance can improve in spite of lingering social inequities, but ultimately those inequities need to be diminished to ensure long-term sustainability. Chattanooga's air pollution reduction policies and innovative "gigabit city" concept promote sustainability across multiple dimensions and have led to substantive quality-of-life improvements and the attraction of young entrepreneurs from across the globe, yet serious social inequities remain (Hundt et al., 2009). In Philadelphia, the city's water department has become a nationally recognized innovator in stormwater management through the use of Green Stormwater Infrastructure installations throughout the city, resulting in more green spaces and tree canopy cover and associated social benefits of recreation spaces (Kondo et al., 2015). The city has also, through a public-private partnership, acquired and greened around 5,000 vacant lots, the equivalent of over 200 acres of land, resulting in largely beneficial impacts across sustainability dimensions in entire neighborhoods.

> ***Recommendation 3*: Urban leaders and planners should implement sustainability policies and programs that identify and establish processes for promoting synergies among environmental, economic, and social policies that produce co-benefits across more than one dimension of sustainability.**

Shared versus Unique Challenges

> ***Finding 4*: All cities share certain sustainability challenges though the severity of these shared challenges varies from place to place. Each city's pathway to sustainability will likely include components common to other urban areas, components that are shared, and components unique to that city.**

Commonalities and uniqueness are reflected in the cities covered in this report. For example, severe water challenges exist in many different forms; shortages and droughts have been keenly felt and partially addressed by Los Angeles, prompting water usage reductions, while Flint has experienced severe drinking water quality problems, when disconnection from a municipal water source and shift to a river source yielded corrosive water. In contrast, New York City generally has an abundant high-quality water supply, though short-duration droughts occur periodically. An excess of water during storm-related flooding and flash flooding has been experienced by many cities and is expected to continue in the face of anticipated extreme weather events and climate change. Additionally, practically all of the cities share vulnerabilities to climate change, but the degree and type of vulnerability varies greatly (e.g., drought for Los Angeles and sea-level rise for New York City).

Housing costs also highlight variability across cities. Insufficient affordable housing, a growing population, and high poverty rates contribute to the housing dilemma and homelessness crisis in Los Angeles. Vancouver, a city with a comparatively high median household income, has also faced issues of housing cost, as land and housing scarcity have driven up housing prices, making the city unaffordable for young families. The high cost of housing is less prominent in Pittsburgh and Grand Rapids.

Beyond these examples, such challenges and variations are shared across cities globally. Solutions and best practices in all three dimensions of sustainability can flow to U.S. cities from other examples nationally, as well as internationally—from other parts of the Global South and Global North beyond the United States, despite local variations on shared issues. In Los Angeles, New York City, and Vancouver, sustainability managers and planners in each city actively participate in regional to global networks of similarly minded planners, in order to draw upon relevant experiences and lessons (successful and otherwise). All three cities participate in C40, an elite international group of the most environmentally progressive cities. Vancouver is also a member of the Carbon Neutral Cities Alliance, a cohort of 17 international cities with the most aggressive environmental goals.

***Recommendation 4*: Urban leaders and planners should look to cities with similar economic, environmental, social, and political contexts to understand and adapt sustainability strategies that have proven to provide measurable impact.**

The Key Role of Science

***Finding 5*: Science-based solutions that are successful locally can provide useful information to other urban areas around the world.**

Sharing among cities requires evidence, and science can aid in the sharing process through establishment of scientific generalizability. Consistent and objective science input is needed to distinguish programs with merely anecdotal credibility from those that have demonstrated impact and results.

Urban sustainability practitioners take two kinds of actions: those that are driven by science and make measurable progress toward sustainability goals, and those that are visible and intended to motivate the community. For example, urban farming has anecdotal credibility, but little solid evidence that it creates benefits; in fact, it may even have negative components, i.e., risks related to irrigation of food crops with urban wastewater and the use of fertilizers and pesticides (Stewart et al., 2013; van Veenhuizen, 2006). It does, however, have community development co-benefits (see Recommendation 3) that may justify urban farming programs.

Alternatively, the case of Grand Rapids demonstrates how actions driven by science can make concrete contributions to urban sustainability goals. The city's first sustainability plan was developed using indicators and specific targets guided by research and data, and further expanded upon in the establishment of baselines for future outcomes assessment through data collection on sustainability measures (Liobimtseva, 2013; Western Michigan Environmental Action Council, 2013).

***Recommendation 5*: Urban leaders and planners should gather scientific input to the maximum extent available in the form of metrics on social, health, environmental, and economic dimensions of sustainability; data related to policies, programs, and implementation processes; and measures of community involvement.**

Partnerships for Sustainability

***Finding 6*: Key pathways to urban sustainability include institutional and sectoral collaborations across stakeholder groups, sustained citizen engagement, effective leadership, and long-term commitment to the issue.**

Public-private partnerships have been shown to be effective in generating and implementing changes that improve environmental, economic, and overall quality-of-life indicators. Of the cities investigated for this report, no durable sustainability initiatives were observed that did not include some form of partnering. The Long Beach Aquarium has an extensive list of local, state, and national partners on a variety of projects and endeavors, while Grand Rapids and Chattanooga receive broad-based community support, in both cases through the partnership of business leadership with local government and citizen engagement to facilitate comprehensive sustainability approaches, e.g., the Grand Rapids Area Community Sustainability Partnership and Chattanooga's Vision 2000 (Hundt et al., 2009; Price, 2011). Universities, national laboratories, foundations, and other independent third-party institutions can act as conveners and mediators to move communities toward sustainability. In addition, successful cities have formed an inner-city sustainability council with representation of key city stakeholders, in addition to engaging with external stakeholders.

***Recommendation 6*: Cities should ensure broad stakeholder engagement in developing and implementing sustainability actions with all relevant constituencies, including nontraditional partners.**

Durable and Dynamic Sustainability Planning

***Finding 7*: Cities that have developed a cohesive sustainability plan with dedicated funding and measurable objectives improve their chance of making substantial progress toward sustainability.**

One of the initial mechanisms for sustainability is the production of a citywide sustainability plan used to coordinate interdepartmental actions (see Box 5-1). All nine of the cities included in this report have sustainability plans backed by some kind of funding mechanism and a process for revision and updating. However, the vast majority of urban areas do not have sustainability officers, written sustainability plans, or the dedicated funding and capacity to revise and update those plans periodically in light of changing environmental, social, and economic conditions. For instance, the Urban Sustainability Directors Network, a peer-to-peer network of local government professionals from cities across the United States and Canada, has over 135 members representing cities and counties. Other notable networks include the Mayors National Climate Action Agenda, a nationwide coalition of mayors of 28 cities on climate change, and C40, an elite international group of the most environmentally progressive cities. However, according to the U.S. Census Bureau, the United States has over 19,354 "incorporated places" (U.S. Census Bureau, 2012). Many sustainability elements, however, are contained within comprehensive, sector-specific, or subarea plans, such as those devoted to energy, climate, and transportation. Though they lack the breadth of sustainability plans, they contain and contribute important elements for sustainability planning.

To be successful, cities will need durable, long-standing sustainability leadership structures written prominently into their operating budgets and plans and, where possible, voted into perpetuity by their citizens.

It is important to note that the mere presence of a sustainability plan does not equate to sustainability, nor does it necessarily signify the successful transition of a city to a sustainability agenda. Also, the presence of a plan assumes the capacity for implementation, which is not the case in all urban areas. A sustainability plan should rather be viewed as a set of intentional actions selected by a city and a community, and as an essential first step in the process.

***Recommendation 7*: Every city should develop a cohesive sustainability plan that acknowledges the unique characteristics of the city and its connections to global processes while supporting mechanisms for periodic updates to take account of significant changes in prevailing environmental, social, and economic conditions. Sustainability plans should strive to have measureable characteristics that enable tracking and assessment of progress, minimally along environmental, social, and economic lines.**

BOX 5-1
Sustainability Plans for the Profile Cities

Los Angeles: GreenLA, Climate LA, Sustainability pLAn
New York City: PlaNYC, OneNewYork, New York Panel on Climate Change
Vancouver: Greenest City 2020 Action Plan
Philadelphia: Greenworks Plans
Pittsburgh: Pittsburgh Climate Action Plan Version 2.0
Chattanooga: The Chattanooga Climate Action Plan
Grand Rapids: City of Grand Rapids Sustainability Plan
Cedar Rapids: iGreenCR
Flint: *Imagine Flint*—Master Plan for a Sustainable Flint

Improving Opportunities, Outcomes, and Quality of Life for All

> ***Finding 8*: Reducing inequalities promotes well-being along economic and environmental dimensions, as well as the social dimension of sustainability.**

Vulnerable populations are disproportionately affected by extreme weather events and by human-made challenges such as historic and contemporary discrimination, and lack of access to jobs, housing, public goods, and services. Addressing these issues results in improved quality of life for all. The opportunity to improve quality of life broadly throughout a city by reducing inequality is a fundamental, but often overlooked, aspect of sustainability planning. Addressing these issues reinforces the linkages across sustainability dimensions and the co-benefits associated with a triple-bottom-line approach.

Much of the impact of inequality falls on the elderly and children. Underprivileged populations are often more vulnerable than others to natural and human-made disasters. As a result, reducing inequality can improve the resilience of communities to both natural and economic disasters. The committee recognizes that inequality will not be completely eliminated; nevertheless, a focus on reducing inequality is a worthy goal and can produce useful co-benefits.

As noted in Recommendation 3, social inequities are often exacerbated by changing environmental and economic conditions. In recognition of this, New York City's plan, One New York, has combined equity with environment and resilience. This provides a broader definition of inequity, suggesting new ways for defining poverty and adding new meaning and purpose to services provided to low-income people, such as New York City's affordable housing program. More broadly, Philadelphia, Los Angeles, and New York City all provide examples wherein sustainability planning combines equity, environmental, and resilience policies (City of Los Angeles, 2007; NYC Office of the Mayor, 2015a; Philadelphia Managing Director's Office, 2015).

> ***Recommendation 8*: Sustainability plans and actions should include policies to reduce inequality. It is critical that community members from across the economic, social, and institutional spectrums be included in identifying, designing, and implementing urban sustainability actions.**

The Importance of Benchmarks and Thresholds

> ***Finding 9*: An extensive review of indicators undertaken in this report found very few accepted standards and benchmarks for sustainability assessment among the indicators that were reviewed. Those with specific thresholds were primarily traditional air and water quality standards.**

A large share of urban sustainability literature argues that metrics are valuable inasmuch as they help understand and reveal "the state or trend of certain environmental or societal conditions over a given area and a specified period of time" (EPA, 2014a). Accurate data are essential to building sustainability indicators with threshold targets and outcomes. No longer can urban areas depend on hunches or low-level impact actions to make progress toward sustainability. Cities should avoid choosing metrics based on the ease with which a city can make progress in a particular area. Most practitioners do not need another rating system and existing standard indicators should be adopted to the maximum extent possible and as appropriate for the particular characteristics of the urban area (Wilbanks and Fernandez, 2012).

There are many rating systems, but none is commonly accepted, and these systems must continue to evolve in order to be more useful to practitioners. Existing metrics are not common, cannot be shared, and have been developed at different scales. Many existing metrics have weak scientific underpinnings and additional research is needed to assess the relevance and applicability of these indicators. Reaching scientific consensus on indicators is a grand challenge of urban sustainability and worthy of attention. Every indicator must then be connected to both an implementation and an impact statement to garner more support, and engage the public in the process.

Most urban areas lack climate change information at a scale and in a format that is relevant to their region and useful to urban policy makers and community stakeholders. Of the city sustainability plans investigated for this report, few contained regional climate information, suggesting that this information either does not exist or is not easily discoverable and usable. Similarly, most urban areas do not have established and funded mechanisms for updating and revising sustainability plans to reflect changes in climate-related conditions.

> ***Recommendation 9*: Cities should adopt comprehensive sustainability metrics that are firmly underpinned by research. These metrics should be connected to implementation, impact, and cost analyses to ensure efficiency, impact, and stakeholder engagement.**

The Urgency in Sustainability

> ***Finding 10*: While the committee has uncovered numerous successful examples of urban sustainability in a variety of cities, the pace and scope of these actions do not appear to be sufficient to meet urgent global challenges, such as climate change impacts, geophysical events, energy scarcity, increasing population inequalities, health threats, and the increasingly negative consequences of these conditions.**

This is a call to action. All three dimensions of sustainability hold serious challenges for urban, regional, and global sustainability. The ongoing long-term drought in Los Angeles and the associated scarcity of both water and energy supplies (due to the energy requirements to transport long-distance water supplies) are prime examples of the challenge of global environmental constraints. Social and economic issues abound across regions and cities. High rates of poverty, housing affordability, unemployment among young and older workers, outmigration of the middle class, the decline of traditional manufacturing industries, and decreased federal spending highlight the challenges facing urban areas. These challenges are exemplified in extreme disparities in socioeconomic status in Philadelphia, outmigration due to deindustrialization in Flint, the loss of the middle class in Pittsburgh due to the decline of the steel industry, as well as single industry collapses in Flint (the auto industry) and Chattanooga (manufacturing) (Bonham and Smith, 2008; Graham, 2015; Greenhouse, 2014).

There are also opportunities to make progress. There is currently a window of opportunity in the form of infrastructure replacement needs throughout the United States, and the integration of risk management and adaptation concepts into suitably designed approaches to addressing these infrastructure problems can yield significant progress toward sustainability.

> ***Recommendation 10*: Urban leaders and planners should be cognizant of the rapid pace of factors working against sustainability and should prioritize sustainability initiatives with an appropriate sense of urgency to yield significant progress toward urban sustainability.**

CONCLUSION

An increasing percentage of the world's population and economic activities are concentrated in urban areas; therefore, cities are central to any discussion of sustainable development. While urban areas can be centers for social and economic mobility, they can also be places associated with significant inequality, debility, and environmental degradation: a large proportion of the world's population with unmet needs lives in urban areas. Those needs must be met while bearing in mind global constraints. There is no single approach to urban sustainability. However, it is valuable to assess practices being implemented in specific urban and metropolitan regions to determine whether and how they might be adapted and applied in other urban areas. Simultaneous action across multiple dimensions can accelerate the pace and depth of on-the-ground transformations. America's urban population is expected to increase by 15 percent by 2030. Much-needed investments in our existing infrastructure, in addition to the need to build more urban space for a growing urban population, indicate an urgent need to design and plan for new, as well as existing, cities.

This study provides a paradigm (the urban sustainability roadmap) that incorporates the social, economic, and environmental systems existing in urban areas that are critical in the transition to sustainable metropolitan regions. This roadmap can serve as a starting point for discussion among academics, practitioners, policy makers, civil society, and other stakeholders on how metropolitan areas can transition to sustainability. There are a large number of metrics and indicator systems spanning a variety of spatial scales, and these can be useful when tailored to particular cities and when geared toward four key principles: the planet has biophysical limits, human and natural systems are tightly intertwined and come together in cities, urban inequality undermines sustainability efforts, and cities are highly interconnected. Research and development on the flows between people and places, network characterization, urban metabolism, types of data, and decision-making processes that link across scales can yield further advancements toward sustainability. Similarly, there is a great need for cross-sectoral and multiscale policies and for science-driven approaches, as well as scientifically grounded indicators and metrics for assessment and benchmarking.

What the city profiles collectively show is that there are opportunities for meaningful change that improve the lives, economy, and environment of all types of cities. Constructing a vision is crucial, as is public buy-in and community engagement. We have seen numerous and varied change across all the city profiles—polluted cities transform themselves into green, vibrant places, and cities with failing industries can diversify their economies. Furthermore, managing tradeoffs among the three dimensions of sustainability while aiming to maximize total net benefits relative to costs is an integral part of the sustainability process. While there is no single way to becoming more sustainable, many strategies and successful examples exist that provide valuable lessons from which cities can learn.

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Appendix A

Committee on Pathways to Urban Sustainability: Challenges and Opportunities Biographical Information

LINDA P.B. KATEHI (*Chair*) (NAE) is chancellor emerita of the University of California, Davis. Previously, she served as provost and vice chancellor for academic affairs at the University of Illinois at Urbana-Champaign; the John Edwardson Dean of Engineering and professor of electrical and computer engineering at Purdue University; and associate dean for academic affairs and graduate education in the College of Engineering and professor of electrical engineering and computer science at the University of Michigan. Dr. Katehi led the effort to establish the Purdue School of Engineering Education, the first department at a U.S. university focused explicitly on engineering education, particularly on K-12 engineering curricula, standards, and teacher education. The author or co-author of 10 book chapters, she has published more than 600 articles in refereed journals and symposia proceedings and owns 16 patents. She is a member of the National Academy of Engineering (NAE), a fellow and board member of the American Association for the Advancement of Science, chair of the Nominations Committees for the National Medal of Science and National Medal of Technology and Innovation, and a member of the Kauffman National Panel for Entrepreneurship. She is currently a member of a number of NAE/National Academy of Sciences committees and the Advisory Committee for Harvard Radcliffe College and a member of the Engineering Advisory Committees for Caltech, the University of Washington, and the University of California, Los Angeles (UCLA). She earned her bachelor's degree in electrical engineering from the National Technical University of Athens, Greece, in 1977, and her master's and doctoral degrees in electrical engineering from UCLA in 1981 and 1984, respectively.

CHARLES BRANAS is a professor of epidemiology at the University of Pennsylvania Perelman School of Medicine. Dr. Branas works to improve health and health care and is especially recognized for his efforts to reduce violence and enhance emergency care. Much of his work incorporates human geography and place-based change. He has authored or co-authored over 150 publications, including the recent book *Changing Places: Using Science to Design a Better World*. His scientific studies have been replicated nationally and in cities across the United States and other countries. Dr. Branas has served on boards and offered scientific expertise for numerous groups, including the National Institutes of Health, the Centers for Disease Control and Prevention, and the National Academies, as well as scientific organizations in Canada, Greece, Guatemala, New Zealand, the Netherlands, and South Africa. His work has been cited by the U.S. Supreme Court and Congress. He is a past president of the Society for Advancement of Violence and Injury Research, and an elected member of the American Epidemiological Society. Dr. Branas received his B.A. in mathematics from Franklin and Marshall College (1990), his M.S. from

Drexel University (1993), and his Ph.D. from the Johns Hopkins Bloomberg School of Public Health (1998), and he completed a postdoctoral fellowship at the University California, Berkeley School of Public Health (2000).

MARILYN A. BROWN is the Brook Byers Professor of Sustainable Systems in the Georgia Institute of Technology's School of Public Policy. Previously she held leadership positions at Oak Ridge National Laboratory and is a Presidential appointee to the board of directors of the Tennessee Valley Authority. She has authored more than 250 publications and four books, including *Green Savings: How Policies and Markets Drive Energy Efficiency* and *Climate Change and Global Energy Security*. Her research focuses on the design and impact of policies aimed at accelerating the development and deployment of sustainable energy technologies, with an emphasis on the electric utility industry, climate adaptation, and the integration of energy efficiency, demand response, and solar resources. Among her honors and awards, she is a co-recipient of the 2007 Nobel Peace Prize for co-authorship of the report on Mitigation of Climate Change, she has served on six committees of the National Academies of Sciences, and she currently serves on the U.S. Department of Energy's Electricity Advisory Committee. Dr. Brown has a B.A. in political science from Rutgers University, a M.R.P. in regional planning from the University of Massachusetts, and a Ph.D. in geography from the Ohio State University.

JOHN W. DAY, JR., is Distinguished Professor Emeritus in the Department of Oceanography and Coastal Sciences at Louisiana State University, where he has taught since 1971. He has published extensively on the ecology and management of coastal and wetland ecosystems and has over 200 peer-reviewed publications. He has conducted extensive research on the ecology and management of the Mississippi Delta region and for the last 30 years, he has studied coastal ecosystems in Mexico. He was a visiting professor in the Institute of Marine Sciences of the National University of Mexico in 1978-1979, at the University of Utrecht in the Netherlands during 1986, at the Laboratoire d'Ecologie, Université Claude Bernard in Arles, France, during 1992-1993, and in the Department of Geography at Cambridge University in 2000-2001. Over the past three decades, Dr. Day has focused on deltas and the impacts of human activities and climate change on deltaic sustainability. He served as chair of the National Technical Review Committee reviewing the restoration program for the Mississippi Delta and is currently active in delta restoration. He is the recipient of the Estuarine Research Federation Cronin Award for excellence in teaching in coastal sciences. Dr. Day received his Ph.D. in marine sciences and environmental sciences from the University of North Carolina in 1971.

PAULO FERRÃO is the President of the board of directors of the Fundação para a Ciência e a Tecnologia (the Portuguese national science and technology foundation). He was the National Director of the MIT-Portugal Program, a major international partnership on science and technology in Portugal, in the field of engineering systems, and was also the coordinator of the Sustainable Energy Systems Ph.D. program at IST. He is a full professor at IST. Dr. Ferrão is co-founder of IN+, Center for Innovation, Technology and Policy Research. His scientific career has evolved within the areas of laser diagnostics for turbulent combustion systems, analysis of energy systems, and industrial ecology, where the principles of thermodynamics have been complemented with social and economic fundamentals in order to promote the analysis of the complex systems that characterize the major issues that are relevant for sustainable development of modern societies. Dr. Ferrão has been active in the area of "sustainable cities," where he published a book at MIT Press on "Sustainable Urban Systems" co-authored with John Fernandez from MIT. He is author of three books and co-author of two others in the area of industrial ecology, its principles, tools, and different case studies. He is author of more than one hundred papers published in journals and book chapters and over a hundred papers presented in conferences and invited talks in different domains. He has co-organized more than a dozen international conferences and led more than 30 scientific projects in the areas of energy efficiency and industrial ecology. Dr. Ferrão received his Ph.D. in mechanical engineering (1993) and his master in energy transfer and conversion (1998) from IST.

SUSAN HANSON (NAS) is Distinguished University Professor Emerita and longtime professor of geography at Clark University. She is an urban geographer with interests in gender and economy, transportation, local labor markets, and sustainability. Her research has examined the relationship between the urban built environment and people's everyday mobility within cities; within this context, questions of access to opportunity, and how gender affects access, have been paramount. Her books include *Ten Geographic Ideas that Changed the World; Gender, Work, and Space* (with Geraldine Pratt); and *The Geography of Urban Transportation*. Dr. Hanson has been the editor of several academic journals, including *The Annals of the Association of American Geographers*, *Urban Geography*, and *Economic Geography,* and has been the geography editor of the *International Encyclopedia of the Social and Behavioral Sciences*, first and second editions. She has led the School of Geography at Clark and is a past president of the Association of American Geographers (AAG), a fellow of the American Association for the Advancement of Science, a former Guggenheim Fellow, a former fellow at the Center for Advanced Study in the Social and Behavioral Sciences at Stanford, and a recipient of the Honors Award and of the Lifetime Achievement Award from the AAG and of the Van Cleef Medal from the American Geographic Society. In 2000 she was elected to the National Academy of Sciences and the American Academy of Arts and Sciences. She is currently division chair of the Transportation Research Board of the National Research Council (NRC), is on the advisory board of the NRC's Division of Behavioral and Social Sciences and Education, and is on the editorial board of the *Proceedings of the National Academy of Sciences*. Her B.A. is from Middlebury College, and before earning her M.S. and Ph.D. at Northwestern University, she was a Peace Corps Volunteer in Kenya.

CHRIS HENDRICKSON (NAE) is the Hamerschlag University Professor of Engineering, co-director of the Green Design Institute at Carnegie Mellon University, member of the National Academy of Engineering, and editor-in-chief of the *ASCE Journal of Transportation Engineering*. His research, teaching, and consulting are in the general area of engineering planning and management, including design for the environment, system performance, construction project management, finance, and computer applications. He has co-authored five books, including *Environmental Life Cycle Assessment of Goods and Services: An Input-Output Approach*, and published numerous articles in the professional literature. Dr. Hendrickson has been the recipient of the Faculty Award of the Carnegie Mellon Alumni Association (2009), Turner Lecture Award of the American Society of Civil Engineers (2002), the Fenves Systems Research Award from the Institute of Complex Engineering Systems (2002), and AT&T Industrial Ecology Fellowships (2000-2002). He is a fellow of the American Association for the Advancement of Science (2007), a distinguished member of the American Society of Civil Engineers (2007), and an emeritus member of the Transportation Research Board (2004). His professional career includes research contributions in computer-aided engineering, transportation systems, construction project management, and environmental systems. He has contributed software tools and methods for sustainable construction, pollution prevention and environmental management, including life-cycle analysis software (http://www.eiolca.net) and a widely cited analysis of the life-cycle consequences of lead acid battery powered vehicles. His education includes bachelor and master of science degrees from Stanford University, a master of philosophy degree in economics from Oxford University, and a Ph.D. from the Massachusetts Institute of Technology.

SUZANNE MORSE MOOMAW is associate professor of urban and environmental planning at the University of Virginia School of Architecture, where she also directs the Community Design Research Center and is the academic lead for the Appalachian Prosperity Project. Specializing in community and economic development at the neighborhood, community, and regional levels, she has a particular focus on the intersection of community design, economic resilience, and quality of life. She is the co-director of the Design-Driven Manufacturing initiative, an effort to expand possibilities for advanced manufacturing in underserved communities. Dr. Moomaw has had a distinguished career in the nonprofit and philanthropic worlds as well as academia. She served as president of the Pew Partnership for Civic Change from 1992 to 2007. She is a member and past chair of the board of trustees of the Kettering Foundation and has served as a board member of Campfire, Inc., Topsfield Foundation, Pew Center for Civic Journalism, and the Piedmont Virginia Community College Board, where she was chair. She is a member of the Academy of Community Engaged Scholarship and has been a fellow at the Virginia Foundation for the Humanities and the Institute for Advanced Learning and Research at Virginia Tech. Dr. Moomaw holds a Ph.D. from The University of Alabama. She is the author of *Smart Communities: How Citizens and Local Leaders Can Use Strategic Thinking to Build a Brighter Future, Second Edition*.

AMANDA PITRE-HAYES is the director of planning for Vancouver Public Library. Previously, she was the director of sustainability for the City of Vancouver where she led a team of 16 to achieve the Council directive to become the world's greenest city by 2020. She has 20 years of experience in leadership roles at Vancity, the Pembina Institute, Accenture, and The Body Shop Canada. At Vancity, Ms. Pitre-Hayes managed the organization's climate change strategy and led its successful effort to be the first carbon-neutral financial institution in North America. As director of climate change consulting with the Pembina Institute, Ms. Pitre-Hayes worked with organizations, such as TD Bank, to become greener by measuring and managing carbon dioxide emissions. As a manager at Accenture, she managed major projects for North American government, energy, telecom, and financial services organizations. At the Body Shop Canada, Ms. Pitre-Hayes served as assistant to the president, supporting the organization with a variety of sustainability initiatives. Ms. Pitre-Hayes is an alumnus of Harvard University's Global Change Agent program and holds an M.B.A. from the University of California, Berkeley.

KAREN C. SETO is professor of geography and urbanization science and associate dean of research at the Yale School of Forestry & Environmental Studies. Prior to joining Yale University, she was on the faculty at Stanford University for 8 years. Dr. Seto's research is on the human transformation of land and the links between urbanization, global change, and sustainability. She is an expert in urbanization dynamics, forecasting urban growth, and examining the environmental consequences of urban expansion. She has pioneered methods using satellite remote sensing to reconstruct historical patterns of urbanization and to develop projections of future urban expansion. She specializes in China and India, where she has conducted urbanization research for more than 15 years. Dr. Seto serves on a number of international and national scientific advisory committees, including as coordinating lead author for the Intergovernmental Panel on Climate Change Fifth Assessment Report, coordinating lead author for the United Nations Convention on Biodiversity Cities and Biodiversity Outlook, and co-chair of the Future Earth (previously IHDP) International Human Dimension Programme on Global Environmental Change Urbanization and Global Environmental Change Project. She also has served on five other National Academy committees. She is co-editor-in-chief of the journal *Global Environmental Change* and is the executive producer of "10,000 Shovels: Rapid Urban Growth in China," a documentary film that integrates satellite imagery, historical photographs, and contemporary film footage to examine the urban changes occurring in China. She was named an Aldo Leopold Leadership Fellow in 2009. Dr. Seto received her B.A. in political science from the University of California, Santa Barbara, her M.A. in international relations and resource and environmental management, and her Ph.D. in geography from Boston University.

ERNEST TOLLERSON served as the interim president and CEO of the Nathan Cummings Foundation (NCF) from August 2014 through mid-November 2015. From 2004 to 2013, he served as a NCF trustee, including one 3-year term as chair of the board of trustees. Prior to rejoining NCF as interim president and CEO, Mr. Tollerson worked for the Metropolitan Transportation Authority (MTA) as director of environmental sustainability and compliance. During seven-and-a-half years at the MTA, he organized and oversaw the work of the Blue Ribbon Commission on Sustainability & the MTA (final report at http://www.mta.info/sustainability). In 2010, he co-chaired the Transportation & Land Use Technical Working Group of the New York State Climate Action Plan Interim Report. Currently, he is a trustee of the Hudson River Foundation and the New York Historical Society. He is also a former member of the management board of the Environmental Grantmakers Association, the affinity group for U.S.-based foundations that fund environmental nongovernmental organizations and projects, and a former member of the board of Demos, a nonpartisan hub for research, ideas, and action to promote the common good. A graduate of Princeton and Columbia's Graduate School of Journalism, Mr. Tollerson spent nearly 25 years as a journalist. He worked as a reporter and editor for a number of newspapers including the *Philadelphia Inquirer*, where he was a political reporter, *New York Newsday*, where he was the editorial page editor, and the *New York Times*, where he was first a national correspondent and later a member of the *Times*' editorial board.

RAE ZIMMERMAN is professor of planning and public administration at New York University's Wagner Graduate School of Public Service and, since 1998, director of the Institute for Civil Infrastructure Systems. In 2011-2013 she directed Wagner's Urban Planning Program for the fifth time. Her teaching and research focus on infrastructure, infrastructure and interdependencies among infrastructure sectors, the environment, climate change, natural hazards, social equity, and security in the context of the quality of life in urban areas and how innovations can be used to adapt to extreme conditions. She has participated in close to 50 grants, serving as principal investigator on about three dozen of those and co-principal investigator or participating researcher on a dozen others funded by government agencies, such as the National Science Foundation, U.S. Environmental Protection Agency, the U.S. Department of Transportation Region 2 Urban Transportation Research Center, the U.S. Department of Homeland Security (through university research centers), state and local government agencies, and other sponsorship. From 2013 to 2015 she was part of the New York State–funded NYS Resiliency Institute for Storms and Emergencies. She authored *Transport, the Environment and Security: Making the Connection*, authored *Governmental Management of Chemical Risk*, co-produced *Beyond September 11th*, co-edited *Digital Infrastructures* and *Sustaining Urban Networks*, and authored or co-authored over one hundred other publications. She has been active on numerous advisory boards and committees, including U.S. Environmental Protection Agency and National Academy committees, and she was appointed to the first NYC Panel on Climate Change (NPCC) in 2010 and the third NPCC in 2015-2016. She serves on the Transportation Research Board's Critical Transportation Infrastructure Protection committee through 2017, and served as an expert for the U.S. Global Change Research Program National Climate Assessment Infrastructure Indicators Technical Team. She is a fellow of the American Association for the Advancement of Science, a fellow and past president of the Society for Risk Analysis, and is on editorial boards of several risk and technology journals. Dr. Zimmerman received a B.A. in chemistry from the University of California (Berkeley), a master of city planning from the University of Pennsylvania, and a Ph.D. in planning from Columbia University.

Appendix B

Details for Urban Sustainability Indicators

Note for online reading: A metric column is included on the even-numbered pages only due to continuation of the table to the next odd numbered page.

ENVIRONMENTAL INDICATORS

Metric	Vancouver	Los Angeles	New York	Philadelphia
Air Quality Criteria Pollutant (NAAQS) Nonattainment[a]	PM-2.5 (24 hr), Ozone (8 hr) Canadian Ambient Air Quality (AQ) Stds.	PM-2.5, 8-hour ozone, lead	PM-10, 8-hour ozone	8-hour ozone
Particulate Matter 2.5 (ppm) (2011) (Average density of fine particulate matter 2.5 microns in diameter in micrograms per cubic meter ($PM_{2.5}$))[b]	4.3 (2011) 4.1 (2012) 6.6 (2013)	8.1	10.8	11.6
Air Quality Index (AQI) (EPA, 2012):[c]	AQHI 2013	AQI	AQI	AQI
Total days AQI available	NA	366	366	366
Good days (AQI = 0-50)	>99% hr	33	130	109
Moderate days (AQI = 51-100)	<1% hr	228	214	230
Maximum AQI (out of 500)	0%	192	150	154
Median AQI (out of 500)	NA	77	55	58
Greenhouse Gas Emissions of SMA in 2010[d]				
Residential CO_2 per capita (metric tons of CO_2 per capita from residential energy consumption)	0.80	1.6	1.8	1.8
Commercial CO_2 per $ gross domestic product (GDP) (kgCO2/$-GDP (2005-$))	NA	0.04	0.01	0.02
Industrial CO_2 per $ value of products (kgCO2/$-GDP from industry (2005-$)	NA	0.27	NA	NA

Pittsburgh	Chattanooga	Grand Rapids	Cedar Rapids	Flint	U.S.*	Std **
8-hour ozone, PM-2.5, SO_2, lead	PM-2.5	—	—	—	Population Exposed**: 130,886 in 000s	Y
14.0	13.5	12.2	11.1	12.2	10.2	Y
AQI	AQI	AQI	AQI	AQI	AQI	N
366 80 230 200 62	352 194 150 137 48	366 254 97 135 41	366 227 138 104 44	242 178 50 147 40		
					17.62	
2.7	3.1	4.7	NA	NA	3.41	N
0.05	0.07	0.22	NA	NA	5.20	N
0.44	0.75	1.22	NA	NA	5.74	N

continued

Metric	Vancouver	Los Angeles	New York	Philadelphia
Water Quality 2012[e]: *State level only* Number of waterways impaired	NA	1,052	1,543	6,954
Example of a waterway applicable to the city		LA River	East, Harlem, Hudson Rivers	Schuylkill, Delaware Rivers
Hydrology[f] Average Annual Precipitation in inches/year	46.8	18.67	46.23	41.45
Landslide Vulnerability[g]	L	M/H	L	L
Existing Tree Canopy (% land cover)[h]	18	21	21	20
Park Acres/1,000 residents 2014[i]	NA	9.3	4.6	7.0
Ecological footprint by Global Footprint Network (Ecological Footprint is calculated by considering all of the biological materials consumed by all the residents in a city and all of the carbon dioxide emissions generated by that city in a given year). Units are global hectares per capita.[j]	6.21	6.4	6.1	6.2
Natural Hazards Vulnerability[k] (#events 1/1/05-6/1/15)	NA	411	656	500+
ECONOMIC INDICATORS				
Economic sector mix (% employment)[l]				
Agric, forestry, fishing, hunting, and mining	0.97%	0.40%	0.10%	0.30%
Construction				
Manufacturing	4.53%	6.40%	5.40%	4.80%
Wholesale trade	5.12%	8.10%	3.30%	5.70%
Retail trade	3.77%	3.10%	2.30%	2.30%
Transportation, warehousing, and utilities	9.13%	9.30%	9.00%	8.80%
Information; finance and insurance, and	4.30%	5.90%	6.10%	6.00%
real estate and rental and leasing				
Professional, scientific, management,	13.08%	11.20%	15.40%	8.50%
and administrative, waste management services	17.49%	13.50%	14.10%	12.20%
Educational services, and health care and social assistance				
Arts, entertainment, and recreation, and accommodation and food services	19.33%	20.60%	25.20%	30.80%
Other services (except public admin)	13.20%	11.10%	10.00%	9.20%
Public administration				
Armed forces				
	4.96%	6.60%	4.90%	4.50%
	4.11%	3.70%	4.20%	6.80%
	0.00%	0.00%	0.00%	0.00%
Financial Health (G.O. Bond ratings 2014 or 2015 S&P ratings or *Moody's – AA+ is S&P equivalent to Aa1)[m]	AA+	AA-	AA	A+
Median Household Income (2009-2013)[n]	$56,113 (2010)	$55,909	$53,107	$37,192
% Unemployment (% of population 16 and older seeking work or employed, but are unemployed)[o]	7.1 (15 yrs and older)	9.9	7.2	10.0

Pittsburgh	Chattanooga	Grand Rapids	Cedar Rapids	Flint	U.S.*	Std **
6,954	1,012	2,584	480	2,584	—	Y
Allegheny Monongahela, Ohio Rivers	Tennessee River	Grand River	Cedar River	Flint River		
34.8	52.44	38.27	37.63	31.38	40.78	N
H	H/M	L	L	L	—	N
42	23	34	13	13	24.95	N
9.8	NA	NA	NA	NA	12.5	N
NA	NA	NA	NA	NA	6.7	N
500+	290	163	500+	365	500+	N
			NA	NA		N
0.50%	0.10%	0.50%			2.00%	
3.90%	5.10%	4.30%			6.10%	
5.80%	12.60%	15.70%			10.50%	
1.90%	2.40%	2.50%			2.60%	
6.10%	12.60%	7.40%			11.60%	
3.50%	7.30%	2.30%			4.90%	
16.00%	9.70%	6.20%			8.70%	
13.00%	10.50%	10.90%			10.90%	
32.90%	22.90%	33.30%			22.80%	
8.30%	9.10%	8.40%			9.50%	
3.40%	4.40%	4.90%			5.00%	
4.60%	3.10%	3.60%			4.80%	
0.00%	0.30%	0.10%			0.70%	
A+	AAA	AA-	Aa1*	—	AA+	N
$51,366	$46,702	$51,667	$57,260	$42,089	$53,046	N
6.5	7.9	6.5	4.8	9.7	7.6	N

continued

Metric	Vancouver	Los Angeles	New York	Philadelphia
ENERGY SECTOR				
Average residential electricity rate (cents/kWh)[p]	7.75	13.03	23.21	12.90
Energy Intensity of SMA in 2010[q]				
Residential energy consumption per capita (MMBtus)	30.8	34.5	49.3	71.2
Commercial energy intensity (kBtu/$ GDP (2005-$))		0.9	0.6	1.2
Industrial energy intensity (kBtu/$GDP(2005-$))	24	8.0	NA	NA
LED Street Lighting (Yes or No)[r]	Yes	Yes	Yes	Yes
System Average Interruption Duration Index (SAIDI)[s]	3.29	65.0	19.0	66.5
TRANSPORTATION SECTOR				
Transportation mode share (% by public transportation)[t]	30.4	10.4	58.7	29.3
Transportation alternatives: walkscore.com (out of 100)[u]				
Walk score	78	64	88	77
Transit score	74	50	81	67
Bike score	—	56	65	68
Transportation Usage:				
Annual Vehicle Miles of Travel 2012[v] Total in thousands (U.S. in millions)	2,908	272,850	290,116	102,015
Per capita DVMT per capita (cities); VMT and DVMT for the United States[x]	NA	23.1	16.3	19.8
Licensed drivers per 1,000 driving-age population (state only)[y]	NA	807	705	857
Mean Travel Time to Work in Minutes (all modes) 2014[z]	20.9	33.6	44.6	35.0
Congestion –TTI (auto only)[aa]	—			
Yearly delay (hours/commuter)	—	85	74	48
Excess fuel (gallons)	—	25	35	23
Cost (dollars/commuter)	1134 (metro Vancouver)	1711	1739	1112
Public Transportation Ridership Average Weekday in '000s 2014[bb]		1433	11664 (NYCT only)	NA
WATER SECTOR				
Water usage, county[cc] Domestic gallons per capita per day	73	100	75	52
SOCIAL INDICATORS				
Population (in '000s)[dd]				
City	603,502	3,928,864	8,491,079	1,560,297
CBSA	2,313,328 (metro)	13,262,220	20,092,883	6,051,170

	Pittsburgh	Chattanooga	Grand Rapids	Cedar Rapids	Flint	U.S.*	Std **
	11.44	10.13	13.71	12.99	13.71	11.88	N
						312	N
	66.4	91.9	71.6	NA	NA	NA	
	1.7	2.1	3.2	NA	NA	NA	
	14.2	25.4	20.2	NA	NA	NA	
	No	Yes	Yes	Yes	No		N
	75.0	83.8	218.0	108.1	218.0	NA	N
	17.6	0.9	3.5	0.6	2.4	5.0	N
						NA	N
	60	27	48	32	40		
	54	—	—	—	—		
	40	30	55	—	—		
	33,226	NA	NA	NA	NA	2,969[w]	N
	19	NA	NA	NA	NA	9,457 VMT 25.9 DVMT	N
	857	890	882	876	882	NA	N
	31.4	24.1	22.7	20	24.9	25.7	N
	39	28	39	7	25	NA	
	21	—	19	—	—	NA	
	889	730	854	153	570	NA	
	213	NA	NA	—	21	NA	
	60	81	65	75	75	88	N
						308.8 million	N
	305,412	173,778	193,792	129,195	99,002		
	2,355,968	544,559	1,027,703	263,885	412,895		

continued

Metric	Vancouver	Los Angeles	New York	Philadelphia
Population Density (People per square mile)[ee]				
City	13,598	8,382	28,060	11,635
CBSA	2,079	2,735	3,005	1,315
Demographics[ff]				
Percent Black or African American	1%	9.2%	28.1%	44.1%
Percent Hispanic or Latino	1.6%	48.4%	29.0%	13.6%
Percent Asian	41%	14.8%	14.4%	7.2%
Median Age (in years)	39.7	35.5	35.8	33.7
Percent Female Population	51.1%	50.7%	52.3%	52.7%
Poverty and Wealth				
% Below 100% of Poverty Level[gg]		17.8%	20.4%	26.5%
Income Inequality (Ratio of household income at the 80th% to income 20th%)[hh]	NA	5.3	10.8	6.2
Children in poverty % (NYC 5 counties are given: Bronx, Kings, NY, Queens, Richmond)[ii]	NA	27%	42% 33 27 22 19	36%
Children in single-parent households % (NYC 5 counties are given: Bronx, Kings, NY, Queens, Richmond)[jj]	NA	36%	64% 39 42 33 27	59%
% home ownership (2009-2013)[kk]	48.5% (2011)	46.9%	32.8%	53.3%
Housing Cost and Income:[ll]				
% Median Gross Rent is of Median Household Income	16.1%	36.8%	32.2%	34.9%
% Housing Costs are of Median Income				
With Mortgages				
Without Mortgages	32.1% 17.4%	34.2% 13.5%	30.5% 15.2%	25.6% 15.6%
Education[mm]				
High School Graduate (Among Those 25 or older) (2009-2013)	92.0% (2011)	76.6%	79.4%	81.2%
Some College (Among Those 25-44) (2009-2013)	73.0% (2011)	58.9%	63.9%	56.5%
Bachelor's Degree (Among Those 25 or Older) (2009-2013)	43.5% (2011)	29.7%	33.7%	23.9%
Safety: Rate of Violent Crimes (Type 1 Violent Crime Offenses Reported /100,000 people)[nn]	—[oo]	474	628	1,190
Safety-Transportation: Roadway fatalities per hundred million Annual VMT[pp]	0.74	0.91	0.92	1.22
Health (selected indicators only) Premature Age-adjusted mortality per 100,000 (NYC 5 counties are given: Bronx, Kings, NY, Queens, Richmond)[qq]	197.5	265.7	363.1 302.7 240.1 242.8 296.3	492.1

	Pittsburgh	Chattanooga	Grand Rapids	Cedar Rapids	Flint	U.S.*	Std **
						89.5	N
	5,513	1,267	4,365	1,825	2,907		
	446	261	369	131	648		
							N
	13.4%	19.8%	10.4%	4.5%	20.6%	13.2%	N
	1.9%	5.1%	10.1%	2.9%	3.2%	17.4%	N
	3.4%	2.1%	2.8%	2.2%	1.1%	5.4%	N
	40.8	39.4	34.9	36.9	39.7	37.5	N
	51.8%	51.8%	50.8%	50.6%	51.8%	50.8%	N
	12.9%	16.6%	15.5%	9.7%	21.0%	15.4%	N
	5.0	5.0	4.3	4.0	4.8	4.4	N
	19%	26%	19%	12%	33%	23%	N
	33%	36%	32%	29%	44%	33%	N
	65.5%	64.9%	70.1%	73.0%	70.3%	64.9%	N
	30.3%	30.2%	34.3%	27.7%	49.3%	21.6%	N
	19.9%	23.5%	23%	20.9%	26.5%	33.6%	N
	13.9%	12.9%	12.9%	12.2%	15.9%	10.6%	
							N
	92.9%	86.3%	89.4%	93.8%	88.7%	86.0%	N
	75.9%	64.7%	68.1%	76.2%	62.7%	56%	N
	35.9%	27.2%	31.7%	31.2%	18.9%	28.8%	N
	421	636	409	212	854	191	N
	1.22	1.40	1.00	1.00	1.00	1.10	N
	352.7	389.8	292.4	281.2	433.7	NA	N

continued

Metric	Vancouver	Los Angeles	New York	Philadelphia
Adult obesity % (NYC 5 counties are given: Bronx, Kings, NY, Queens, Richmond)[rr]	NA	21%	28% 23 15 24 28	30%
Poor or fair health % (NYC 5 counties are given: Bronx, Kings, NY, Queens, Richmond)[ss]	NA	22%	24% 18 16 18 12	20%

NOTES

*U.S. information is given where it is available and applicable. NA indicates not available. A double dash (—) indicates not applicable. National data for countyhealthrankings.org for the United States are primarily 2014 national average values from the RWJF (Robert Wood Johnson Foundation) and University of Wisconsin Population Health Institute. 2014. National Statistics Reference Table. Online. Available at http://www.countyhealthrankings.org. Accessed October 12, 2015.

**Std signifies whether or not a regulatory standard is available for the indicator. Y = an official standard. N = no standard; however, guidelines might exist. A (—) = not likely to be relevant or applicable.

[a] Nonattainment in 1 or more counties in the Standard Metropolitan Area (SMA) and for various years, as listed in one or the other reports or both: (1) EPA. 2015b. Criteria Pollutant Nonattainment Summary Report (as of October 1, 2015). Online. Available at http://www3.epa.gov/airquality/greenbook/multipol.html and (2) EPA. 2015c. Summary Nonattainment Area Population Exposure Report (as of October 1, 2015). Available at http://www3.epa.gov/airquality/greenbook/popexp.html. Accessed February 5, 2016. The value indicated in the U.S. column is EPA's estimate of "population living in an area" across all of the nonattainment criteria pollutants. See EPA. 2015c. Summary Nonattainment Area Population Exposure Report.

[b] RWJF and University of Wisconsin Population Health Institute. 2014. National Statistics Reference Table identified for each county. NYC values were weighted for the five counties. The U.S. average is inferred from the trends graph which compares smaller areas to the United States.

[c] Zero is the best value and 500 is the worst. Canadian cities use the Air Quality Health Index (AQHI). See EPA. 2015a. Air Quality Index. Online. Available at http://www3.epa.gov/airdata/ad_rep_aqi.html. Accessed February 5, 2016.

[d] Cox, W. 2014. Sustaining the City: Understanding the Role of Energy and Carbon Dioxide Emissions in Sustainable Development in Major Metropolitan Areas. PhD dissertation, Georgia Institute of Technology, Tables A.4, A.14, and A.22. The U.S. figure is the total for all sectors as Per Capita CO_2 Emissions from the Consumption of Energy (Metric Tons of Carbon Dioxide per Person). See Union of Concerned Scientists. 2014. Each Country's Share of CO_2 Emissions. Online. Available at http://www.ucsusa.org/global_warming/science_and_impacts/science/each-countrys-share-of-co2.html#. Accessed February 8, 2016. The residential, commercial, and industrial values for the U.S. are the unweighted mean values across the nation's largest U.S. metro areas in 2010 based on Cox, 2014.

[e] Water quality. Impaired waters are listed by the U.S. EPA (2012) under section 303(d) of the Clean Water Act. See http://ofmpub.epa.gov/waters10/attains_nation_cy.control.

[f] Hydrology. Source for average annual rainfall. US Climate Data. 2016. Online. Available at http://www.usclimatedata.com. Accessed February 8, 2016. Rainfall is one factor in the availability of water for consumption. Other factors include evaporation, uptake by vegetation, and runoff (not captured).

[g] Landslide incidence. Values are L, Low (less than 1.5% of area involved); M, Moderate (1.5%-15% of area involved); and H, High (greater than 15% of area involved). See USGS. 2014b. Landslide Overview Map of the Conterminous United States. Online. Available at http://landslides.usgs.gov/hazards/nationalmap. Accessed February 8, 2016.

[h] U.S. Forest Service. 2015. Urban Tree Canopy Assessments (New York City, Philadelphia, and Pittsburgh). Online. Available at http://gis.w3.uvm.edu/utc. Accessed October 12, 2015; U.S. (forest only, 2006). See USGS. 2015. National Land Cover Database 2006 (NLCD2006): Product Statistics. Online. Available at http://www.mrlc.gov/nlcd06_stat.php. Accessed January 25, 2016; Los Angeles (2008): See McPherson et al., 2008; Glick (1996): See American Forests, 2000.

[i] The Trust for Public Land. 2015. 2015 City Park. Online. Available at http://www.tpl.org/2015-city-park-facts. Accessed January 25, 2016. The U.S. figure is the median for all cities reported.

[j] Moore, D. 2011. Ecological Footprint Analysis: San Francisco-Oakland-Fremont, CA. Global Footprint Network. Online. Available at http://www.footprintnetwork.org/images/uploads/SF_Ecological_Footprint_Analysis.pdf. Accessed October 12, 2015. p. 6.

[k] Natural Hazards (all hazards) – number of all events, January 1, 2005 through June 1, 2015. Compiled from the National Oceanic and Atmospheric Administration (NOAA) National Climatic Data Center (NCDC) Storm Events Database. The New York City number is for all five boroughs (counties) during the time period. 500+ signifies that the number of events exceeded NOAA's 500-event threshold and the actual number has to be computed by subdividing and reaggregating the time periods (as was done for NYC).

[l] Industry Mix. U.S. Census Bureau. 2014b. American Community Survey 2014. Online. Available at http://factfinder.census.gov/faces/nav/jsf/pages/index.xhtml### Table S0804. Accessed January 25, 2016.

Pittsburgh	Chattanooga	Grand Rapids	Cedar Rapids	Flint	U.S.*	Std **
27%	29%	29%	28%	37%	28%	N
13%	18%	12%	11%	19%	16%	N

[m] Bond ratings (S&P except where otherwise noted). The scale for S&P ratings for investment grade (from high to low): AAA, AA+, AA, AA-, A+, A, A-, BBB+, BBB, BBB- (other ratings are below investment grade). Los Angeles: http://cao.lacity.org/debt/ratings.pdf; New York: http://comptroller.nyc.gov/wp-content/uploads/2015/06/NYC-GO-Announcement-060315.pdf; Philadelphia: http://www.phila.gov/investor/Bond_Ratings.html; Pittsburgh: http://www.post-gazette.com/local/city/2014/08/08/Moody-s-raises-Pittsburgh-s-bond-rating/stories/201408080164; Chattanooga: https://performance.chattanooga.gov/dataset/S-P-Bond-Rating/d8cz-pkf3; Grand Rapids: http://www.mlive.com/news/grand-rapids/index.ssf/2014/09/credit_rating_why_we_care_what.html; Cedar Rapids: http://www.washingtontimes.com/news/2014/apr/25/moodys-drops-cedar-rapids-bond-rating-a-notch; U.S.: Scaggs, 2015. See http://www.bloomberg.com/news/articles/2015-06-10/s-p-affirms-u-s-aa-credit-rating-maintains-stable-outlook.

[n] U.S. Census Bureau. 2014d. Quick Facts: United States. Available at http://www.census.gov/quickfacts/table/PST045214/00. Accessed October 2, 2015.

[o] RWJF and University of Wisconsin Population Health Institute. 2014. National Statistics Reference Table. Each city accessed in terms of the main county or counties that comprise the area. See Appendix Table 3 for a list of these counties.

[p] Applies to the territory served by the principal utility company serving the city. See Electricity Local. 2015. Local Electricity Information & Resources. Online. Available at http://www.electricitylocal.com. Accessed October 12, 2016.

[q] Cox, W. 2014. Sustaining the City: Understanding the Role of Energy and Carbon Dioxide Emissions in Sustainable Development in Major Metropolitan Areas. Ph.D. dissertation, Georgia Institute of Technology, Tables A.1, A.11, and A.19. MMBtu = 1 million British thermal units. The U.S. figure of 312 million Btu per person is for all sectors from U.S. Department of State. 2014. U.S. Climate Action Report 2014, p. 65.

[r] Municipal Solid-State Street Lighting Consortium. 2013. Primary Participants Organizations. U.S. Department of Energy. Online. Available at http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/consortium-participant-list.pdf. Accessed October 12, 2015. City, either the municipality or a utility in the municipality has installed light-emitting diode (LED) street lighting.

[s] SAIDI represents the average amount of time per year that power supply to a customer is interrupted, expressed in minutes per customer per year. 2013 (except Cedar Rapids, which is 2011); Applies to the territory served by the principal utility company serving the city and is not coterminous with the city of metro area. The principal utility company for each city is as follows. LA: Los Angeles Department of Water & Power; NY: Consolidated Edison Co-NY Inc; Philadelphia: PECO Energy Co.; Pittsburgh: Duquesne Light Company; Chattanooga: City of Chattanooga; Grand Rapids: Consumer Energy Company; Cedar Rapids: Cedar Falls Utilities; Flint: Consumer Energy Company. Sources: EIA, 2015. http://www.eia.gov/electricity/data/eia861; http://www.iowarec.org/media/cms/EDR20110150_IPL_6963C8356CC1C.pdf; State of New York Department of Public Service, 2014.

[t] Percent using public transportation: http://factfinder.census.gov/faces/nav/jsf/pages/index.xhtml### Table S0804

[u] Calculated using walkscore.com.

[v] DOT. 2014b. Table 5-4: Highway, Demographic, and Geographic Characteristics of 30 Largest Urbanized Areas: 2012. Values are for Daily Vehicle Miles of Travel (DVMT) for the Federal-aid urbanized area in 2012.

[w] DOT. 2014a. Table 5-3: Highway Vehicle Miles Traveled (VMT: 2007, 2012). U.S. figures are in billions for total annual VMT, that is, total VMT in 2012 in the U.S. was 2,968,815,000,000 across the entire year. The per capita value for the U.S. is VMT over the year. An estimated conversion to DVMT (based on 365 days of travel) would be 25.9.

[x] DOT. 2014b. Table 5-4: Highway, Demographic, and Geographic Characteristics of 30 Largest Urbanized Areas: 2012. Values are for Daily Vehicle Miles of Travel (DVMT) for the Federal-aid urbanized area in 2012.

[y] Licensed drivers by sex and ratio to population. See FHWA. 2016. Highway Statistics 2013. Online. Available at https://www.fhwa.dot.gov/policyinformation/statistics/2013; VMT by urbanized area. See FHWA. 2014b. Highway Statistics Series: Highway Statistics 2010, Table HM-71. Online. Available at https://www.fhwa.dot.gov/policyinformation/statistics/2010/hm71.cfm. Accessed October 12, 2015.

[z] U.S. Census Bureau. 2014a. Online. Available at http://factfinder.census.gov/faces/nav/jsf/pages/index.xhtml### Table S0802. Accessed January 25, 2016.

[aa] TTI (Travel Time Index)—The ratio of travel time in the peak period to the travel time at free-flow conditions. A value of 1.30 indicates a 20-minute free-flow trip takes 26 minutes in the peak period. Excess Fuel Consumed—Increased fuel consumption [in gallons] due to travel in congested conditions rather than free-flow conditions. Congestion Cost—Value of travel time delay (estimated at $17.67 per hour of person travel and $94.04 per hour of truck time) and excess fuel consumption (estimated using state average cost per gallon for gasoline and diesel).

continued

See Texas A&M Transportation Institute and INRIX. 2015. 2015 Urban Mobility Scorecard, p. 18. Online. Available at http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/mobility-scorecard-2015-wappx.pdf. Accessed January 25, 2016.

[bb] American Public Transportation Association. 2015. Public Transportation Ridership Report: Fourth Quarter & End-Of-Year 2014. Online. Available at http://www.apta.com/resources/statistics/Documents/Ridership/2014-q4-ridership-APTA.pdf. Accessed January 25, 2016.

[cc] Domestic, publicly supplied per capita use, in gallons/day. See USGS. 2014a. Estimated Use of Water in the United States County-Level Data for 2010. http://water.usgs.gov/watuse/data/2010. Accessed January 25, 2016.

[dd] U.S. Census Bureau. 2014d. Quick Facts: United States. Online. Available at http://www.census.gov/quickfacts/table/PST045214/00. Accessed October 2, 2015.

[ee] U.S. Census Bureau. 2014d. Accessed October 2, 2015. The U.S. population density would depend upon whether or not just land area is calculated (2,959,064.44 square miles) rather than total area of land plus water (3,119,884.69 square miles for the contiguous area), and whether or not density refers to the contiguous area of 48 states or the entire nation (including Hawaii and Alaska).

[ff] U.S. Census Bureau. 2014d. Accessed October 2, 2015. Principal county(ies) representing the case-study city (see Appendix Table 3). For NYC a weighted average for the five counties (boroughs) was used. U.S. population density is for the 50 states and DC. See U.S. Census Bureau. 2010. 2010 Census Data. Online. Available at http://www.census.gov/2010census/data. Accessed April 12, 2016.

[gg] U.S. Census Bureau. 2014d. Accessed October 2, 2015. Principal county(ies) representing the case-study city (see Table 2.3). For NYC each county (borough) is listed.

[hh] Principal county(ies) representing the case-study city (see Table 2.3). For NYC a weighted average for the five counties (boroughs) was used. See RWJF and University of Wisconsin Population Health Institute. 2015b. Los Angeles (LO). Online. Available at http://www.countyhealthrankings.org/app/california/2015/rankings/los-angeles/county/outcomes/overall/snapshot. Accessed October 12, 2015; Similar citations for the remaining seven cities. RWJF and University of Wisconsin Population Health Institute. 2015a. County Health Rankings and Roadmaps. Online. Available at http://www.countyhealthrankings.org. Accessed October 12, 2015.

[ii] RWJF and University of Wisconsin Population Health Institute. 2014. National Statistics Reference Table selected for each county. Online. Available at http://www.countyhealthrankings.org. Accessed October 12, 2015.

[jj] RWJF and University of Wisconsin Population Health Institute. 2014. National Statistics Reference Table selected for each county. Online. Available at http://www.countyhealthrankings.org. Accessed October 12, 2015.

[kk] U.S. Census Bureau. 2014d. Quick Facts: United States. Online. Available at http://www.census.gov/quickfacts/table/PST045214/00. Accessed October 2, 2015. Principal county(ies) representing the case study city (see Appendix Table 3). For NYC a weighted average for the five counties (boroughs) was used.

[ll] Governing Data. 2016. Housing Affordability Burden for U.S. Cities. Online. Accessed April 7, 2016. Available at: http://www.governing.com/gov-data/economy-finance/housing-affordability-by-city-income-rental-costs.html. Drawn from U.S. Census Bureau , 2010-2012 American Communities Survey. U.S. Census Bureau. 2014c. American Community Survey 2014. Online. Available at http://factfinder.census.gov/faces/tableservices/jsf/pages/productview.xhtml?pid=ACS_14_1YR_DP04&prodType=table. Accessed April 8, 2016. MetroVancouver. 2015. Housing and Transportation Cost Burden Study. Online. Available at http://www.metrovancouver.org/services/regional-planning/PlanningPublications/HousingAndTransportCostBurdenReport2015.pdf. Accessed April 8, 2015. Statistics Canada. 2010. Median total income, by family type, by census metropolitan area (All census families). Online. Available at http://www.statcan.gc.ca/tables-tableaux/sum-som/l01/cst01/famil107a-eng.htm. Accessed April 8, 2016. MetroVancouver. 2010. Metro Vancouver Housing Data Book. Online. Available at http://www.metrovancouver.org/services/regional-planning/PlanningPublications/MV_Housing_Data_Book.pdf. Accessed April 8, 2016.

[mm] U.S. Census Bureau. 2014d. Quick Facts: United States. Online. Available at http://www.census.gov/quickfacts/table/PST045214/00. Accessed October 2, 2015. Principal county(ies) representing the case study city (see Appendix Table 3). For NYC a weighted average for the five counties (boroughs) was used.

[nn] Principal county(ies) representing the case study city (see Appendix Table 3). For NYC a weighted average for the five counties (boroughs) was used. See RWJF and University of Wisconsin Population Health Institute. 2015b. Los Angeles (LO). Online. Available at http://www.countyhealthrankings.org/app/california/2015/rankings/los-angeles/county/outcomes/overall/snapshot. Accessed October 12, 2015. Similar citations for the remaining seven cities. See RWJF and University of Wisconsin Population Health Institute. 2015a. Loca and Roadmaps. Online. Available at http://www.countyhealthrankings.org. Accessed October 12, 2015.

[oo] Data not comparable to U.S. figures.

[pp] FHWA. 2014a. Fatality Rate Per 100 Million Annual VMT-2013(1): Functional System, Table FI-30. Online. Available at https://www.fhwa.dot.gov/policyinformation/statistics/2013/fi30.cfm. Accessed October 12, 2015. States only. Per hundred million Annual VMT. Other sources include the NHTSA Fatality Analysis Reporting System (FARS).

[qq] RWJF and University of Wisconsin Population Health Institute. 2014. National Statistics Reference Table. Online. Available at http://www.countyhealthrankings.org. Accessed October 12, 2015. The health indicators used represent just a few that exist nationally, for example, from the Centers for Disease Control, and also locally. New York City, for example, has produced neighborhood level values under their "Community Health Profiles" for numerous health indicators. Some are disease specific and others pertain to specific dietary habitats.

[rr] RWJF and University of Wisconsin Population Health Institute. 2014. National Statistics Reference Table. Online. Available at http://www.countyhealthrankings.org. Accessed October 12, 2015.

[ss] RWJF and University of Wisconsin Population Health Institute. 2014. National Statistics Reference Table. Online. Available at http://www.countyhealthrankings.org. Accessed October 12, 2015.

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DOT. 2014b. Table 5-4: Highway, Demographic, and Geographic Characteristics of 30 Largest Urbanized Areas: 2012. Online. Available at http://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/state_transportation_statistics/state_transportation_statistics_2014/index.html/chapter5/table5-4. Accessed October 12, 2015.

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Appendix C

Constraints on the Sustainability of Urban Areas[1]

John W. Day, Louisiana State University

Biophysical constraints will make achieving sustainability for urban areas, especially large ones, challenging in this century. A number of these challenges are already evidenced in several of the cities profiled in Chapter 4. Among the drivers of these challenges are megatrends in population growth and distribution, climate change, energy scarcity, diminished ecosystem services, and requirements of the food system (Day et al., 2014). This appendix briefly addresses each of these in turn.

SETTLEMENT PATTERNS AND POPULATION DISTRIBUTION

The population of the country increased dramatically over the past two centuries and has become increasingly concentrated in urban areas, with urban areas now accounting for roughly 80 percent of the U.S. population (U.S. Census Bureau, 2012). Many see urban living as a "solution" to many of the resource problems facing society. However, global constraints will threaten the sustainability of densely populated regions (UNEP, 2012). Population is now concentrated into a number of large regions (Figure C-1), while areas outside of such megaregions have fallen behind national trends in key measures such as wages and employment over the past three decades. However, these underperforming regions (Figure C-2) are engaged in activities that underwrite the whole economy (farming, forestry, fishing, and mining—especially energy production) and are thus essential for sustaining the rest of the country.

Urbanization of the world's population is now greater than 50 percent and is projected to continue to increase in the 21st century. This means that population growth is dependent on the fewer and fewer people who work in basic resource industries such as those mentioned above that form the foundation of the economy. For example, less than 2 percent of the population works on farms in the United States (The World Bank, 2016). Supporting an ever-larger population requires the cheap energy and resources that support modern productive agriculture and cheap transportation of products for long distances.

Large urban areas such as those depicted in Figure C-1 use large amounts of resources and energy. In the words of Rees (2012), "Cities are self-organizing far-from-equilibrium dissipative structures whose self-organization is utterly dependent on access to abundant energy and material resources" and are unsustainable in their present form and function (Day et al., 2014, 2016). But human impact now is greater than the regenerative capacity of

[1] Note: this section was summarized from Day et al. (2016), supplemented with additional information.

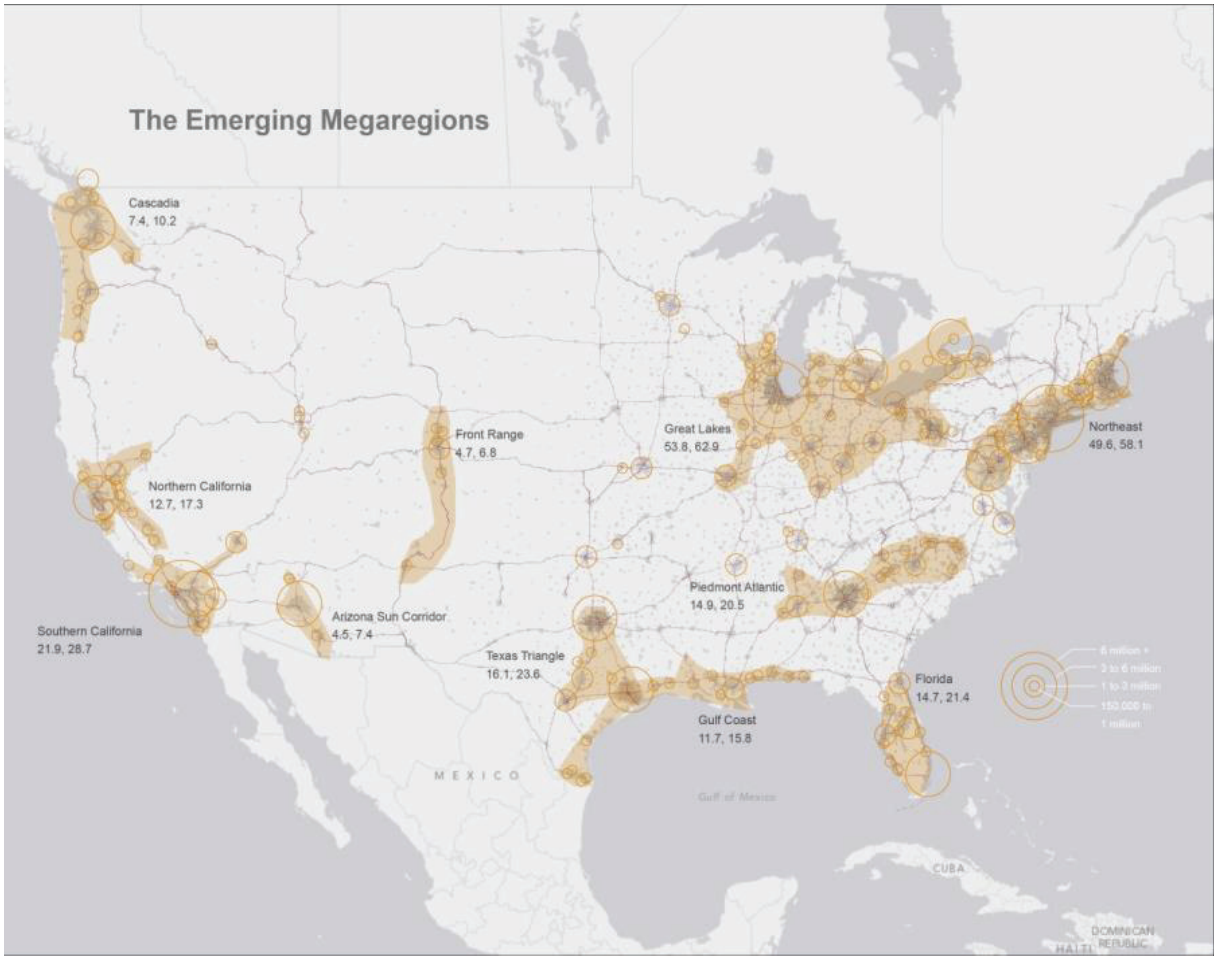

FIGURE C-1 The 11 megaregions of the United States.
NOTE: The 2010 and projected 2025 population in millions are listed below the name of each region (e.g., Southern California 21.9, 28.7). SOURCE: Adapted from Regional Plan Association's America 2050. Reprinted with permission from the America 2050 program, Regional Plan Association.

ecosystems to continue to support humanity as measured by ecological footprint analysis (Rees, 2006). Decker et al. (2000) reviewed energy and material flows through the 25 largest urban areas in the world. They concluded that, consistent with Figure C-2, megacities are weakly dependent on the local environment for energy and material inputs, but for water supply and waste sinks largely dependent on the local region. Los Angeles and other cities in the West and Southwest are examples of this. Rees (2012) concluded that if cities are to become sustainable in the future, "they must rebalance production and consumption, abandon growth, and re-localize." Many cities are now putting forth initiatives particularly in the areas of decentralized, renewable energy systems, lower resource-demanding forms of transportation such as walking and biking, and recycling and engaging in the reduction of water use to address many of these resource deficiencies.

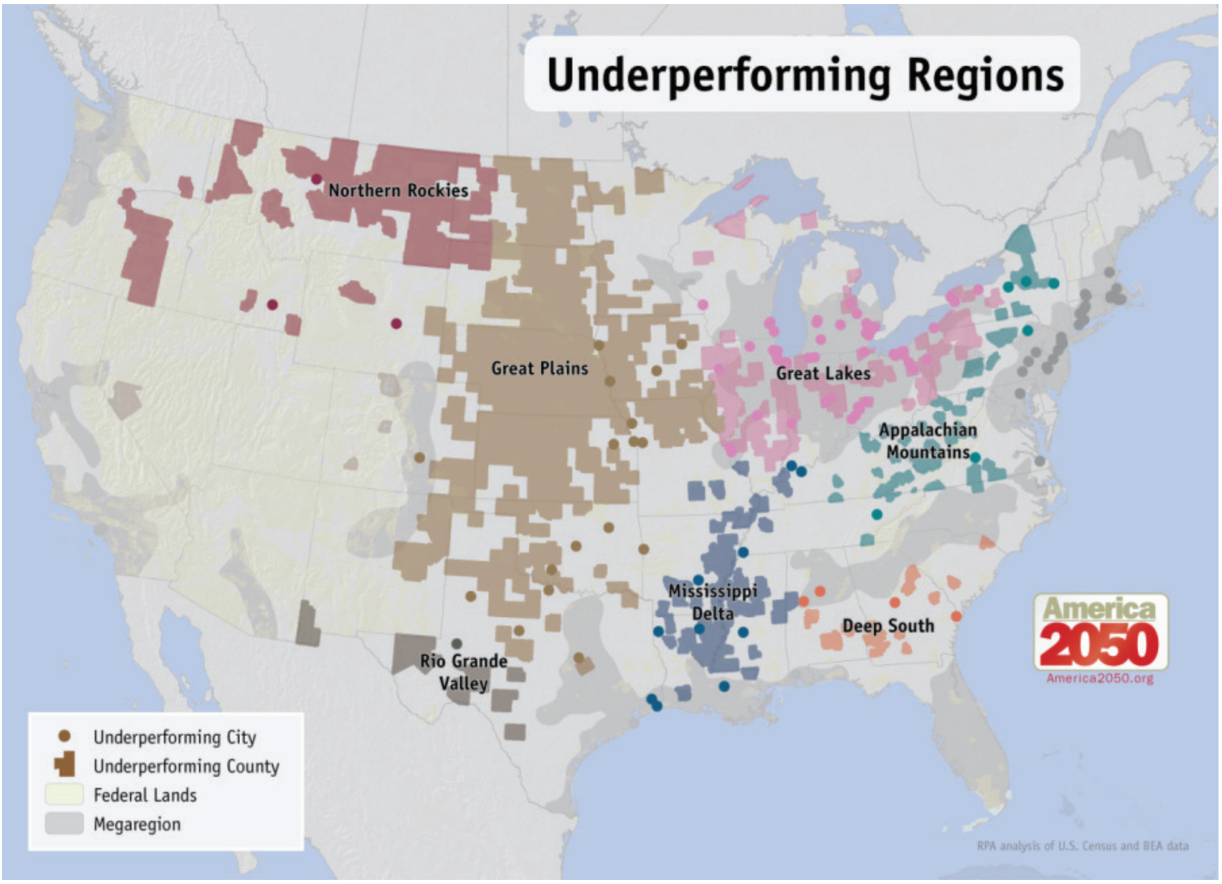

FIGURE C-2 Regions of the United States that have not kept pace with national trends over the past three decades in terms of population, employment, and wages. SOURCE: Produced by the Regional Plan Association, 2009. Reprinted with permission from the America 2050 program, Regional Plan Association.

LANDSCAPE PATTERNS OF CLIMATE CHANGE

Global climate change impacts, such as increasing temperatures, sea-level rise, more variable weather, changes in precipitation, and other factors, will challenge sustainability efforts in urban areas of North America in this century (IPCC, 2007; USGCRP, 2009; Walsh et al., 2014). CO_2 concentrations in the atmosphere now regularly exceed 400 ppm, a dramatic increase over levels in the late 19th century of 280 ppm (IPCC, 2007). These are the highest CO_2 levels of the past three million years. CO_2 levels are now tracking at the highest IPCC scenarios (Friedlingstein et al., 2014).

Globally, temperatures increased by nearly 1°C over the last 100 years, and the increase in the Arctic was four to five times higher. Temperatures are projected to increase 1°C to 5°C in this century (IPCC, 2013).

Precipitation is projected to both increase and decrease (IPCC, 2007; USGCRP, 2009), depending on the region. Decreasing precipitation will impact already dry areas in the southern Great Plains and the Southwest, and increases of precipitation in other parts of the United States create a greater risk of flooding (Cook et al., 2015).

Precipitation is predicted to decrease in the Southwest and the lower half of the Great Plains. Cook et al. (2015) reported that climate change will likely increase drought severity in coming decades that will likely exceed the medieval dry period of 1100-1300 CE. Climate in the Southwest is described in a number of books (Ashworth, 2007; deBuys, 2011; Ingram and Malamud-Roam, 2013; Powell, 2008; Ross, 2011). Drying in the region will impact natural ecosystems, agriculture, and urban areas.

Precipitation is projected to increase in the upper Mississippi and Ohio (USGCRP, 2009). There will likely be more extreme weather events with intense precipitation (Min et al., 2011; Pall et al., 2011). Tao et al. (2014a) reported that the combined impacts of climate change and land-use change will lead to increases in peak Mississippi River discharge of 10 to 60 percent by the end of the 21st century.

Because so many metropolitan areas are located on the coast, climate change will strongly impact these areas. Two trends that will affect coastal areas are accelerating sea-level rise and more frequent, stronger hurricanes. Sea level is projected to rise by 1 meter or more in the 21st century (IPCC, 2013; Moser et al., 2012; Pfeffer et al., 2008; Vermeer and Rahmstorf, 2009). The highest estimates are that sea level may rise by 3 meters or more in this century (Hansen et al., 2015).

The number and intensity of hurricanes is related to ocean surface water warming in both the Atlantic and Pacific oceans (Elsner et al., 2008; Emanuel, 2005; Hoyos et al., 2006; Mei et al., 2015; Webster et al., 2005), and projections are that the frequency of the most intense tropical cyclones will increase (Bender et al., 2010; Knutson et al., 2010). Grinsted et al. (2012) reported that hurricane surge was related to warming. Almost all of the costliest Atlantic tropical cyclones occurred since 2000 (Blake et al., 2011). The highest surge for Sandy was nearly 10 meters, and water levels at Battery Park reached nearly 5 meters, the highest ever recorded (NCAR, 2012).

Climate change will likely cause more frequent extreme weather events (IPCC, 2013). Strong precipitation events will occur more often (Min et al., 2011; Pall et al., 2011) and Arctic sea ice melting is related to harsher winters (Greene, 2012; Master, 2014).

In summary, climate change impacts will vary across the landscape. Drought and water scarcity will impact California and the Southwest, and flooding potentially will increase elsewhere. Sea-level rise and more intense tropical cyclones will impact coastal areas. Extreme weather events will become more common across the United States (IPCC, 2013).

ENERGY IMPACTS ON SUSTAINABILITY

Energy is critical to considerations of sustainability, especially in urban areas. First, the consumption of fossil fuels is the primary and most important forcing leading to climate change (IPCC, 2013). Second, energy, and especially fossil fuels, is at the heart of modern society and the industrial economy. Third, energy is at the heart of the globalized industrial food system that is absolutely critical for urban areas, especially large ones. Changes in the cost, availability, and mix of the energy supply system in the 21st century will affect the functioning of modern society and the ability of cities to feed themselves and to continue to import large amounts of energy and other materials. Because fossil fuels are so critical and central to modern society, the focus in this section is mainly on these fuels.

Global energy use is roughly 500 quads per year (quadrillion Btu) and total energy use about doubled from 1973 to 2011. Fossil fuels account for more than 80 percent of world energy use. Other energy sources are less than 15 percent of total energy use. Hydropower, nuclear, and combustible biomass represent most non–fossil fuel use with the “new” renewables (solar, wind, and liquid biofuels) representing about 1 to 2 percent of the total (Smil, 2015).

What is the future of fossil fuel production? One approach that has been commonly used is the Hubbert analysis. M. King Hubbert used an approach (see references at end of the paragraph for a discussion of Hubbert’s approach) based on historical production rates of oil combined with estimates of the ultimate recovery from different fields, for entire regions, and for the world as a whole. Hubbert predicted that U.S. conventional oil production would peak around 1970 and world production would peak during the first decade of the 21st century, both of which have occurred (Aleklett, 2012; Campbell and Laherrère, 1998; Deffeyes, 2001; Hall et al., 2003).

If historical energy consumption patterns are put together with the concept of peak oil and projections for future oil availability, and the availability of energy in general, a disturbing picture emerges. Campbell and Wöstmann (2013) projected world conventional oil and natural gas production peaking between 2020 and 2030 and then declining. Maggio and Cacciola (2012) used a Hubbert analysis to forecast future projections of all three fossil fuels. They projected that conventional oil production will peak during the second decade of this century, natural gas about 2040, coal just after midcentury, and total fossil fuel production will peak around the same time as natural gas. To replace fossil fuels and nuclear in this century as some suggest, wind and solar would have to grow by nearly two orders of magnitude.

An important issue to consider in any discussion of energy is the net energy yield of any particular energy source. This has been quantified as energy return on investment (EROI), or the ratio between energy outputs to the energy required for production for a particular technology or fuel. Oil and coal had very high EROI up until the mid-20th century: up to 80:1 for coal and 100:1 or greater for oil. The EROI for domestic and imported oil has declined considerably since about 1950. Compared to oil and coal at their highest, the net energy of most other sources of energy have considerably lower EROI values. Hydropower can be as high as 40:1, wind at best can be 20:1 to nearly 40:1, and solar photovoltaics, tar sands, and biofuels are almost always less than 10:1 (Dale et al., 2012; Palmer, 2014; Weißbach et al., 2013). The EROI of liquid biofuels and oil from tar sands is so low as not to represent important viable energy sources for society (Brandt et al., 2013; Hall and Day, 2009; Hall et al., 2014). In spite of the direct economic implications, however, externalities in the form of the environmental costs need to be considered.

Many suggest that renewables, especially wind and solar, will be able to replace fossil fuels in a relatively short period of time. A major problem with solar and wind energy is intermittency. Both solar and wind are intermittent and are often not abundant in areas with the greatest demand (Palmer, 2014; Prieto and Hall, 2013). Winds may be more persistent in coastal areas, but there are higher costs for placing windmills in saltwater and there are high requirements for chromium, zinc, and other elements to make steel less corrosive (Davidsson et al., 2014). Replacing fossil fuels with solar and wind would require enormous amounts of resources, so much so “that the growth of the renewable energy sector may impact investment in other areas of the economy and they stymie economic growth” (Dale et al., 2012). To replace fossil fuels with wind and solar would require very rapid growth rates. Based on the work of Maggio and Cacciola (2012), to increase fossil fuels by a factor of 10 to current levels took 64, 55, and 110 years for oil, natural gas, and coal, respectively. Vaclav Smil (2015) reported that over the past century and a half, it took decades for new energy technologies to become dominant proportions of the energy market. For example, oil took 40 years to grow from 5 to 25 percent of the global primary energy supply, and it will probably require natural gas 60 years to do the same (BP, 2015). Wind and solar increased from about 0.1 percent of total U.S. primary energy consumption in 2000 to about 1 percent in 2010 and 2.2 percent in 2014 (BP, 2015). Even if this rapid rate of growth were to continue, and the materials and manufacturing capacity were not limiting, fossil fuels would still supply 78 percent of U.S. primary energy in 2030, and 75 percent in 2040 (Smil, 2015).

Other renewables that produce electricity include tidal and wave energy, but these produce much less than 1 percent of total world energy use and they are not likely to contribute significantly to future energy use (Dale et al., 2012) beyond very limited geographic circumstances. Biofuels have a very low net energy yield, often hardly greater than 1, and production competes with food production and the preservation of natural ecosystems. Even if all plants on Earth were converted into biofuels, the net energy yield would not supply present world energy demand (Dukes, 2003).

The energy costs of storage (Luo et al., 2015) have not been considered in evaluating renewable EROI of renewables. Replacing fossil fuels with wind and solar would have a huge demand for metals and other resources that would compete with other sectors of the economy (Dale et al., 2012).

ECOSYSTEM SERVICES

Ecosystem services contribute to societal well-being (Costanza et al., 1997; MEA, 2005) and the economy cannot exist without these ecosystem services provided by nature (Costanza et al., 1997). Natural systems, including agroecosystems, are the source of all the energy and materials that form the base of the human economy. This includes agricultural products, fisheries, timber, minerals, and energy (fossil fuels, hydropower, winds, ore for nuclear energy, biomass). Thus sustaining natural ecosystems is absolutely critical to sustain the economy, including that of urban areas (UNEP, 2012). However, degradation of natural systems is leading to a reduction of ecosystem services (MEA, 2005). The Millennium Ecosystem Assessment (MEA) documented pervasive ecosystem degradation for 15 out of 24 key ecosystems that humans depend on for survival (MEA, 2005; UNEP, 2012). In the United States, ecosystem services are higher in the eastern part of the country due to higher precipitation and rates of primary production. The ecological footprint of society is now more than nature can sustainably support. Because more than 80 percent of the U.S. population lives in urban areas, cities constitute areas of high demand for resources and sinks for waste generation in total, though on a per capita basis cities tend to rank lower than less dense regions (Dodman, 2009; Meyer, 2013). Cities in regions with low levels of ecosystem services, as in the Southwest, will be more at risk as the impacts of climate change and energy scarcity impact society.

AGRICULTURE AND FOOD

Providing adequate food is central to the sustainability of urban areas, especially large ones. The food system that provides food to urban areas covers nearly a billion acres in the United States and is dependent on a globalized industrial agriculture system. In 2007, there were over 922 million acres, 20 percent less than in 1950, about evenly divided between pasture and crops (USDA, 2007). Although there is great amount of U.S. food production, significant amounts of the food consumed in the country are imported. This system is highly energy intensive, much of which in the United States is irrigated, and where crop production is highly variable across the landscape. The great majority of U.S. food production is west of the Mississippi River in areas that are irrigated and where water shortages are projected to grow.

The fertility of U.S. soils is highly variable. Figure C-3 shows the soil fertility index derived by Schaetzl et al. (2012), illustrating the variability in soil quality for plant growth across the nation. Inevitably, utilizing soils for

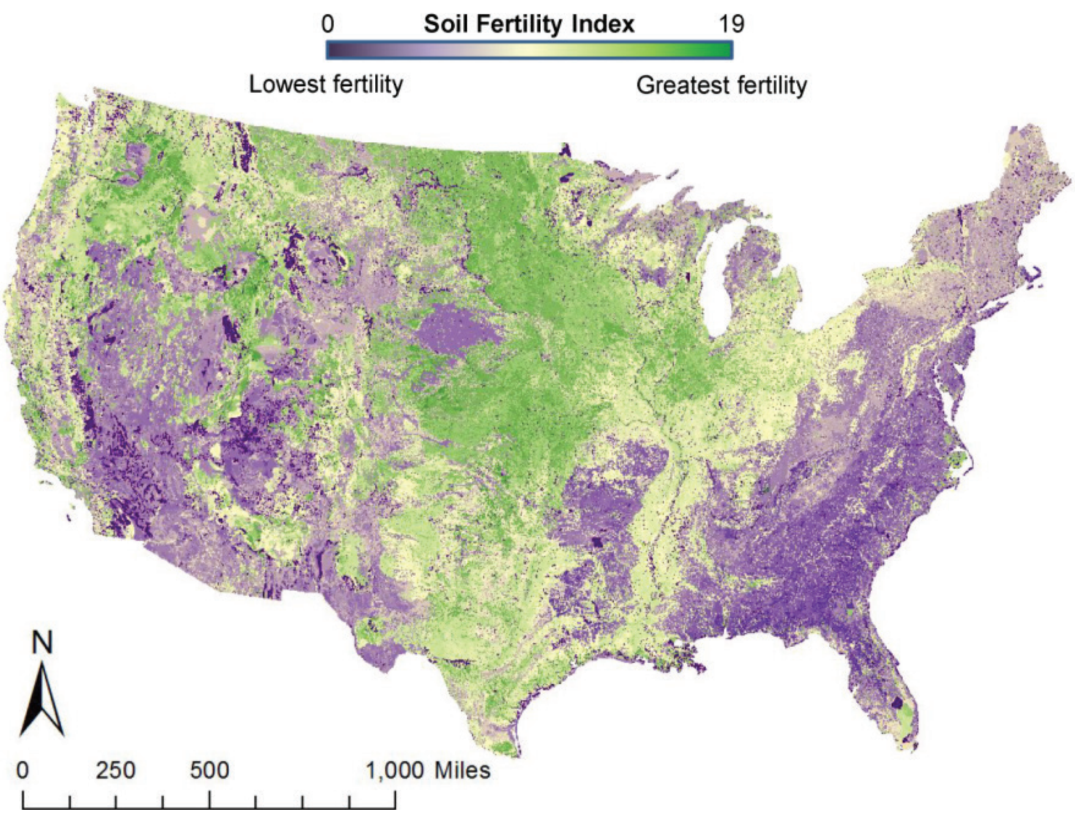

FIGURE C-3 Soil fertility for different regions in the United States. SOURCE: Schaetzl et al., 2012; Day et al., 2016. Reprinted with permission from Springer.

agriculture causes changes in soil properties and can enhance the risk of erosion (Powlson et al., 2011). The richest soils are in the Midwestern “breadbasket” and the upper Great Plains. The Mississippi Valley and the southern Great Plains also have fertile soils. But much of the east, southwest, and mountain states have low fertility and require soil amendments.

The industrialized agricultural system is highly energy intensive and consumed about 16 percent of U.S. energy used in 2007 (Canning et al., 2010; Hamilton et al., 2013). The total U.S. food system (i.e., farms, transportation, processing, storage, preparation, etc.) consumes more than 7 units of energy to deliver 1 unit of edible food energy (Heller and Keoleian, 2000).

An important consideration for urban sustainability is food. Clearly, cities must have sufficient food, both in quantity and healthfulness, to be sustainable. Prior to the industrial revolution, cities obtained most of their food from their local “foodshed.” Local foodshed refers to food-producing areas inside and within a relatively short distance of the city (e.g., 100 km). With the industrial revolution, agriculture has gone from being local to global, and most food comes from far distances.

Feeding megacities from local production is not feasible. If 100 percent of the current agricultural production of New York State was allocated to New York City, it would meet only 55 percent of the city’s demand (Peters et al., 2009). In regions of high population density, demands among cities for food limits the ability to meet demand from local or regional production. In New England, local production can only meet 16 and 36 percent of the region’s plant- and animal-based food demands, respectively (Griffin et al., 2014). The City of Philadelphia might be able to be fed from a 100-mile radius if the demand of other cities were ignored. However, in the Northeast, regional food demand is far greater than the supply (Kremer and Schreuder, 2012). Low-meat or vegetarian diets can reduce land requirement to less than 30 to 40 percent (Balogh et al., 2011).

Food production from local foodsheds could satisfy the majority of U.S. food demand, including that of most small to mid-sized cities (assuming that current local crop production could be changed to provide a well-rounded diet) (Zumkehr and Campbell, 2015). Sufficient capacity of local or regional production to meet urban or regional demand has been reported in studies for small cities in upstate New York, southeastern Minnesota, and the Midwestern U.S. region (Galzki et al., 2014; Hu et al., 2011; Peters et al., 2009), but not for Willamette Valley in Oregon (Giombolini et al., 2011).

Other factors must be considered in supplying food to cities, such as lower production or crop failure due to climate variability, lack of local production of oils and grains that make up much of dietary calories, competition of food crops with nonedible or export crops, mismatch between local supply and demand, and the costs and resources required for transport (Desjardins et al., 2010; Giombolini et al., 2011). In a larger context, most foodshed analyses do not take into consideration energy and material inputs needed to sustain local food systems, which are often as reliant on nonrenewable energy resources as is agriculture in general. Food production in cities must also deal with contamination problems (Wortman and Lovell, 2013). Finally, significant food production in cities would require that large numbers of city people become farmers!

SYNTHESIS

The trends discussed in this section will affect cities to different degrees. Large cities are especially at risk because of their high demand for energy and resources, and may require innovative ways of obtaining and using those resources more efficiently and effectively. Dense urban cores are functionally integrated with the entire metropolitan areas and likely cannot exist without this larger area. The supply lines that support cities stretch across the globe so that cities are dependent on the globalized economic system that will be impacted by rising energy costs.

The least sustainable region of the United States will likely be the Southwest from the Great Plains to California, primarily because of climate change that will lead to less water for people, agriculture, and natural systems. This region has a high population, especially California, and low levels of ecosystem services. Population in the Southwest is highly concentrated in urban areas, all with uncertain water supplies. Much of the economy of the Southwest is dependent on tourism and discretionary income spending. Coastal areas will be impacted also because of stronger storms and sea-level rise.

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