A BETTER CITY

REPORT SUMMER 2016

STATE OF THE BUILT ENVIRONMENT

GREATER BOSTON'S INFRASTRUCTURE


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ACKNOWLEDGMENTS

Any report of this scope and magnitude requires the assistance of many organizations and individuals. We gratefully acknowledge the time and effort put forward by members of our Advisory Committee, by the many who helped supply us with data, and by those who provided us with extraordinary advice. We could not have accomplished this work without their good work and good wishes. To the extent that our report is a useful addition to the dialogue about Greater Boston's infrastructure, we owe much to them. To the extent that segments of our analysis ultimately prove inaccurate or off-base, the responsibility lies entirely with us.

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A Better City is a diverse group of business leaders united around a common goal—to enhance Boston and the region's economic health, competitiveness, vibrancy, sustainability and quality of life. By amplifying the voice of the business community through collaboration and consensus across a broad range of stakeholders, A Better City develops solutions and influences policy in three critical areas central to the Boston region's economic competitiveness and growth: transportation and infrastructure, land use and development, and energy and environment.

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The Kitty and Michael Dukakis Center for Urban and Regional Policy at Northeastern University conducts interdisciplinary research, in collaboration with civic leaders and scholars both within and beyond Northeastern University, to identify and implement real solutions to the critical challenges facing urban areas throughout Greater Boston, the Commonwealth of Massachusetts, and the nation. The Dukakis Center's collaborative research and problem-solving model applies powerful data analysis, a bevy of multidisciplinary research and evaluation techniques, and a policy-driven perspective to addressing a wide range of issues facing cities and towns.

AUTHORS
- Barry Bluestone
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PREFACE

For nearly fifteen years, the Dukakis Center for Urban and Regional Policy at Northeastern University has been producing an annual *Greater Boston Housing Report Card*. That report series has helped policymakers, citizens, business leaders, and the media keep track of the region's housing needs. It has kept attention trained on a variety of housing issues and, in some cases, has led to action to increase housing supply.

A Better City has provided our research staff the opportunity to extend this type of research to an understanding of Greater Boston's built environment and to project the region's infrastructure needs through 2030. We hope this report will stir dialogue and debate over how to meet our need for transportation, energy, water, sewerage, and open space, and how to render the region more resilient in the face of climate change, sea-level rise, and storm surge.

Scores of individuals in many organizations helped provide the data that form the basis of our analysis in the pages that follow. We cannot thank them enough for their assistance and encouragement.

While we have made every effort to produce a report grounded in strong data and reasonable projection techniques, we recognize that all of our data should be carefully vetted. We look forward to expanding our efforts in next year's report and, in that spirit, welcome ideas for improving upon or adding to these baseline numbers and forecasts.

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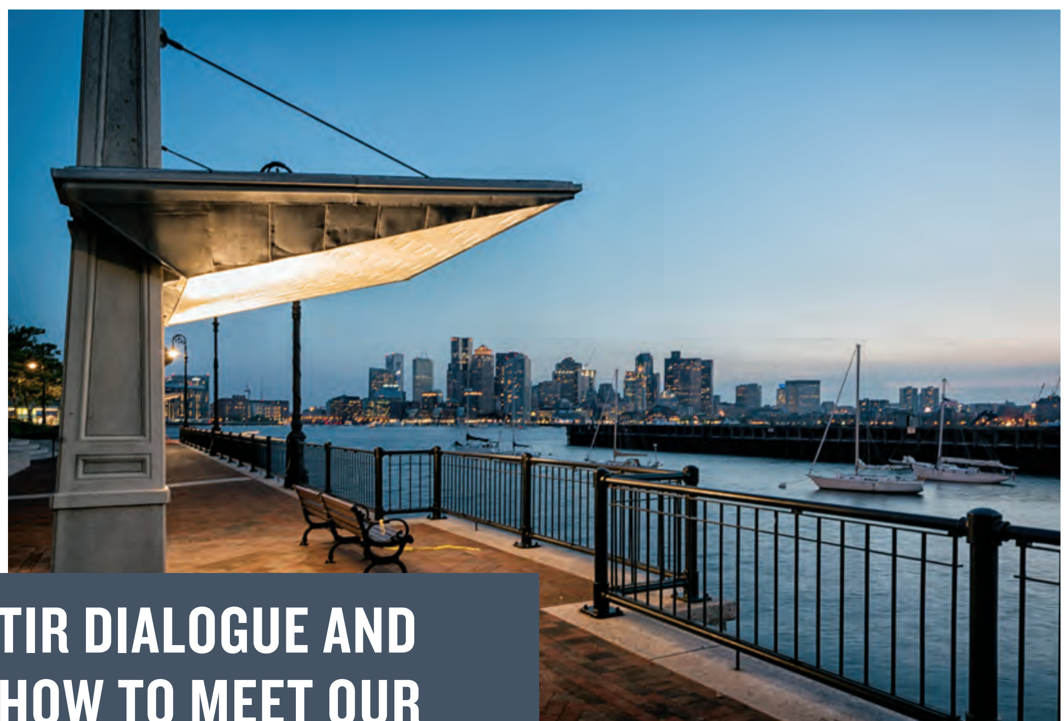

"WE HOPE TO STIR DIALOGUE AND DEBATE OVER HOW TO MEET OUR NEEDS FOR TRANSPORTATION, ENERGY, WATER, AND OPEN SPACE."

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LETTER FROM THE PRESIDENT & CEO

Dear Colleagues:

A Better City is at a key point in its organizational development. We are celebrating the start of our next decade by launching a series of new initiatives related to our recently adopted strategic plan. This *State of the Built Environment* report and accompanying conference was identified as a major priority. This report will strengthen the focus in our three core areas: transportation and infrastructure, land use and development, and energy and environment. We are very pleased to have retained and funded Northeastern University's Dukakis Center for Urban and Regional Policy to lead this comprehensive research report and assessment.

A Better City's business and institutional leaders hope that this detailed assessment will help catalyze planning, policies and action to sustain and grow Boston's and the region's economy and global competitiveness. To meet these goals we will need a 21st-century infrastructure system.

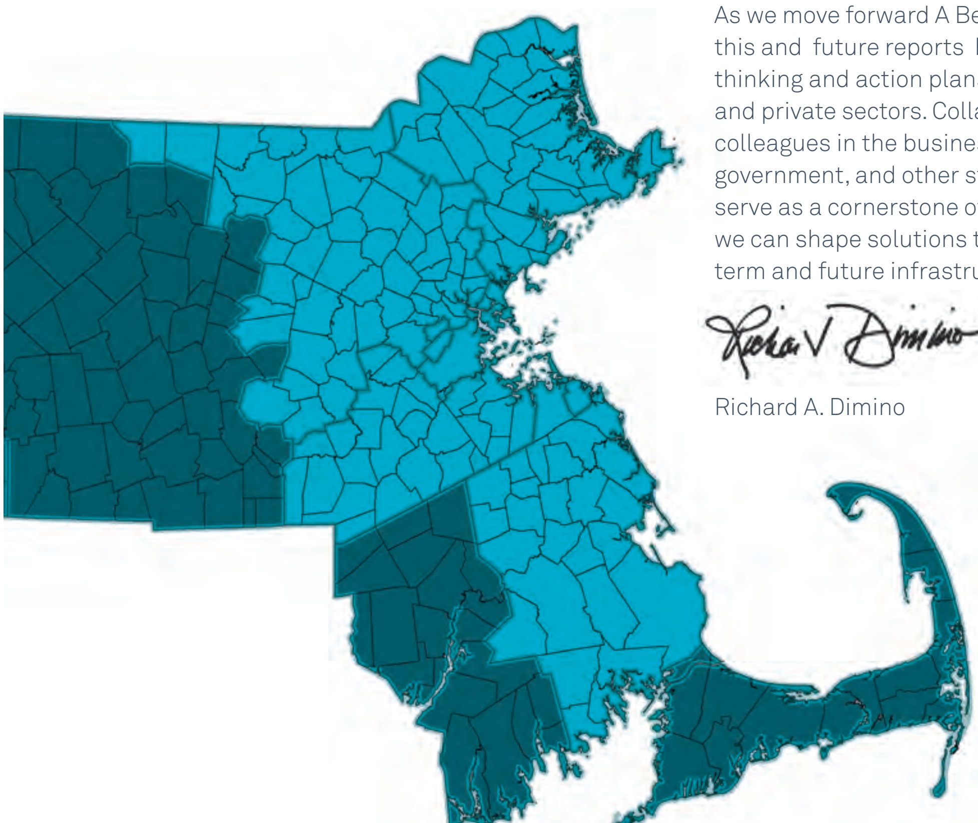
We appreciate the significant time and effort devoted to this report by the Dukakis Center team. We also wish to thank a number of state and city agencies together with the Metropolitan Area Planning Council and our advisors for their contributions.

We hope that this report will serve as a valued resource for metro region infrastructure information and data. We intend to share this report and its contents broadly with stakeholders, collaborators and the public.

Finally, A Better City intends to regularly assess the condition of Greater Boston's infrastructure. We have with this report a good start and a preliminary baseline, but also know that we have more work to do. Your comments regarding this report will be greatly appreciated as we seek to make improvements in future efforts.

As we move forward A Better City hopes this and future reports help to inform the thinking and action plans of both the public and private sectors. Collaborating with our colleagues in the business community, government, and other stakeholders will serve as a cornerstone of our efforts. Together we can shape solutions to address our near-term and future infrastructure challenges.

Richard A. Dimino



EXECUTIVE SUMMARY

EXECUTIVE SUMMARY

Since the 1990s, Greater Boston's population and economy have been rebounding at a rapid pace, but such formidable growth places heavy burdens on the region's infrastructure. The region's population alone has jumped more than 13 percent since the 1990 Census, requiring significant improvements in the built environment. In the past, the region has faced such challenges with major infrastructure investments, from filling in the Charles River marshes to form the Back Bay to building Route 128, the nation's first circumferential limited-access highway.

Today, we face equally daunting infrastructure challenges. In addition to planning for population and business growth—requiring additions to our transportation system, energy grid, water, sewer, and recycling capacity, and conservation land—we must prepare for the extreme effects of climate change. Not only will the area experience increasingly severe weather, but climate scientists predict that Boston will be among the U.S. cities hardest hit by rising sea-levels and storm surge.

The purpose of this first report, modeled after the Dukakis Center's annual *Greater Boston Housing Report Card*, is to take the measure of current infrastructure throughout the 147 communities in Suffolk, Essex, Middlesex, Norfolk, and Plymouth Counties, and to project the requirements for augmenting the built environment to meet the region's needs in 2030. Our ultimate aim is to assist in appropriate planning for the anticipated growth of the region.

Between 2010 and 2030, we project that the population in the five counties of Greater Boston will have grown by nearly 430,000, or 10.5 percent. Where will they live? How will they get to and from work, school, and other essential destinations? Will their communities be outfitted with appropriate levels and types of transportation, energy, water and sewage capacity, recycling and waste facilities, and open and conservation land to suit their environmental and economic needs, ensuring a growing and prosperous economy? Through careful longitudinal tracking of multiple systems and demographic shifts across many jurisdictions, we hope to provide resources essential to the sort of state-of-the-art performance-based planning that will be imperative in the years ahead. **Based on our projections, the conclusion is pretty straightforward. As a region we must find ways to expand our infrastructure, enhance the efficiency with which we use it, and find ways to conserve energy, water, and open space in order to accommodate the population growth and expanded economic output we project through 2030. The complexity lies in determining which course to take and ultimately how to pay for it.**

METHODOLOGY AND RESOURCES

With this initial report, a template for future studies, we have identified dozens of data sets that track demand and performance in four principal types of infrastructure: transportation; energy; water and sanitation; and environment, open space, and resilience. A large number of public sector agencies and private sector companies provided data to make this project possible. For our projections we relied heavily on population and labor force forecasting through 2030 by the Metropolitan Area Planning Council (MAPC). We have harvested data from innumerable siloed sources to prepare one report for easier assimilation by policymakers, business leaders, and citizens. Using the MAPC projections, we have been able to develop estimates for household use and business consumption of infrastructure resources so that we can estimate how much and what kinds of service delivery will likely be needed to accommodate a growing and demographically varied population while advancing a strong economy. In the future, these numbers will undoubtedly shift as new and more recent data become available and, particularly in the energy and waste sectors, systems achieve efficiencies. For now, however, we are convinced that the figures included in this inaugural report represent a strong baseline for current use and anticipated future demand.

Our 2030 projections are based on several **behavioral assumptions**, which fall under the rubric of "business as usual." That is, we assume no change in age-specific labor force participation, no change in transportation modes in use today, and no efficiency or conservation improvements in energy and water consumption. In future reports, we will work from this baseline to provide counterfactuals —"what-ifs"—projecting scenarios that could result from behavioral change. Our current modeling assumptions are as follows:

- The Greater Boston region will enjoy economic growth more or less in line with the 1.2 percent annual increase in productivity the U.S. enjoyed between 2006 and 2015, and small annual increases in the size of the labor force as the number of younger workers grows somewhat faster than the number of retiring Baby Boomers.
- The number of commuters will increase with the size of the labor force and, in this baseline projection, will continue to use the same age-specific and region-specific transit modes they use today.
- The use of energy, water, and sewage per household and per business enterprise will remain the same as today.
- Demand for air travel and seaport cargo will grow at the same annual rate as they have over the past decade.
- Sea-level rise and storm surge will match the best forecasts of regional climatologists.

CURRENT INFRASTRUCTURE DEFICITS

Even today, *before* we experience additional population growth and economic expansion, much of Greater Boston's infrastructure is inadequate, deteriorating, and out of date.

- According to MassDOT, 37 percent of state-owned roads are currently in "poor" or only "fair" condition. At the present rate of maintenance, 79 percent of the state's roadways could be in poor to fair condition by 2025. In addition, Greater Boston's 2,115 bridges could be improved. Eleven percent are either closed to traffic or functionally deficient, and nearly 20 percent are restricted from use by heavy commercial vehicles.
- Highway congestion has become so bad that typical AM and PM commuting speeds within Greater Boston on the Mass Pike, I-93, Routes 3 and 24, and I-495 are below 25 mph and on many segments below 20 mph.
- MBTA vehicles are in desperate need of maintenance and modernization. More than a third of operating Red Line cars were acquired more than 40 years ago, and 44 percent of Green Line trolley rolling stock dates back to 1989. To reach a "state of good repair," the T calculates the system needs over $7 billion in improvements. The transit system also faces a number of capacity constraints.
- While Logan Airport has been able to keep up with demand for passenger and freight service through the use of larger aircraft and higher load factors, the Conley container port terminal has neither the water depth nor crane capacity to handle any of the new larger container vessels.
- While Massachusetts and Boston have made great strides in reducing Greenhouse Gas Emissions, meeting national goals by 2030 will require steady improvement in energy efficiency and conservation.
- Greater Boston is blessed with nearly 900 miles of hiking trails, but the Department of Conservation and Recreation reports that less than half are considered in good repair.

- While strides have been made in recycling, as of 2010 less than a third of all waste is being recycled.
- Sea-level rise and storm surge are inevitable, but much of the built environment near the Boston waterfront is not currently resilient.

DEMOGRAPHIC AND ECONOMIC OUTPUT PROJECTIONS

Such is the current state of Greater Boston's infrastructure. But based on our behavioral assumptions and projection methodology, we expect to see the following changes by 2030—all of which will tax the region's infrastructure further:

- The population of the five counties of Greater Boston (Essex, Norfolk, Middlesex, Plymouth, and Suffolk) will increase from a little less than 4.1 million in 2010 to 4.5 million in 2030: + 428,000. This amounts to an increase of 6.6 percent between 2010 and 2020 and another 3.6 percent between 2020 and 2030.
- While the region's young population (age 0–24) is projected to decline by nearly 100,000 between 2010 and 2030, along with a loss of 57,000 45 to 64 year olds, the number of 25 to 44 year olds is expected to increase by nearly 140,000. The number of older residents—aging Baby Boomers—will skyrocket by more than 380,000.
- The population will not expand uniformly throughout Greater Boston. In the Inner Core, including Boston and the cities close by, we project the population to grow by 17.5 percent by 2030. In the Regional Urban Centers such as Lawrence, Lowell, Lynn, and Quincy, the population is expected to increase by 12 percent. Meanwhile, in the Suburbs surrounding the Inner Core and Regional Urban Centers, the population is expected to increase by just 4.3 percent—as fewer young people choose to live there and a significant number of Baby Boomers move away or pass on.
- Overall, as a result of an increase in 25-44 year olds offset by the large increase in older residents who retire from the labor force, Greater Boston's labor force will grow much more slowly than its population. We project a total labor force increase of 6.4 percent between 2010 and 2030 and less than 2 percent between 2020 and 2030.

"TO REACH A 'STATE OF GOOD REPAIR,' THE T CALCULATES THE SYSTEM NEEDS OVER $7 BILLION IN IMPROVEMENTS."

- Economic output by existing firms and new ones will expand by 13.1 percent between 2010 and 2020 and by another 12.9 percent between 2020 and 2030. As such, over the full 2010–2030 period, we project a near 28 percent increase in economic activity in Greater Boston.

KEY FINDINGS: PROJECTED FUTURE INFRASTRUCTURE DEMAND

Based on these behavioral assumptions and projections, we have identified the following increases in infrastructure demand:

TRANSPORTATION

- **Commuting**: Across all of Greater Boston, we project that there will be an additional 117,000 commuters between 2010 and 2030—5.2 percent more than the 2.25 million in the labor force in 2010.
    - ***Highway Use***: According to our projections, we expect to see at least 80,000 more autos, trucks, and tractor trailers on Greater Boston's roads and highways by 2030, an increase of nearly 5 percent.
    - ***Public Transit:*** The region can expect to have to accommodate more than 14,000 additional subway commuters, more than 11,000 additional bus and trolley commuters, and more than another 1,000 daily commuter rail customers. This represents a 6.8 percent increase in subway and bus/trolley use by commuters and nearly a 3 percent increase in commuter rail. Constrained roads and highways, and significant growth in transit-oriented development may lead to even greater increases in transit demand.
- **Air Travel**: If passenger air travel continues to grow at the same pace as it did over the 2005–2015 period, Logan Airport will have to find a way to handle 63 percent more passengers on domestic and international flights annually.
- **Seaport**: If the Conley Terminal is going to keep up with demand for seaport cargo, it will need to find a way to increase its container ship capacity by 93 percent—increasing its ability to handle TEU containers from its current 181,000 per year to 350,000 a year by 2030.

ENERGY

- **Electricity**: In terms of electricity demand in the five-county region, we project the need for adding 1.25 million megawatt hours of service to accommodate a 10.2 increase in residential service, and a 27.7 percent increase in commercial and industrial use. This amounts to adding overall 17.4 percent more electric power to the Greater Boston grid.
- **Natural Gas**: In terms of natural gas for residents and businesses, we project increased demand of 14.3 percent between 2010 and 2030.

WATER AND SANITATION

- **Water/Sewage**: We project increased water demand by residents, businesses, municipal governments and large nonprofit institutions of nearly 13.5 percent. Total sewage use will rise by only 5 percent since we project no increase in average daily rain and snow runoff between 2010 and 2030.

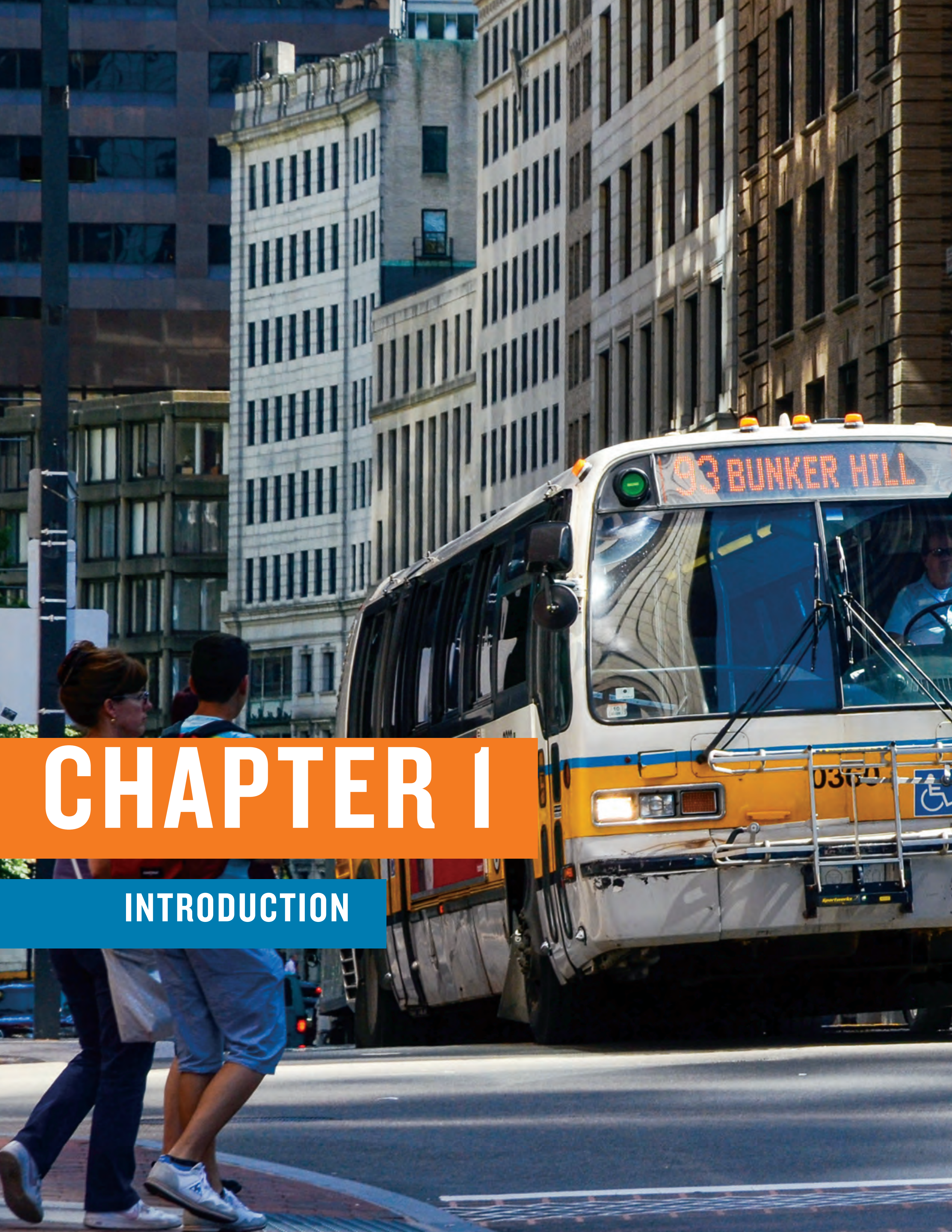
ENVIRONMENT, OPEN SPACE, AND RESILIENCE

- **Trash/Recycling:** Overall, we will need trash disposal and recycling facilities to process an additional 130,000 tons of waste per year—7.9 percent more in 2030 than in 2010.
- **Sea-Level Rise:** We need to focus on making large parts of Greater Boston near Boston Harbor and along the seacoast more resilient to expected sea-level rise and storm surge that could inundate large swaths of the region. The need will be most imperative in Boston proper, due to the density of its commercial infrastructure and housing.

A host of ideas—old, new, and unforeseen—must be evaluated in terms of their cost-effectiveness and the relative benefits they provide to meeting our future infrastructure needs. First, though, we must recognize the full extent to which we will have to add to Greater Boston's built environment. Only then can we balance investments in new infrastructure with conservation, new technology, and efficiency measures in ways that meet the needs of a growing population and an expanding economy.

CHAPTER 1

INTRODUCTION




QUAKER LN
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NO
STOPPING
ANY
TIME

CHAPTER 1

Greater Boston is no stranger to bold infrastructure plans. From the leveling of Boston's five great hills to create new land for development (early 19th century) and later the Back Bay land-infill project (1857–1900) to the installation of the nation's first subway system (1897) and the gargantuan venture dubbed the Big Dig (2006), the citizens of Boston proper and the region have exercised uncommon foresight, imagination, and engineering acumen in accommodating the built environment to shifts in population, transportation technology, and taste. The 146 communities that form a thick ring around Boston have also been twisted into new shapes, as postwar federal highway and housing policies turned small towns into suburbs—many later served by commuter rail—and the completion of the Tobin Bridge (1950) and Route 128 (1955), the nation's first outer beltway, grounded the so-called Massachusetts Miracle.

For all the ingenuity Greater Boston has shown in the past, however, we now face infrastructure challenges that are substantial in scale and complexity. In addition to planning for population and business growth, we must prepare for the extreme effects of climate change. Not only will the area experience increasingly severe weather, but climate scientists predict that Boston will be among the cities hardest hit by rising sea levels. The challenge before us is clear: to prepare the region's built environment for a growing number of households and businesses, while ensuring that our infrastructure is both adaptable to climate change and participates in mitigating greenhouse gas emissions.

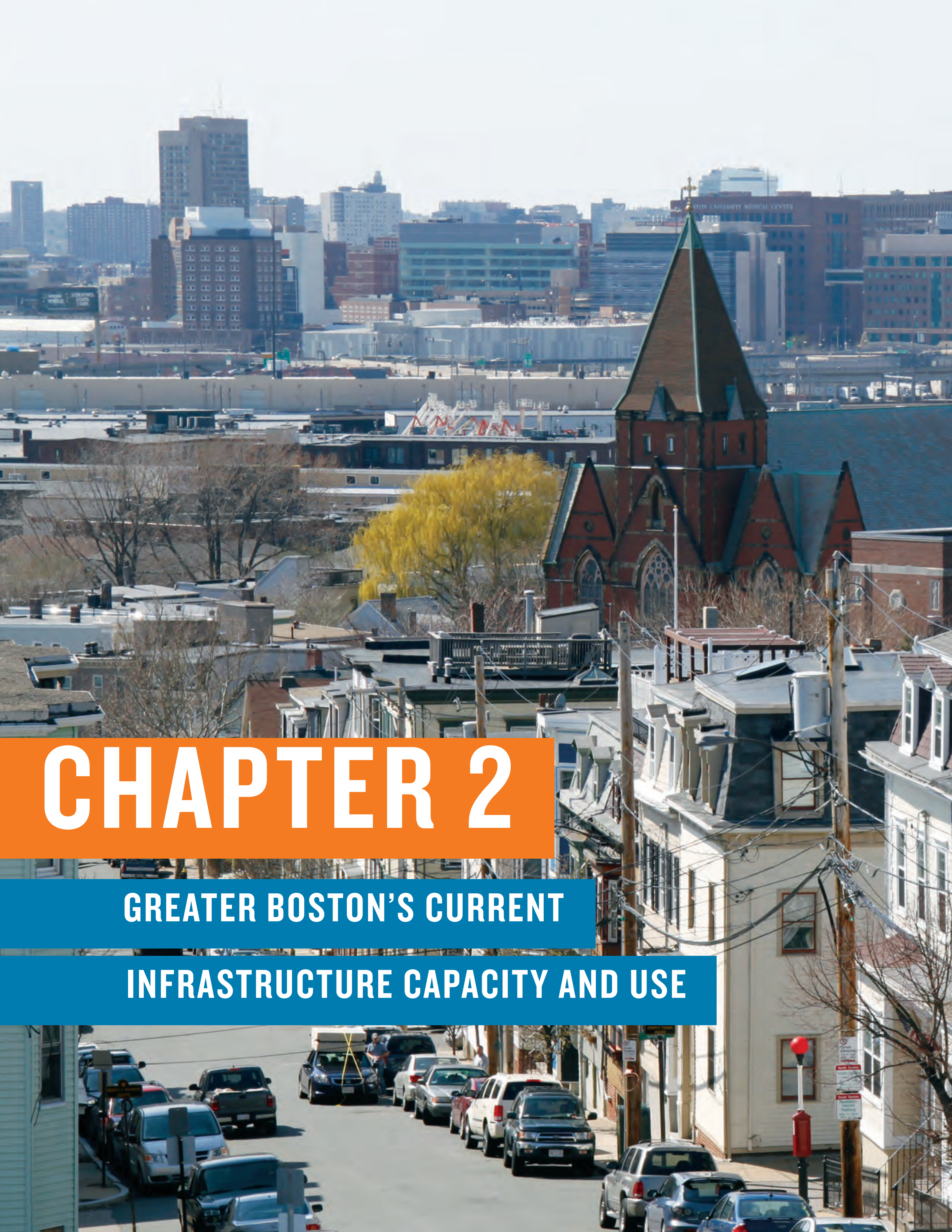
It is a tall order, one that requires careful tracking over time of multiple systems and demographic shifts across many jurisdictions. The purpose of this first annual report is to lay the groundwork for just such tracking. Modeled after the Dukakis Center's annual *Greater Boston Housing Report Card*, which launched in 2002, it covers the 147 communities in Suffolk, Essex, Middlesex, Norfolk, and Plymouth Counties. Defined in this way, Greater Boston's population in 2010 included nearly 4.1 million residents, and here we project it to grow by nearly 430,000 by 2030, or 10.5 percent. Where will they live? How will they get to and from work, school, and other essential destinations? Will their communities be outfitted with appropriate levels and types of transportation, energy, water and sewage capacity, recycling and waste facilities, and open and conservation land to suit their environmental and economic needs, ensuring a growing and prosperous economy? We aim to find out.

With this initial report, a template for future studies, we have identified dozens of data sets that will be updated each year. Most of the data we gathered are for the 147 targeted municipalities that comprise Greater Boston. A large number of public sector agencies as well as private sector companies provided data to make this project possible. For our projections we relied heavily on population and labor force forecasting through 2030 by Boston's regional Metropolitan Area Planning Council (MAPC).[1]

"WE NOW FACE INFRASTRUCTURE CHALLENGES THAT ARE SUBSTANTIAL IN SCALE AND COMPLEXITY."

With all these (and other) organizations gathering data and churning out what has come to be known as "performance-based planning" recommendations, readers might well wonder how this report differs from the rest. In today's parlance, what is the "value-add"? Like MAPC, we bring together infrastructure capacity and use data harvested from innumerable siloed sources into one report for easier assimilation by policymakers, business leaders, and citizens.[2] But we also break down the data further into household and *business* consumption, and convert labor force data into firm output projections. Both moves enable us to project where, how much, and what kinds of service delivery will likely need to be increased to accommodate a growing and demographically varied population while advancing a strong economy. In the future, these numbers will undoubtedly shift as new and more recent data become available and, particularly in the energy and waste sectors, systems achieve efficiencies. For now, however, we are convinced that the figures included in this inaugural report represent a useful baseline for current use and anticipated future demand.

To streamline our presentation of so much detail, we have arranged the data on current use into four broad infrastructure types: transportation, energy, water and sanitation, and environment and open space. These data are presented in chapter two, which follows. Chapter three covers our population and employment projections through 2030, based on extensive data modeling efforts. Chapter four projects the five-county region's infrastructure needs given projected demographic changes and growth in business activity. **Based on our projections, the conclusion is pretty straightforward. As a region we must find ways to expand our infrastructure, enhance the efficiency with which we use our infrastructure, and find ways to conserve energy, water, and open space in order to accommodate the population growth and expanded economic output we project through 2030. The complexity lies in determining which course to take and ultimately how to pay for it.**



CHAPTER 2

GREATER BOSTON'S CURRENT INFRASTRUCTURE CAPACITY AND USE


Street
Cleaning

CHAPTER 2

For a report of this nature we are compelled, like Lewis Carroll's White Rabbit, to "begin at the beginning," to establish a baseline portrait of Greater Boston's current infrastructure and the demands made on it. With that in place, we can then project in later chapters the region's future demand, taking into account a growing population supported by a developing economy with greater infrastructure needs, and a somewhat slower growing labor force—thanks in part to retiring Baby Boomers.

This chapter is broken down into four sections, covering transportation, energy, water and sanitation, and environmental and open-land infrastructure. We have shared all the relevant data we were able to acquire, with anticipation that in future years we will have yet more data sets that will enable us to refine our research. We have also included data on currently unused capacity where available.

Overall, Greater Boston's infrastructure is doing a relatively good job of meeting the population's current resource needs. Still, it is generally at capacity, having absorbed an uptick in population of more than 330,000 residents since 2000.[3] And as most everyone knows who commutes to work using the region's roads and highways or the MBTA, the area's transportation system is not meeting current demand and certainly not potential demand.

Let us begin, then, with our most visible infrastructure system, and the one that causes the most immediate stress when it is not functioning properly: transportation.

TRANSPORTATION INFRASTRUCTURE

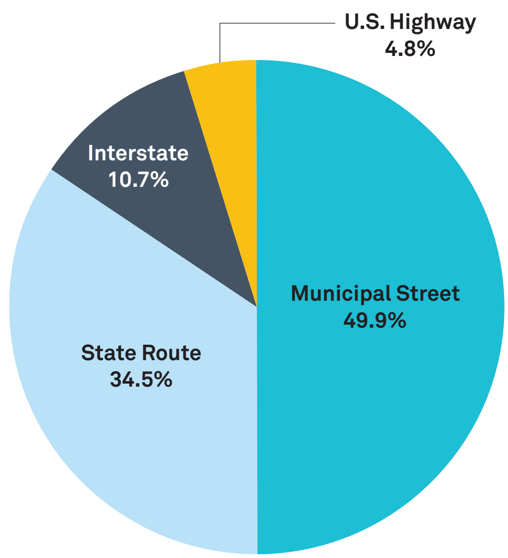
As in all urbanized areas throughout the United States, the people of Greater Boston are highly dependent on automotive travel for commuting to work and school, for recreation and service, and for shopping. Work commuting routes and schedules, however, dominate traffic patterns. As **Table 2.1** shows, two-thirds of the labor force gets to and from work on area roads by auto or truck, motorcycle, or taxi. Currently, 18.5 percent use some form of public transit including subway, bus, trolley, commuter rail, or ferryboat. More than 9 percent of commuters reach work by walking or cycling, while 4.5 percent "commute" (often electronically) by working at home.

ROADS

As **Table 2.2** illustrates, Greater Boston has a little more than 500 miles of Interstate highway and another 230 miles of U.S. Highways and more than 1,600 miles of state routes. The region's cities and towns are responsible for nearly 2,400 miles of road. **Figure 2.1** shows the distribution of these roadways. The Interstates and U.S. Highways make up about 16 percent of the roadway miles—although a much higher percentage of "lane-miles." A third of the road miles in the region are state routes and nearly half are municipal streets and roadways.

According to MassDOT, 37 percent of state-owned road miles (excluding Interstates) are currently in "Poor" or "Fair" condition. DOT projects that given current investments in pavement upkeep, road conditions could deteriorate further to the point where 79 percent would be in "Poor" or "Fair" condition by 2025.[4] Lack of repair to the region's highways costs motorists in vehicle repair and depreciation and increased tire wear.[5]

FIGURE 2.1: Greater Boston Roadway Composition by Road Type



Source: MassGIS (MassDOT, "Massachusetts Department of Transportation Roads" Data Layer; June 2014.)

TABLE 2.1: Greater Boston Commuters by Age and Transit Mode, 2009-2014

	16-24	25-44	45-64	65-74	75+	ALL AGES	% BY MODE
Auto/Truck	165,566	644,811	617,077	59,956	10,233	1,499,049	66.7%
Motorcycle	158	1,269	823	6	0	2,253	0.1%
Bus/Streetcar	35,123	77,681	50,056	4,227	658	165,942	7.4%
Subway	38,901	113,570	54,879	5,141	409	210,824	9.4%
Rail	3,273	18,854	13,874	1,037	106	36,910	1.6%
Taxi	1,501	2,422	1,604	177	27	5,619	0.3%
Ferryboat	123	1,035	711	23	51	1,903	0.1%
Bicycle	4,441	16,747	9,275	588	119	31,094	1.4%
Walk	64,365	72,405	39,437	4,696	1,280	176,437	7.9%
Other	3,721	6,725	5,205	404	29	15,786	0.7%
Work at Home	9,928	34,479	46,442	7,031	1,415	100,309	4.5%
Total Workforce	327,100	982,011	839,383	83,306	14,326	2,246,126	100.0%

Source: U.S. Census PUMS Files

TABLE 2.2: Length of Roadways by County and Road Type in Miles

	ESSEX	MIDDLESEX	NORFOLK	PLYMOUTH	SUFFOLK	GREATER BOSTON
Municipal Street	470.9	785.2	476.5	299.2	350.4	2,382
State Route	345.0	560.9	238.7	424.6	78.7	1,648
Interstate	131.6	186.7	103.1	57.4	33.8	513
U.S. Highway	44.8	89.1	31.9	47.2	17.8	231
TOTAL	992.3	1,621.9	850.3	828.5	480.7	4,774

Source: MassGIS ("Massachusetts Department of Transportation (MassDOT) Roads" Data Layer; June 2014)

BRIDGES

Roadway efficiency is, of course, dependent on the quality of the bridges that sustain continuous traffic movement. **Table 2.3** shows that the condition of Greater Boston's 2,115 bridges could be improved. Eleven percent are either closed to traffic or functionally deficient, while nearly 20 percent restrict heavy commercial traffic.

TABLE 2.3: Greater Boston Bridges

	NUMBER	PERCENT
Number of bridges	2,115	100%
Number of functioning bridges	1,468	69.4%
Number of bridges with Limited Load Factor	414	19.6%
Number of functionally deficient bridges	209	9.9%
Number of bridges closed to traffic	24	1.1%

Source: MassDOT

TRAFFIC

Consistent data are not available for *local traffic congestion* that can slow access to major highways, but **Table 2.4** confirms what automotive commuters know instinctively: traffic moves at a snail's pace on our major routes during the rush hours of 7 to 9 AM and 4 to 7 PM. At *best*, drivers move 23.1 mph on average going northbound away from Boston on I-93 during the evening rush hour. At *worst*, drivers move 10.3 mph on average going northbound toward Boston on US 3 during the morning rush hour. Clearly, such congestion (which, due to population growth, has likely grown worse since 2012, for which the most recent numbers are available) risks hampering the region's economy and quality of life.

TABLE 2.4: Greater Boston's Major Highways Average Rush Hour Speeds (mph), 2012

I-495	NORTHBOUND	SOUTHBOUND
Average AM Congested Speed	17.5	11.7
Average PM Congested Speed	13.9	15.9
I-93	**NORTHBOUND**	**SOUTHBOUND**
Average AM Congested Speed	19.6	21.9
Average PM Congested Speed	23.1	19.9
I-95	**NORTHBOUND**	**SOUTHBOUND**
Average AM Congested Speed	18.00	21.4
Average PM Congested Speed	16.1	20.7
RTE 128	**NORTHBOUND**	**SOUTHBOUND**
Average AM Congested Speed	17.7	18.7
Average PM Congested Speed	18.3	18.9
MA 24	**NORTHBOUND**	**SOUTHBOUND**
Average AM Congested Speed	22.4	N.A.
Average PM Congested Speed	19.9	22.5
MA 3	**NORTHBOUND**	**SOUTHBOUND**
Average AM Congested Speed	18.7	16.6
Average PM Congested Speed	15.2	18.0
US 3	**NORTHBOUND**	**SOUTHBOUND**
Average AM Congested Speed	10.3	22.5
Average PM Congested Speed	22.2	17.8
I-90	**EASTBOUND**	**WESTBOUND**
Average AM Congested Speed	20.5	18.3
Average PM Congested Speed	15.6	23.1

Source: MassDOT Express Highway Congestion Data (2012)

PUBLIC TRANSIT

Given the more than 2.2 million commuters in Greater Boston, it is critical to have a public transit system to supplement auto and truck transit. **Table 2.5** provides basic statistics on the region's public transit network. The T operates nearly 1,000 buses with 8,500 bus stops. Counting commuters and other bus passengers, it served nearly 440,000 bus transit users on a typical weekday in 2014. In addition, the system had 215 light rail vehicles (e.g. trolleys) in service, transporting more than 227,000 riders per weekday. Greater Boston has 138 commuter rail stations, serving 129,000 passengers on a typical weekday.

Much of the MBTA fleet and related facilities are in desperate need of maintenance and modernization. MBTA's fleet of vehicles is aging rapidly. Of the 218 Red Line cars, 34 percent were acquired in 1970 and were last re-manufactured in 1985. All of the 120 Orange Line subway cars were built between 1979 and 1981 and have not been re-manufactured. The oldest of the Green Line trolleys—comprising 44 percent of its rolling stock—was built before 1989.

As for its bus fleet, 13 percent of T buses were built before 1996, twenty years ago.[6] According to the MBTA, the system requires $7.3 billion in improvements in order to reach a state of good repair (SGR).[7] Of this total, more than $2.6 billion is needed for investment in buses and trainsets. Another $1.4 billion is required for improved signals, more than $730 million for stations and facilities, and $460 million for MBTA power stations.[8]

As a result of this chronic lack of investment in the T, large sections of the system have been rated as "congested," "highly congested," or "over capacity." According to a 2012 report for the Urban Land Institute and authored by the Dukakis Center, large sections of the Orange Line and the C and D portions of the Green Line, as well as large portions of the Red Line were rated as "highly congested." In downtown Boston, the Green Line was rated as "over capacity," while South Station has been operating well above its designed capacity for commuter rail and Amtrak trains.[9] In addition the 2015 South Boston Waterfront Sustainable Transportation Plan reported that the Silver Line is at or exceeds capacity during peak hour periods.

TABLE 2.5: Public Transit Statistics

Number of buses in daily operation	**991**
Number of bus stops	**8,500**
Number of bus transit riders per weekday	**438,880**
Number of bus transit riders per weekend day	**186,095**
Number of light rail vehicles in daily operation	**215**
Number of light rail stations	**74**
Number of light rail track miles	**26**
Number of light rail transit riders per weekday	**227,645**
Number of heavy rail vehicles in daily operation	**432**
Number of heavy rail stations	**66**
Number of heavy rail transit riders per weekday	**539,315**
Number of commuter rail locomotives	**82**
Number of commuter rail passenger cars	**421**
Number of commuter rail stations	**138**
Number of commuter rail transit riders per weekday	**129,019**
Number of commuter rail transit riders per weekend day	**23,199**
Miles of dedicated busways	**17**
Number of bikes in bike share programs	**1,300**
Percent of Population within 1/2 mile of transit	**29.4%**
Percent of population commuting via public transit for 60+ mins	**30.7%**

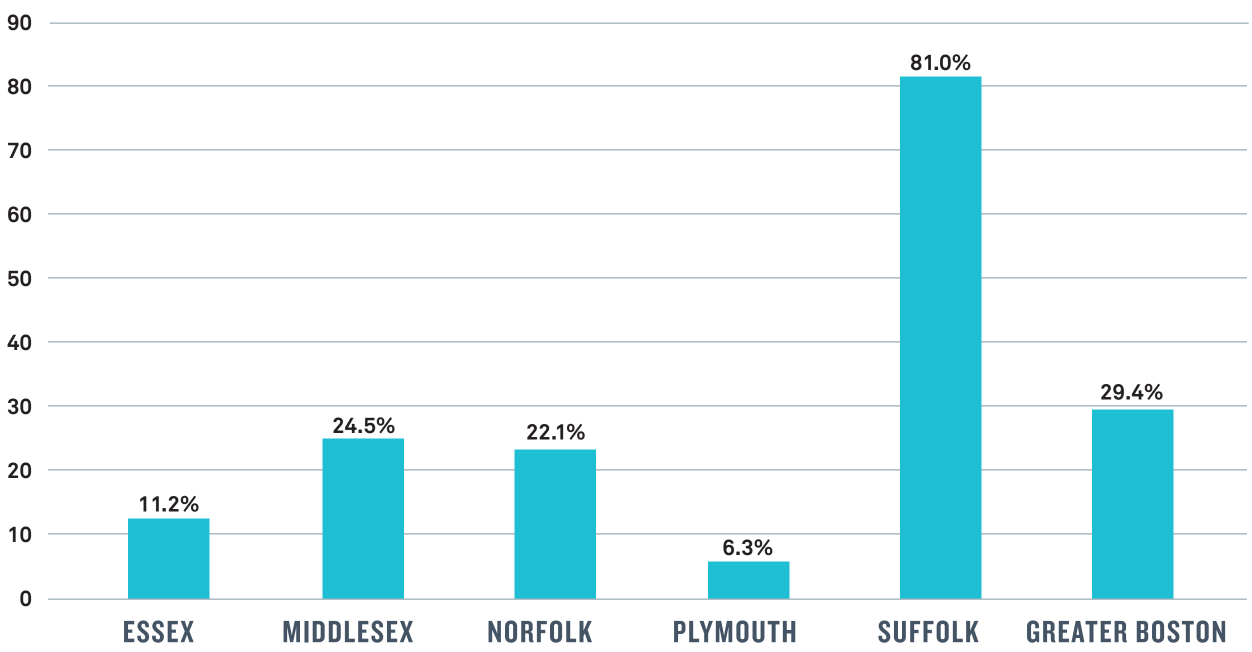
Source: MBTA, tstation.info, "Ridership and Service Statistics: Fourteenth Edition, 2014"

A large majority of Greater Boston's residents have to go a considerable distance to reach a transit stop. While most of Suffolk County and a good part of Middlesex County residents live near public transit stops, across all of Greater Boston less than 30 percent of the population lives within a half-mile of a bus stop, subway station, or commuter rail station. **Figure 2.2** shows, not surprisingly, that more than 80 percent of Suffolk County's population lives within a half-mile of a transit stop. Middlesex County, which has the largest percentage of roadways among all five counties, comes in second, with nearly a quarter of its population living in close proximity to a transit stop.

Once on public transit, nearly 30 percent of riders have commute times of an hour or more, a duration that often equals highway commute times depending on destination.[10]

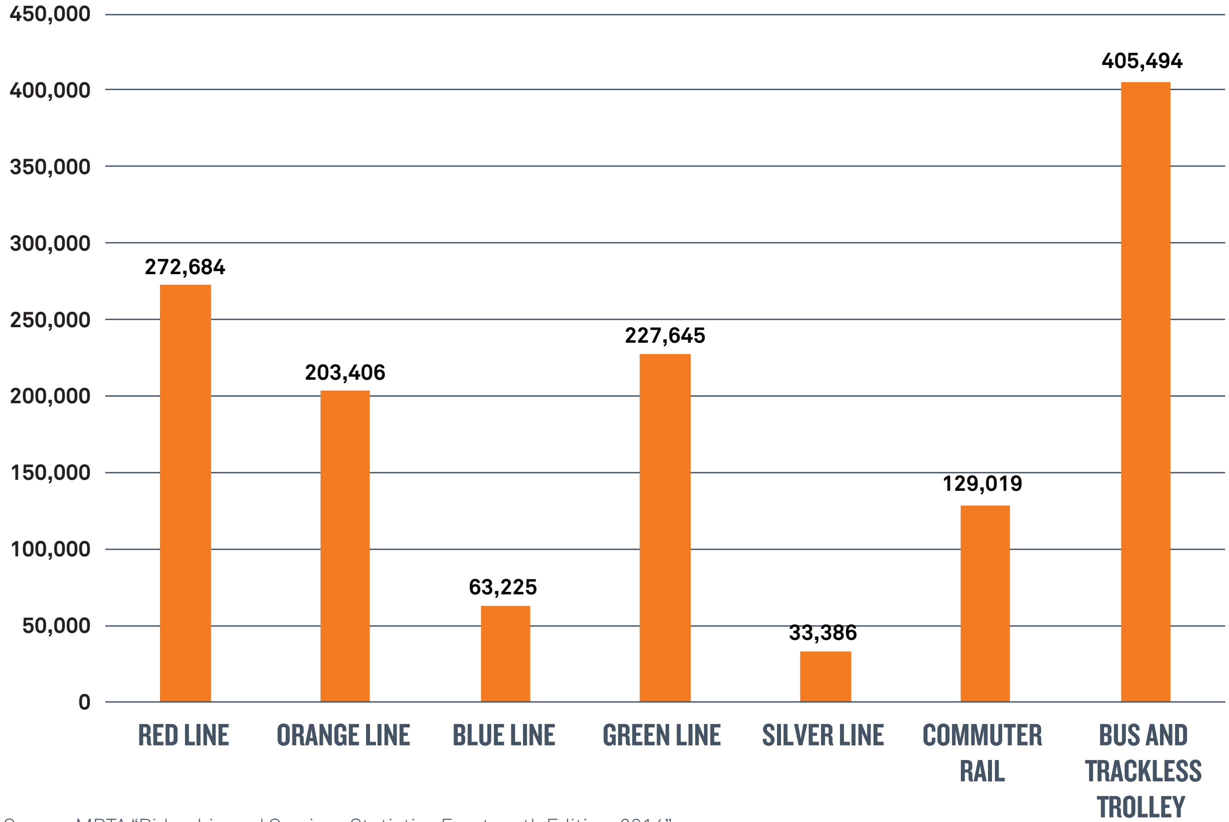
A small number of commuters use the Silver Line, a dedicated busway, and there were more than 1,300 bicycles available through bike-sharing programs in 2010.

FIGURE 2.2: Population Living Within a Half-Mile of Any Transit Stop by County



Source: MAPC and Dukakis Center, tstation.info

FIGURE 2.3: Typical MBTA Weekday Ridership by Line, 2013



Source: MBTA "Ridership and Services Statistics Fourteenth Edition, 2014"

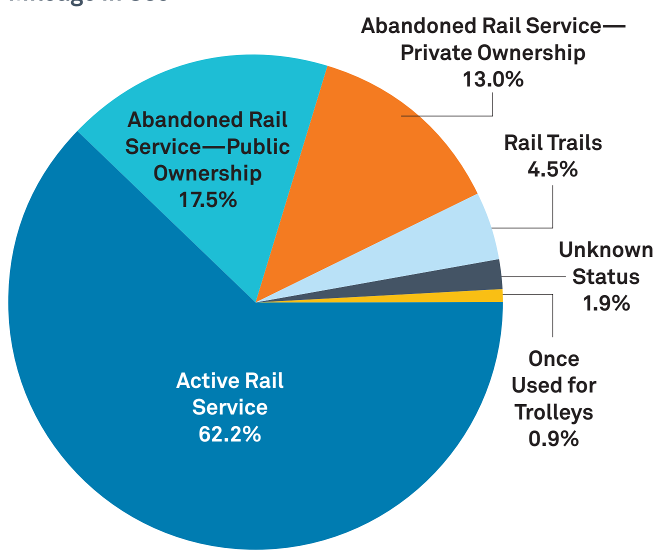
Breaking down weekday transit ridership by MBTA line, **Figure 2.3** reveals that throughout Greater Boston only about 14 percent (129,019) of the region's workers traveled to work by commuter rail during FY2013. Of the remaining ridership (800,346), slightly more than half (406,000) took a bus or trackless trolley to work while nearly 540,000 used one of the four subway rail lines.

RAIL/FREIGHT

Greater Boston is criss-crossed by 1,438 miles of rail track, with 52 percent dedicated to subway and commuter rail, and most of the rest given over to operations and freight demands.[11]

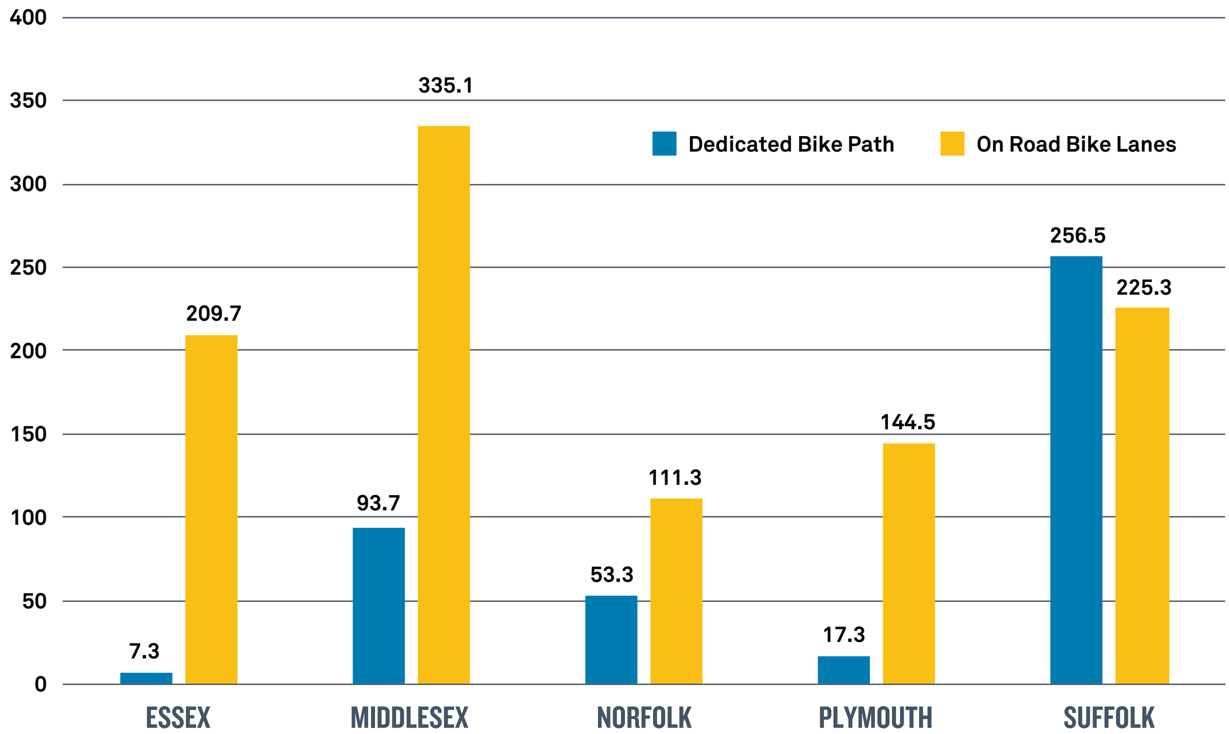
In all, as shown in **Figure 2.4**, 62 percent of rail track in Greater Boston is in active use with an additional 5 percent of rail right-of-ways turned over for bicycling and walking trails.

FIGURE 2.4: Greater Boston Railway Track Mileage in Use



Source: MassGIS ("Trains," April 2015)

FIGURE 2.5: Length of Bikeways by County in Miles



Source: MassGIS

BICYCLE

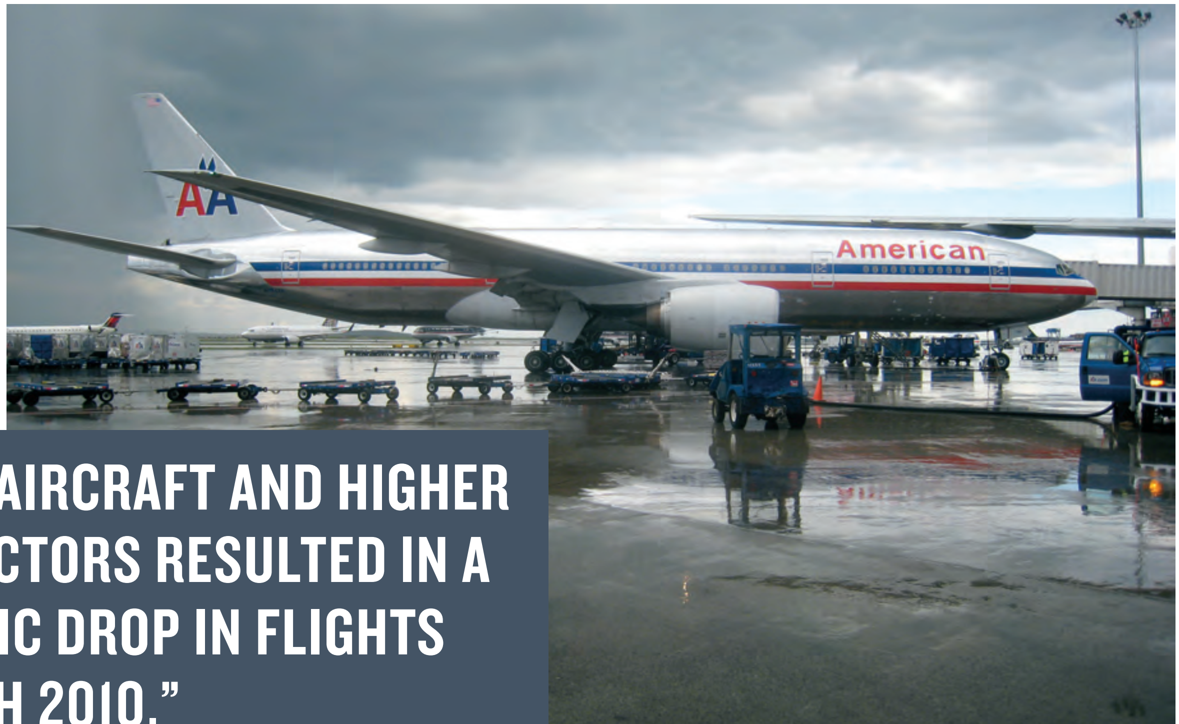
Finally, any discussion of commuter transportation would be incomplete without covering bicycle travel. **Figure 2.5** shows that Greater Boston is endowed with 1,454 miles of bicycling thoroughfares. Bicycling infrastructure is most prevalent in Suffolk County, which has close to the same number of dedicated bike path miles (256.5) as on-road bike lane miles (225.3), constituting two-thirds of biking miles in the region. Not surprisingly, the four predominately suburban counties, which have newer and more spacious roads and fewer sidewalks, have dispro-portionately more on-road lanes than dedicated bike paths.

AIRPORT AND SEAPORT FACILITIES

Two critical features of Greater Boston's transpor-tation infrastructure are Logan International Airport and the Port of Boston, which are both governed by the Massachusetts Port Authority, or MassPort.

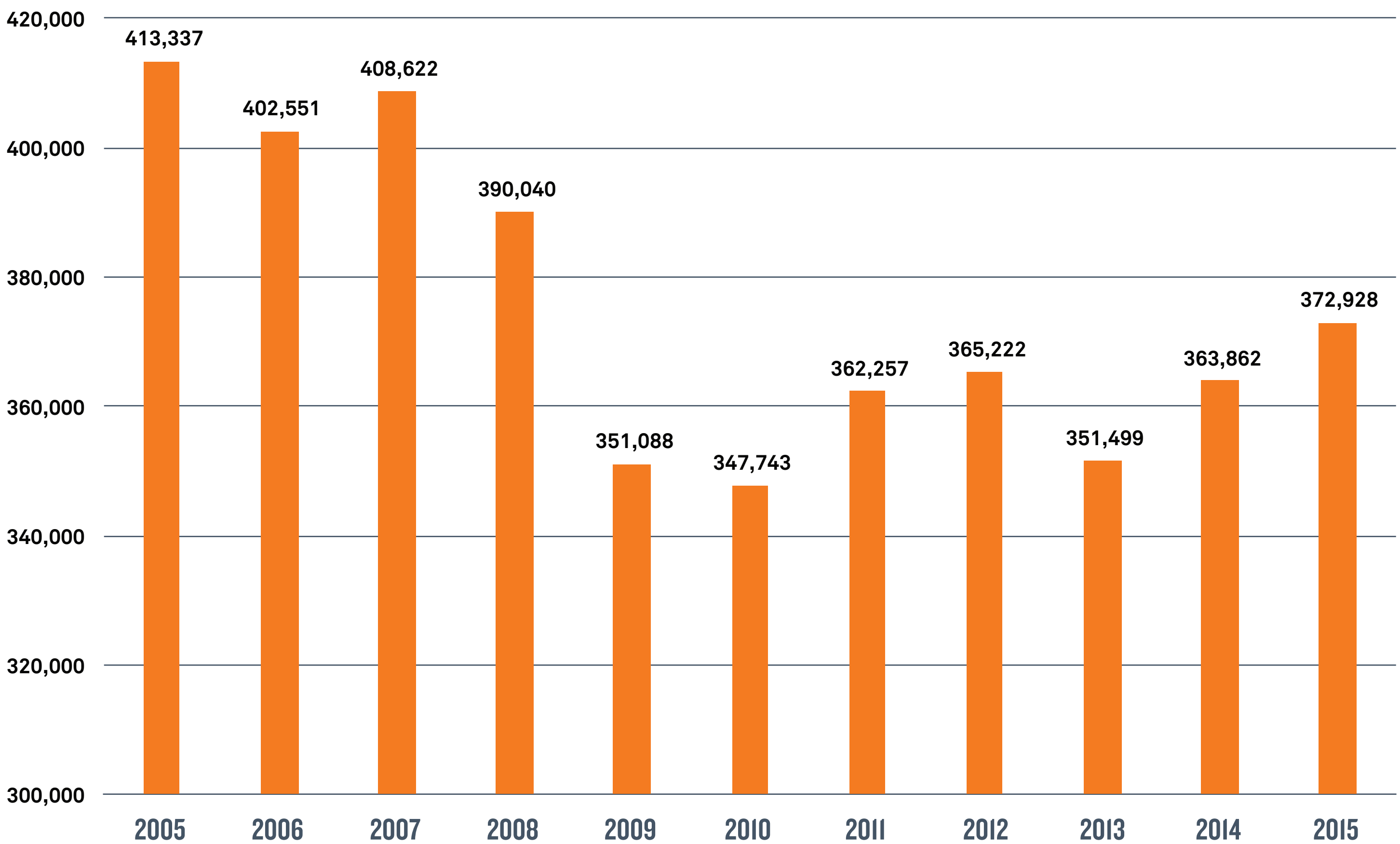
Passenger Air Travel

Figure 2.6 provides data on take-offs and landings at Logan from 2005 to 2015. One might be surprised by the dramatic drop in flights through 2010. Part of this was due to the effect of the Great Recession, but it was also driven by the use of larger aircraft and higher load factors. This is confirmed by the fact that, with the economy recovering, the number of flights has remained well below the level at the midpoint of last decade. From 2005 through 2008, Logan recorded more than 400,000 flights per year. From 2009 through 2015, the number never reached as high as 375,000.



"LARGER AIRCRAFT AND HIGHER LOAD FACTORS RESULTED IN A DRAMATIC DROP IN FLIGHTS THROUGH 2010."

FIGURE 2.6: Number of Take-offs and Landings, Logan Airport, 2005–2015



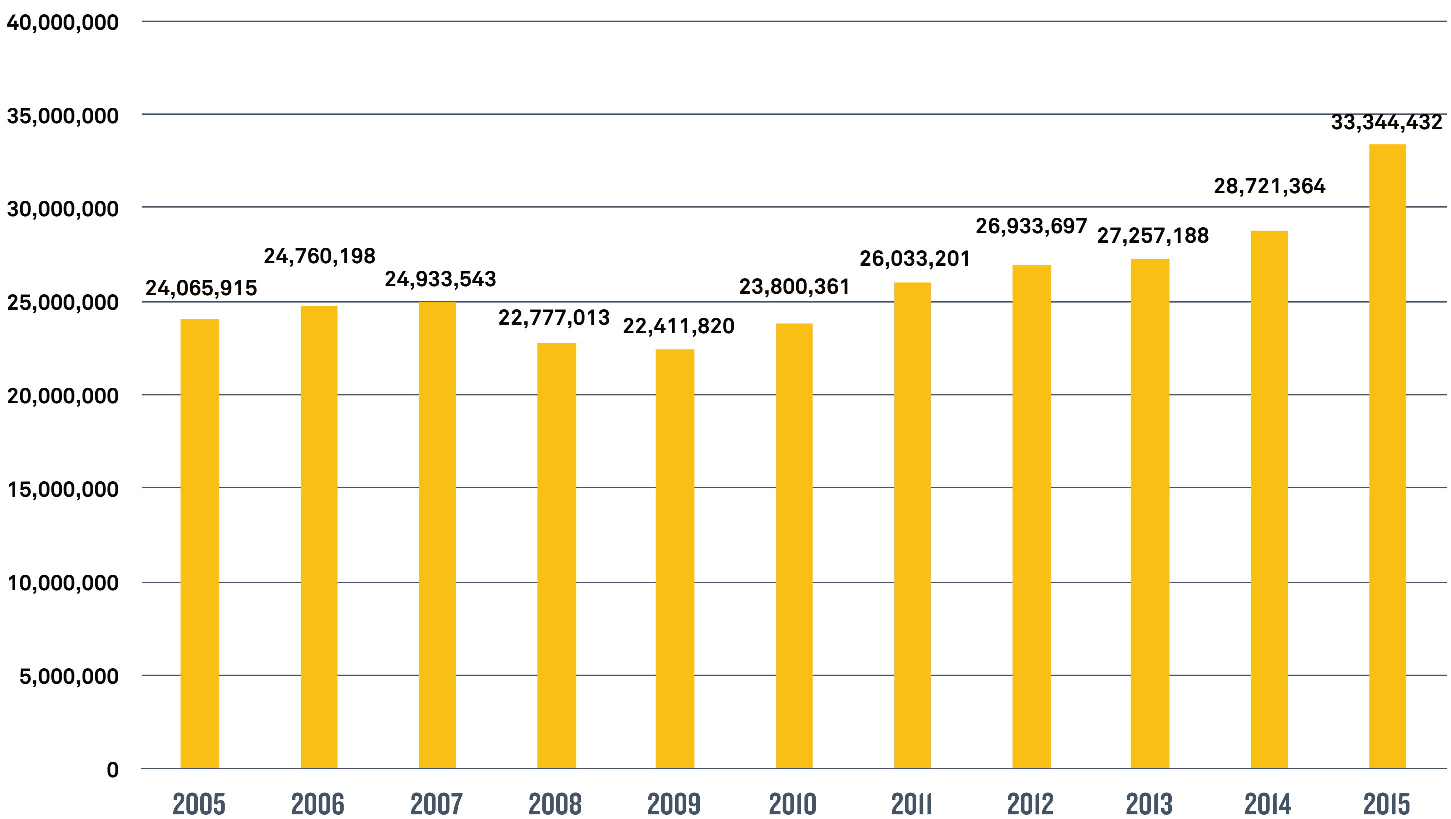
Source: MassPort

Data on the number of passengers flying into and out of Logan accords with the use of larger aircraft and higher load factors. As **Figure 2.7** reveals, the number of passengers flying into and out of Logan since 2005 has continued to climb except during the Great Recession. Just between 2009 and 2015, the number of passengers using Logan Airport has increased by a whopping 49 percent—with more than a six million-passenger increase between 2013 and 2015 alone. These numbers suggest that with recent airline efficiencies, Logan is not yet at capacity, but it is clearly on course to reach and exceed its limits within the next fifteen years—if not earlier.

Air Freight

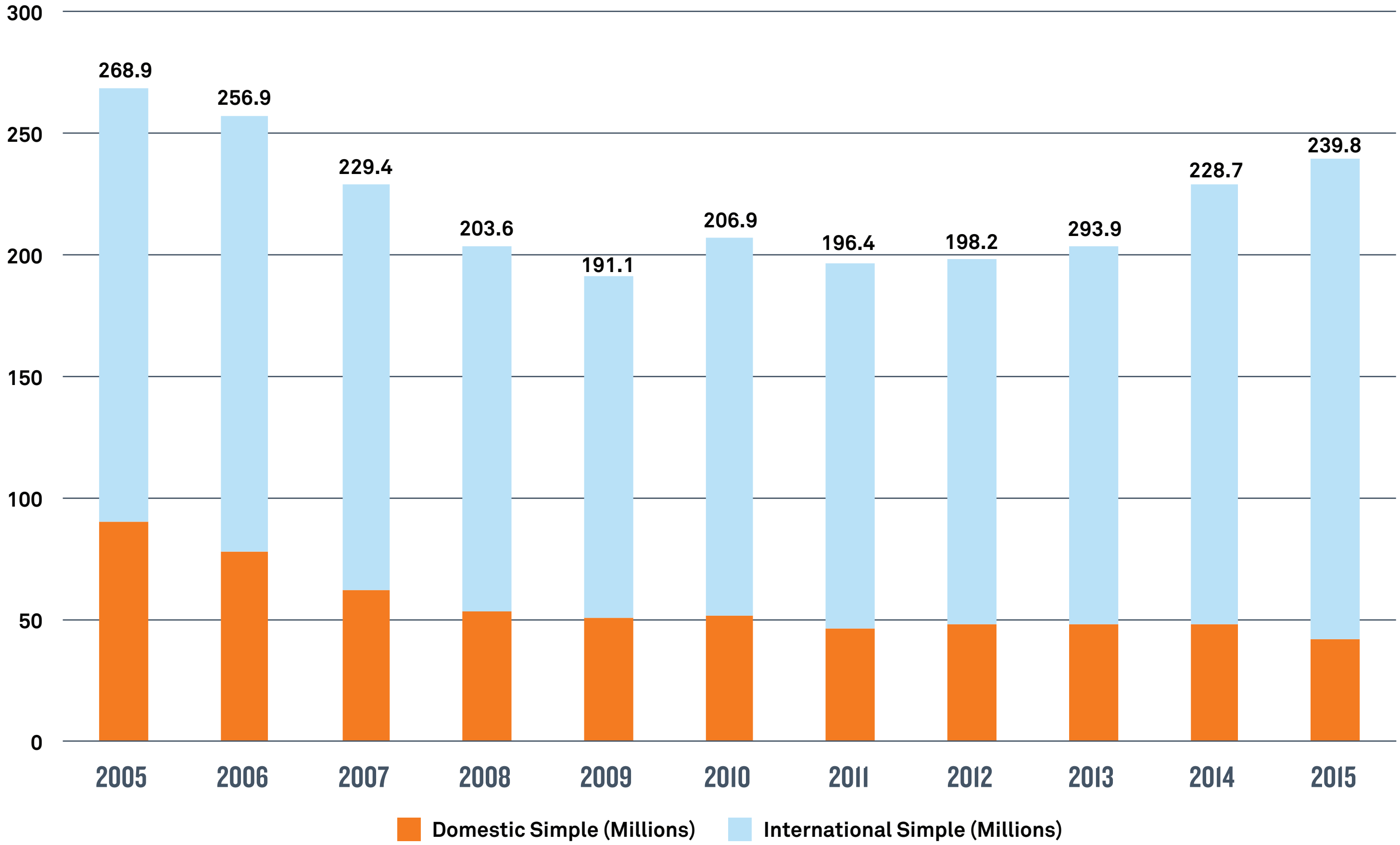
Logan also serves as a major transportation hub for air freight. As **Figure 2.8** reveals, total air freight (in millions of pounds) moving through the airport declined from 2005 through 2009—largely as the result of a weakened economy during the Great Recession of 2007–2009. By 2009, a total of 191 million pounds of air freight departed from or arrived here in Boston. Of this total, 73 percent or 140 million pounds were being shipped internationally. By 2015, total freight handled at Logan had increased to 240 million pounds, an increase of nearly 26 percent since 2009. Now more than four-fifths of Logan's air freight (83%) consists of international imports and exports.

FIGURE 2.7: Total Airport Passengers, Domestic and International Flights, Logan Airport,2005–2015



Source: MassPort

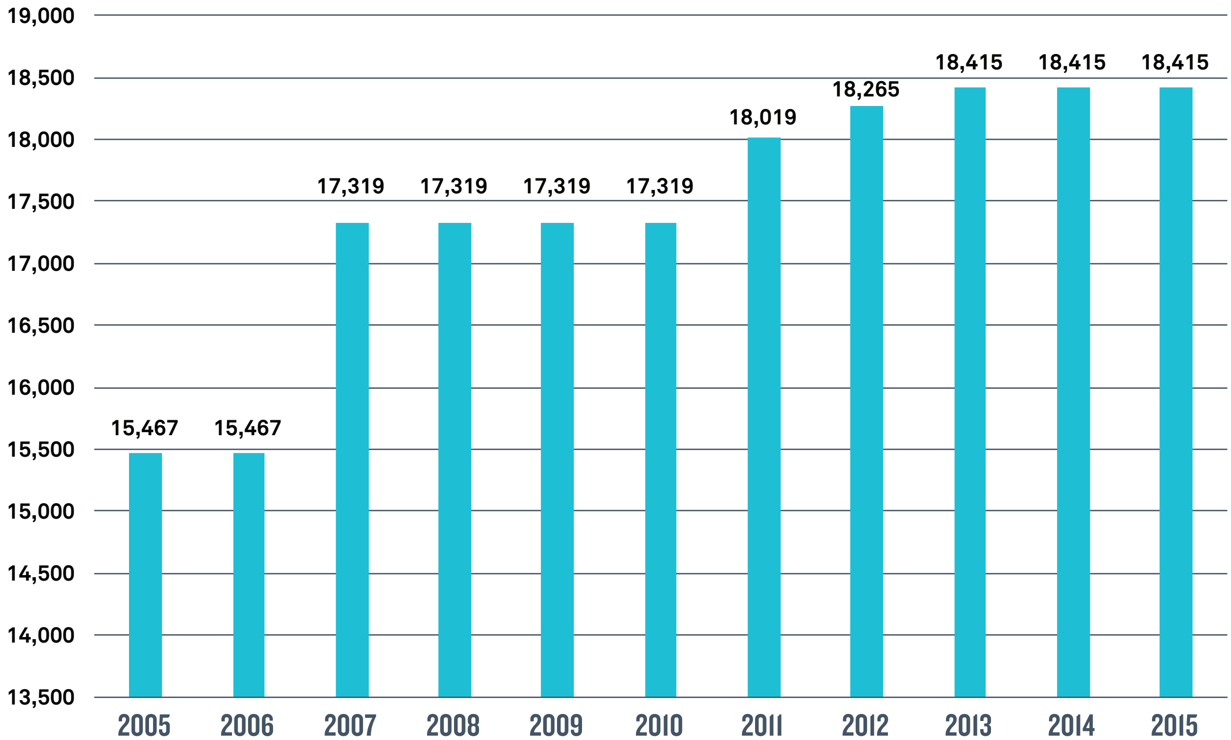
FIGURE 2.8: Freight in Millions of Pounds, Domestic and International Flights, Logan Airport, 2005–2015



Source: MassPort

"LOGAN IS ON COURSE TO REACH AND EXCEED ITS LIMITS WITHIN FIFTEEN YEARS."

FIGURE 2.9: Number of Parking Spaces, Logan Airport, 2005–2015



Source: MassPort

Airport Parking

Another concern is airport parking. As **Figure 2.9** shows, MassPort has constructed only 2,948 additional parking spaces since 2006, and no new spaces since 2013. During that time the Silver Line opened, providing bus service to the airport, which presumably took up some of the slack. Overall, though, it is clear that in the future transportation to and from the increasingly stressed, land-limited airport will require careful calibration among planners—and may even require expanding airline facilities beyond the Boston metro region.

SEAPORT FREIGHT

Boston, of course, is also a major seaport. As **Table 2.6** shows, the Conley Terminal in South Boston covers more than 100 acres and has six large cranes to load and unload container ships. Two of these cranes can load and unload Panamax and Panamax Max container ships with a maximum length of 950 feet and a beam of 105 feet that can accommodate 13 TEU containers per row.[12] These ships carry a maximum of 4,500 TEUs.[13]

The other four cranes can handle larger ships up to 1,065 feet in length and 140 feet in width. With the ability to handle ships that carry up to 17 TEUs side-by-side and 6 TEUs high, Conley's four larger cranes can handle carriers up to the size of Post Panamax II ships capable of carrying up to 8,000 TEUs. These ships were first introduced in the year 2000.

Larger New Panamax ships, first introduced in 2014 and capable of carrying 12,500 containers, cannot dock in Boston because of their size—nor can the Post-Panamax III and Triple E carriers that are capable of up to 18,000 TEUs.

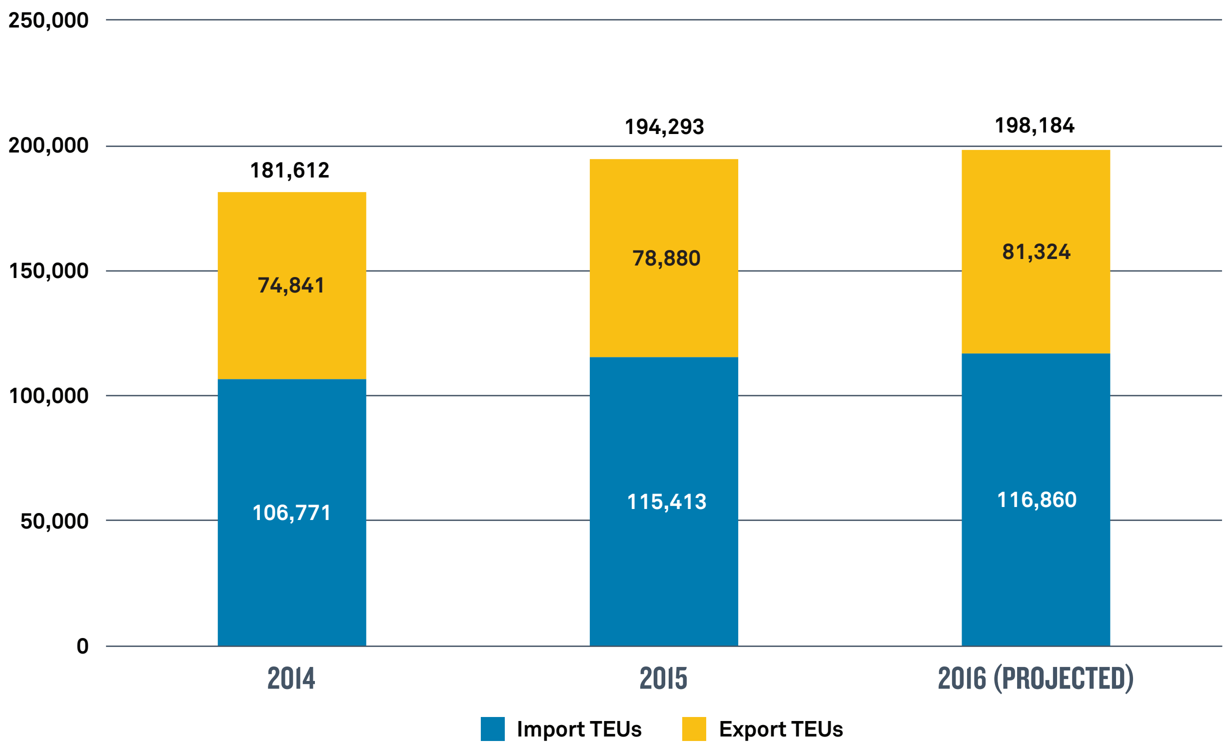
In spite of its limited ability to accommodate the world's largest cargo ships, the Seaport's Conley Terminal is handling a growing volume of cargo trade. We project, as **Figure 2.10** suggests, that by the end of 2016, more than 198,000 TEUs will have been handled this year, up 9.1 percent just since 2014.

TABLE 2.6: Seaport Statistics

Seaport size in acres	101
Number of cranes	6
Cargo capacity (TEU's, TEUs = Twenty-Foot Equivalent Units)	415,000
Max size of container ships	1065 feet long x 140 feet wide
Max number of container ships (# of TEU wide x Length)	17 TEUs x 320 Meters
Total tons of cargo handled by seaport	237,166

Source: MassPort

FIGURE 2.10: Seaport Cargo Containers in TEUs, 2014–2016 (Projected)



Source: MassPort

ENERGY INFRASTRUCTURE

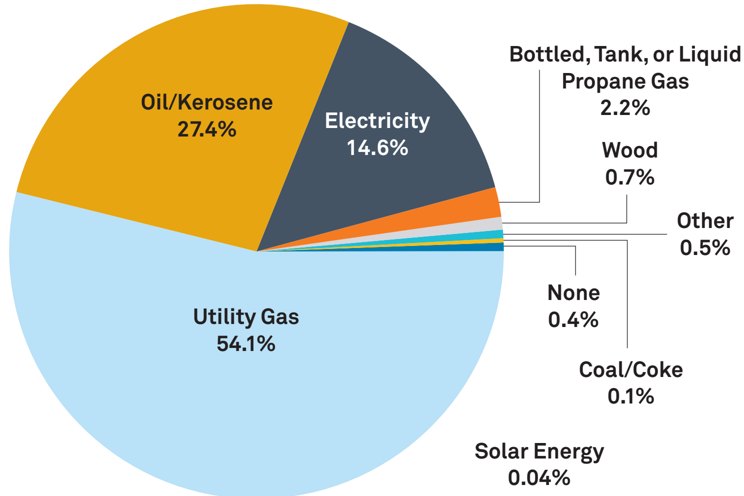
Beyond transportation, population growth and increased economic output will require additions to our energy infrastructure. Households require energy for home heating and appliances while businesses require electric and gas energy to run their operations.

HEATING FUEL

Although coal accounts for a negligible proportion of Greater Boston's energy portfolio, the region currently is heavily reliant on fossil fuels. As **Figure 2.11** illustrates, 83.7 percent of household heating alone is fossil-fuel-based, with 27.4 percent from oil and kerosene, 2.2 percent from propane, and a dominant 54.1 percent covered by cleaner natural gas.

Table 2.7, which breaks down home heating systems by county, makes clear that Plymouth and Norfolk Counties, which use the least amount of natural gas (presumably because they lack pipelines), make up the difference with oil. Household heating figures tell only part of the story, however, since energy is needed to support other uses, such as air conditioning and other household appliances, lighting, and computer-based technologies, as well as commercial, industrial, and government applications.

FIGURE 2.11: Greater Boston Household Heating Fuel by Type



Source: U.S Census

TABLE 2.7: Estimated Home Heating Systems by County

	ESSEX	MIDDLESEX	NORFOLK	PLYMOUTH	SUFFOLK	5-COUNTY REGION
Utility Gas	55.3%	57.1%	49.8%	44.2%	57.0%	54.1%
Oil/Kerosene	28.3%	26.6%	32.9%	39.2%	15.9%	27.4%
Electricity	12.2%	12.9%	14.1%	9.3%	23.9%	14.6%
Bottled, Tank, or Liquid Propane Gas	2.5%	1.8%	1.8%	4.6%	1.9%	2.2%
Wood	0.9%	0.6%	0.6%	1.7%	0.1%	0.7%
Other	0.5%	0.4%	0.5%	0.5%	0.4%	0.5%
None	0.2%	0.5%	0.2%	0.3%	0.7%	0.4%
Coal/Coke	0.1%	0.1%	0.1%	0.1%	0.0%	0.1%
Solar Energy	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%

Source: US Census ("House Heating Fuel," 2010-2014 5-Year ACS, Table B25040)

ELECTRICITY AND GAS CONSUMPTION

Table 2.8 breaks down electricity and natural gas consumption by number of households and business establishments, showing that more than 41 percent of the region's electricity (as measured in kWh) and 29 percent of its natural gas (as measured in therms) is used by commercial and industrial establishments.

RENEWABLE ENERGY

Massachusetts is on track to exceed its 2020 renewable energy targets,[14] and as **Table 2.9** shows, Greater Boston is playing a strong part in the transformation. Hydro, wind, and solar accounted for 9.8 megawatts of annual electricity yield in 2014. These figures do not include "other" renewable energy sources, such as biomass, because current data are not entirely reliable. They also do not include energy savings from building weatherization, Energy Star appliances, and other efficiency measures, to which the densely populated Boston area can make significant contributions.

TABLE 2.8: Greater Boston Energy Consumption

ELECTRICITY		
	2010 Number of Households/ Establishments	2010 Average Annual kWh Used
Residential	1,573,877	12,365,388
Commercial/Industrial	131,928	8,839,890
NATURAL GAS		
	2010 Number of Households/ Establishments	2010 Annual Therms Used (Millions)
Residential	1,573,877	2,052
Commercial	87,739	509
Industrial	15,951	336

Source: Eversource, U.S. Census

TABLE 2.9: Average Private Alternative Fuel Method Capacity by Type by County in kW

	ESSEX	MIDDLESEX	NORFOLK	PLYMOUTH	SUFFOLK	GREATER BOSTON
Hydro	8,630	240	0	0	2,000	4,728
Wind	1,082	34	100	2,419	1,468	1,432
Solar	2,373	2,859	2,697	2,938	6,005	3,066
Other	840	15,070	952	0	14,163	9,789

Source: Massachusetts Department of Environmental Regulation

WATER INFRASTRUCTURE[15]

Obviously, sufficient supplies of clean water are critical in any region. Greater Boston has been served well by the Quabbin Reservoir and the aqueducts that bring water from the middle of the state to the region. Built between 1930 and 1939, the Quabbin is the primary water supply for Boston as well as 40 other communities in Greater Boston. It has an aggregate capacity of 412 billion gallons and covers an area of nearly 39 square miles.[16]

WATER AND SEWER

Tables 2.10A–C provide current data on the demand for water and sewer by Greater Boston's residents, commercial and industrial firms, municipal governments, and large nonprofit institutions, based on available data from the Massachusetts Water Resources Administration (MWRA).

Water

Across the five counties, residents use an average of 29.6 gallons per day for washing, cooking, and other household needs. By our calculations, the typical commercial firm now consumes about 875 gallons per day while, on average, each industrial enterprise uses about 1,200 gallons per day. As such, in all of Greater Boston, residents are using more than 120 million gallons per day, with commercial and industrial firms consuming another 90 million gallons and municipal and institutional enterprises using 114 million gallons, for a grand total of 325 million gallons per day. As **Figure 2.12** reveals, residential consumer demand for water represents about 37 percent of total water demand and municipal agencies and nonprofit institutions (including colleges, universities, and hospitals) another 35 percent, with the remaining 28 percent consumed by commercial and industrial firms.

2.10A: 2010 Per Capita Demand (Gallons/Day)

	WATER	SEWER
Residential	29.6	19.5
Commercial	874.4	183.1
Industrial	1,206.8	1,050.8

2.10B: 2010 Water (Million Gallons/Day)

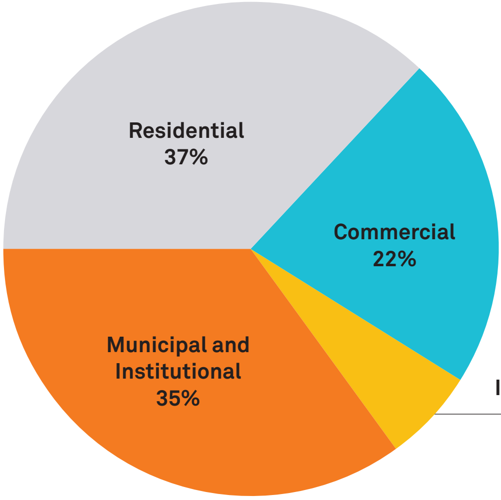
	GREATER BOSTON
Residential	120.6
Commercial	71.7
Industrial	19.6
Municipal and Institutional	114.0
Total	325.8

2.10C: 2010 Sewer (Million Gallons/Day)

	GREATER BOSTON
Residential	79.6
Commercial	15.1
Industrial	16.8
Municipal and Institutional	75.3
Rain and Snow Runoff	342.3
Total	529.0

Source: MWRA Statistics on Water and Sewer Demand

FIGURE 2.12: Greater Boston Water Use by Type of Consumer, 2009



Source: Massachusetts Water Resources Authority, U.S. Census Bureau

Sewer

The Deer Island Waste Water Treatment Plant is responsible for treating much of the sewage generated in Greater Boston. Deer Island, which went into full operation in 2000, is the second largest sewage treatment plant in the U.S.[17] Today, Deer Island has the capacity to treat 1.2 billion gallons of sewage per day, about twice the total sewage and water runoff generated per day in all of Greater Boston. According to the MWRA, rain and snow runoff accounts for more than 60 percent of water treatment.

ENVIRONMENT AND OPEN SPACE

Greater Boston has been relatively well served by its careful environmental stewardship and coastal location and this is evident in its air quality and open-space preservation.

AIR QUALITY

Figure 2.13 shows that the region performs exceptionally well across all four national air-quality standards: sulphur and nitrogen dioxide, carbon monoxide, and particulate count. Greater Boston also falls below national average ozone levels, as illustrated in **Figure 2.14.**

GREENHOUSE GAS EMISSIONS

There are historical data on greenhouse gas emissions (GHG) and specifically CO_2 emissions for the Commonwealth and for Boston. From 1990 through 2005, the Massachusetts annual greenhouse gas emission inventory indicated that CO_2 emissions averaged 95 million metric tons per year. Beginning in 2006, emissions fell sharply so that by 2011 total CO_2 emissions had fallen to 80 million metric tons, a 16 percent reduction in five years.

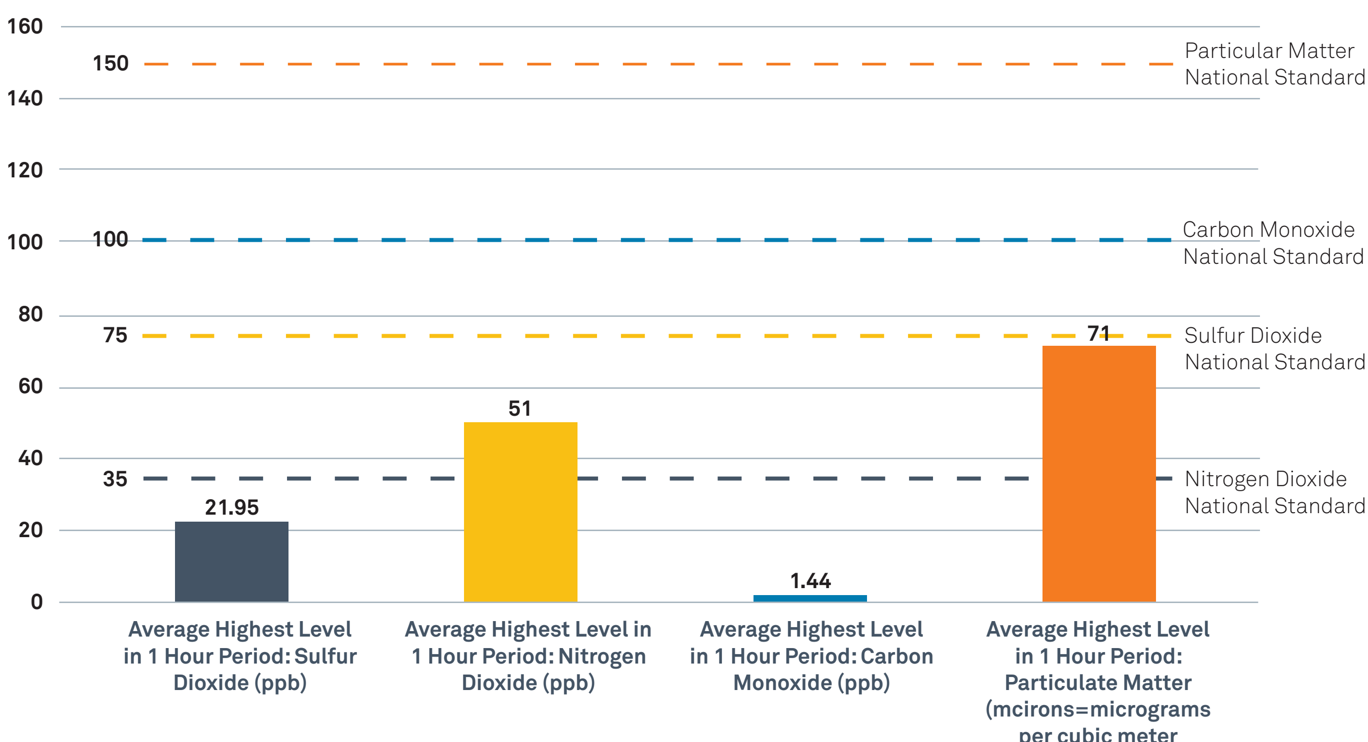
Of total GHG emissions in 2011 in the Commonwealth, 40 percent was related to transportation, 25 percent to residential, 15 percent to commercial enterprise, and 15 percent to industrial enterprise. Of total CO_2 emissions in Massachusetts, 60 percent was the result of petroleum use, 35 percent natural gas, and 6 percent coal. Commercial and industrial firms operating in Boston were responsible for just over half (52%) of total GHG emissions. Electricity, natural gas, fuel oil, and steam generation for residential units added 21 percent to total emissions. Private vehicles and the operations of the MBTA[18] were responsible for the balance of emissions.

The City of Boston also has experienced a reduction in its GHG emissions from energy use in buildings and other facilities, and for transportation. In 2005, total emissions exceeded 7.4 million metric tons. By 2009, its gas "inventory" was down to 6.7 million tons and by 2013 it had fallen to 6.1 million metric tons. Of the total in 2013, 36 percent was the result of electricity generation, 27 percent from vehicle fuel, and 26 percent from natural gas. The remainder was the result of fuel oil use and steam generation.[19]

OPEN SPACE

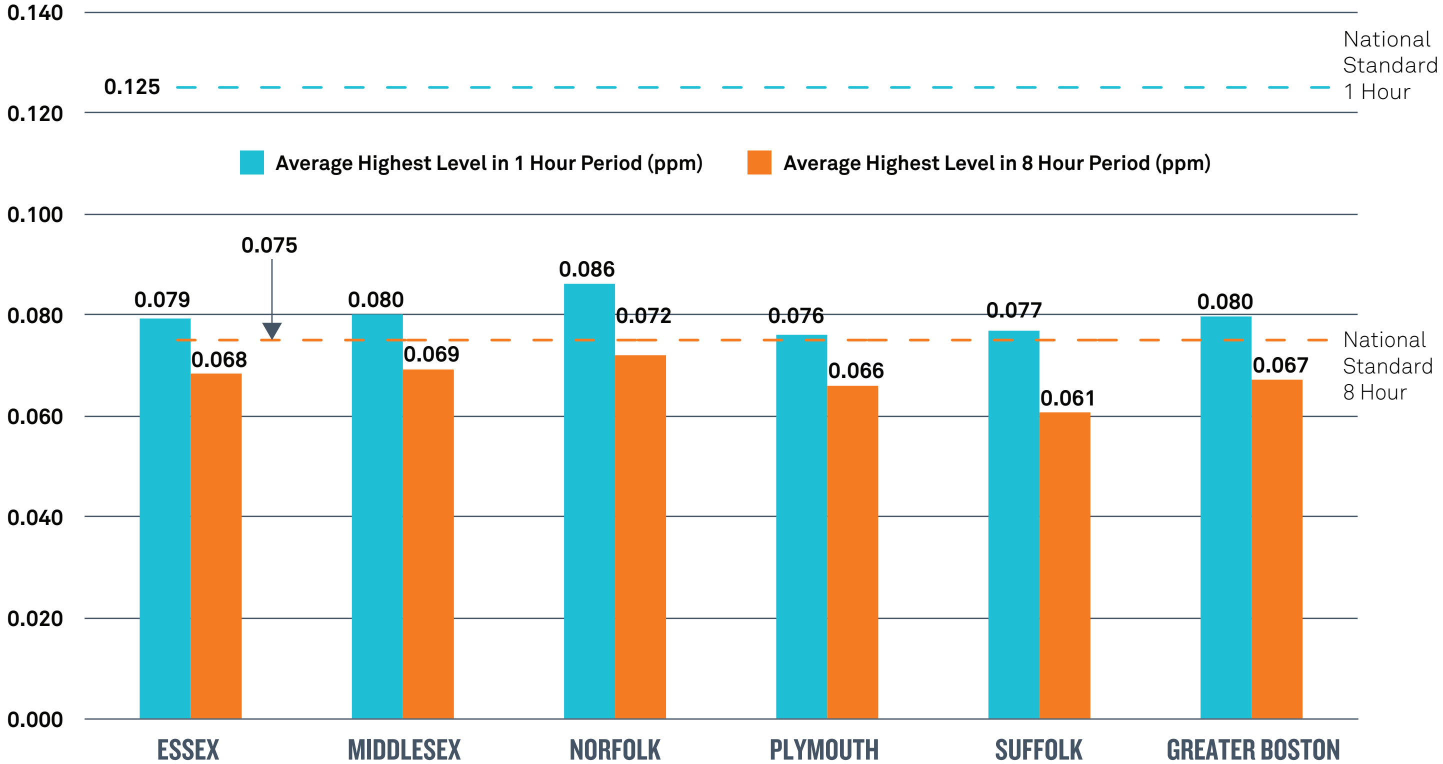
On average, as **Figure 2.15** makes clear, almost a quarter of Greater Boston consists of open land, with distribution fairly even across all five counties. Even Suffolk County, by far the county with the densest population, has kept nearly 20 percent of its land as open space.

FIGURE 2.13: Greater Boston Average Air Quality Measures



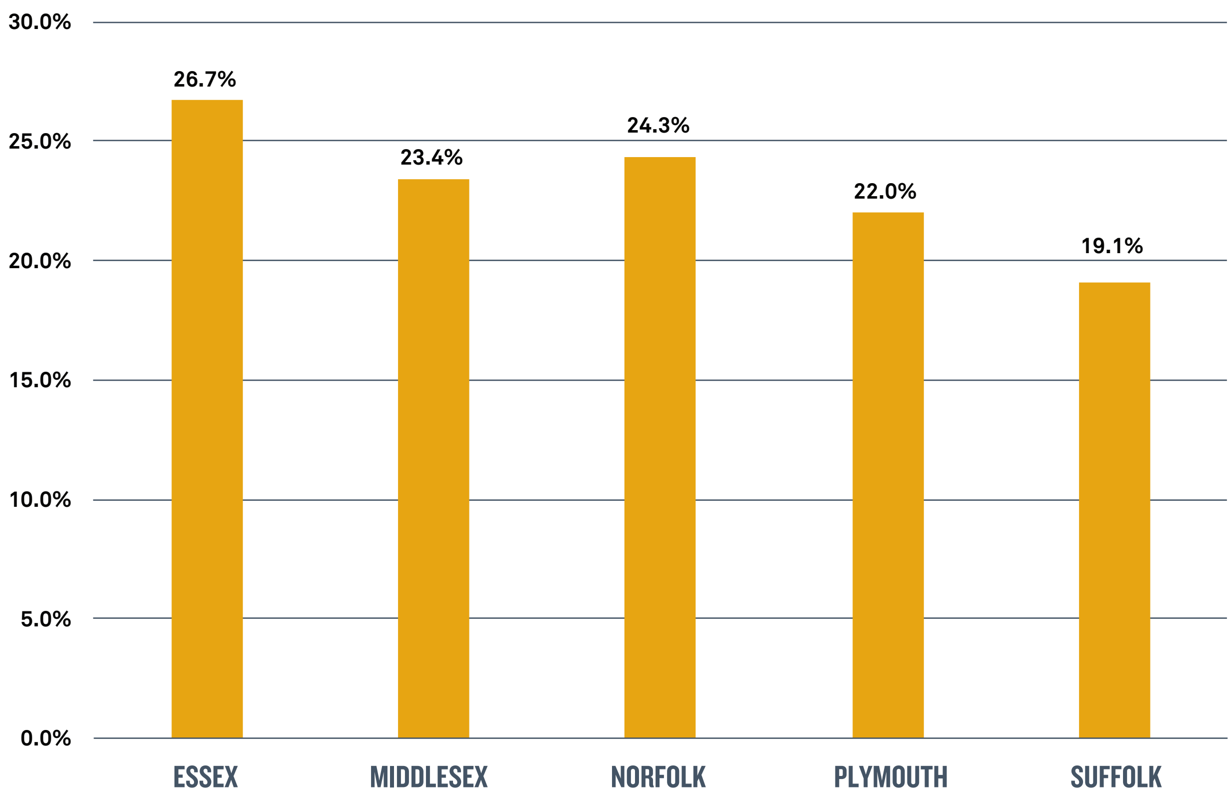
Source: Massachusetts Department of Environmental Protection, "Massachusetts 2014 Air Quality Report," June 2015

FIGURE 2.14: Greater Boston Ozone Presence in Air in Parts per Million, 2014



Source: Massachusetts Department of Environmental Protection, "Massachusetts 2014 Air Quality Report," June 2015

FIGURE 2.15: Greater Boston Total Open Space as a Percentage of Total County Area, 2010



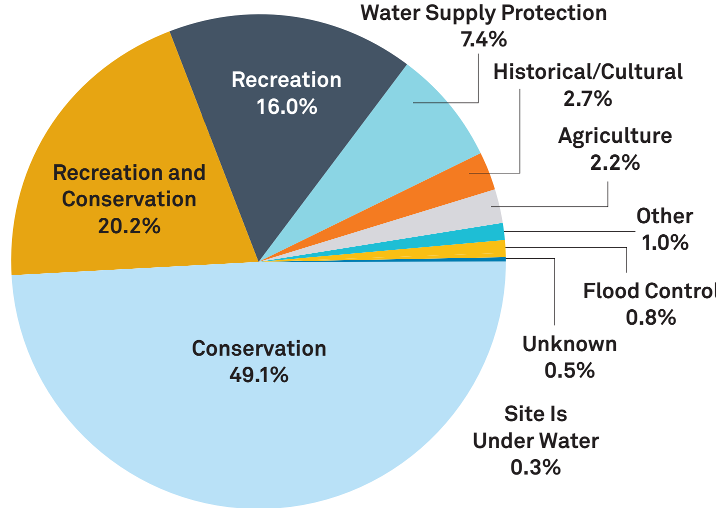
Source: MassGIS ("Protected and Recreational Open Space," March 2015)

Figure 2.16 reveals that most of the area's open land—85.3 percent—has been reserved for recreation, conservation, or both, while another 7.4 percent protects water supply routes. The rest is protected for agricultural, historical, and other uses.

Greater Boston is home to 1,170 miles of state-owned trails managed by the Department of Conservation and Recreation (DCR). **Table 2.11** shows that 84 percent of these trails are in Essex, Middlesex, and Plymouth Counties.

According to the Department of Conservation and Recreation, state-owned trails are generally in good to fair condition, as shown in **Figure 2.17** No more than 3.6 percent of any county's trails, save those of Suffolk, are in poor condition. Interestingly, Suffolk County has the highest proportion of both well-maintained trails (71.2 percent) and those in poor condition (6.4 percent).

FIGURE 2.16: Greater Boston Open Space by Land-Use Type



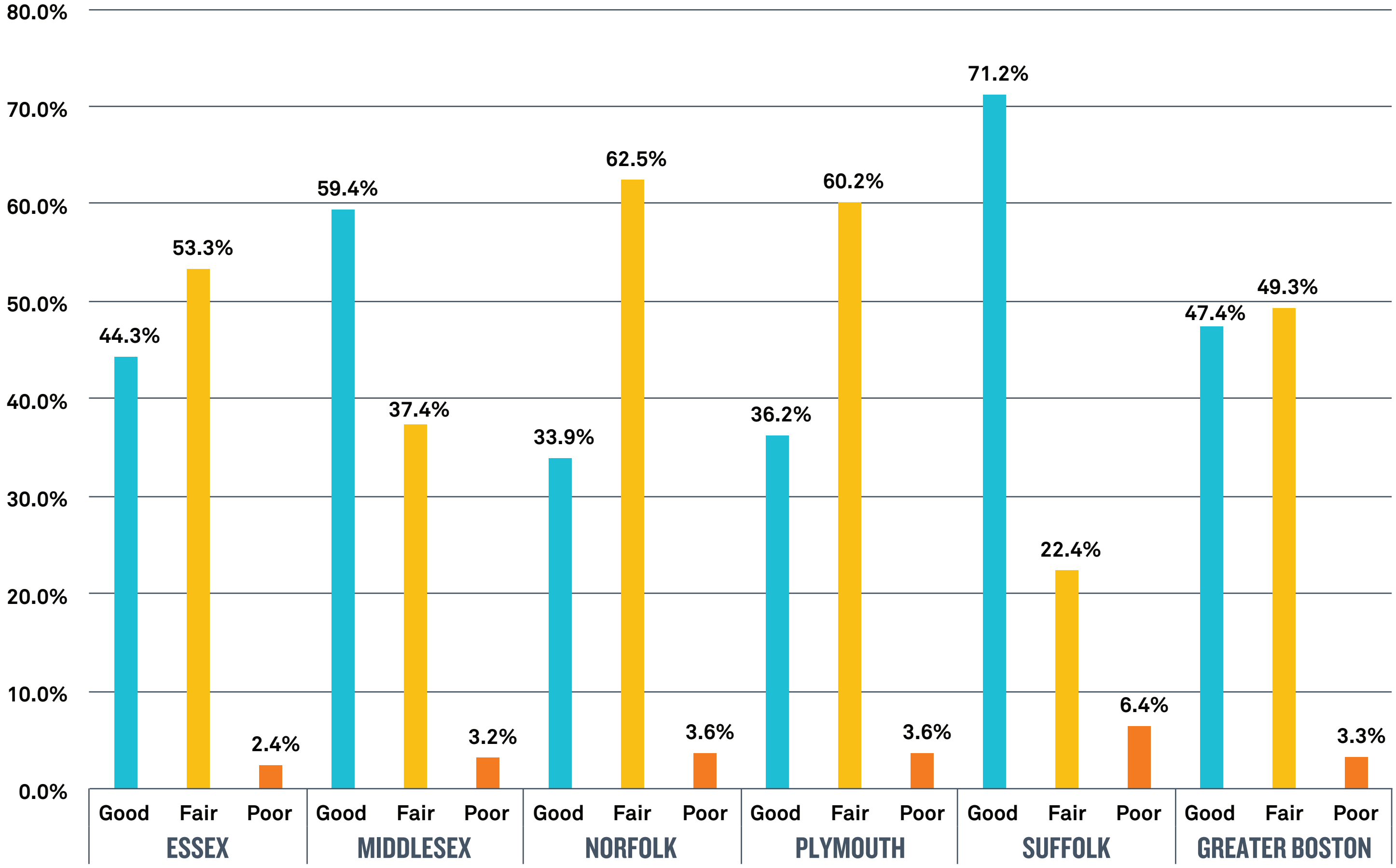
Source: MassGIS ("Protected and Recreational Open Space," March 2015)

TABLE 2.11: Length of DCR Trails by Type by County in Miles

	ESSEX	MIDDLESEX	NORFOLK	PLYMOUTH	SUFFOLK	TOTAL
Administrative Road	3.8	10.1	1.1	3.0	1.6	19.6
Forest Road/Trail	91.2	144.8	58.7	127.1	4.9	426.6
Other	5.1	25.5	1.8	5.1	1.9	39.4
Public Road	54.2	76.1	22.4	55.6	0.6	208.8
Trail	99.0	189.8	69.1	97.0	21.4	476.3
TOTAL	253.2	446.2	153.1	287.9	30.3	1,170.7
% of Total	21.6%	38.1%	13.1%	24.6%	2.6%	100%

Source: MassGIS ("DCR Roads and Trails," June 2015)

FIGURE 2.17: **Condition of DCR-Maintained Trails by County**



Source: MassGIS ("DCR Roads and Trails," June 2015)

WASTE MANAGEMENT

To the extent that trash can be diverted from landfills, it preserves land for other uses. **Table 2.12** provides a snapshot of Greater Boston's trash management. Each of the region's more than 1.5 million households produce on average approximately 1,600 pounds of waste per year. Of that volume, only 31.5 percent is recycled—even though more than 80 percent of households have trash and/or recycling services. The disposition of the remaining waste is unclear, since we do not have data on how much of it is repurposed, incinerated, or ends up in landfills.

EACH YEAR HOUSEHOLDS PRODUCE APPROXIMATELY 1,600 POUNDS OF WASTE AND RECYCLE ONLY 31.5% OF IT.

TABLE 2.12: Trash and Recycling

	GREATER BOSTON
Total Households	1,561,219
Total Households with Trash Service	1,275,344
Percentage of Households with Trash Service	81.7%
Total Households with Recycling Service	1,321,782
Percentage of Households with Recycling Service	84.7%
Annual Total Tons of Trash	889,355
Average Tonnage/Household: Trash	0.57
Annual Total Tons of Recycling	409,685
Average Tonnage/Household: Recycling	0.26
Annual Total Waste Produced	1,299,040
Trash as Percentage of Overall Waste	68.5%
Recycling as Percentage of Overall Waste	31.5%

SOURCE: Massachusetts Executive Office of Energy and Environmental Affairs. 2015 Municipal Solid Waste and Recycling Survey; MAPC "Stronger Region" Projections; Massachusetts Department of Labor and Workforce Development

SEA-LEVEL RISE/RESILIENCY

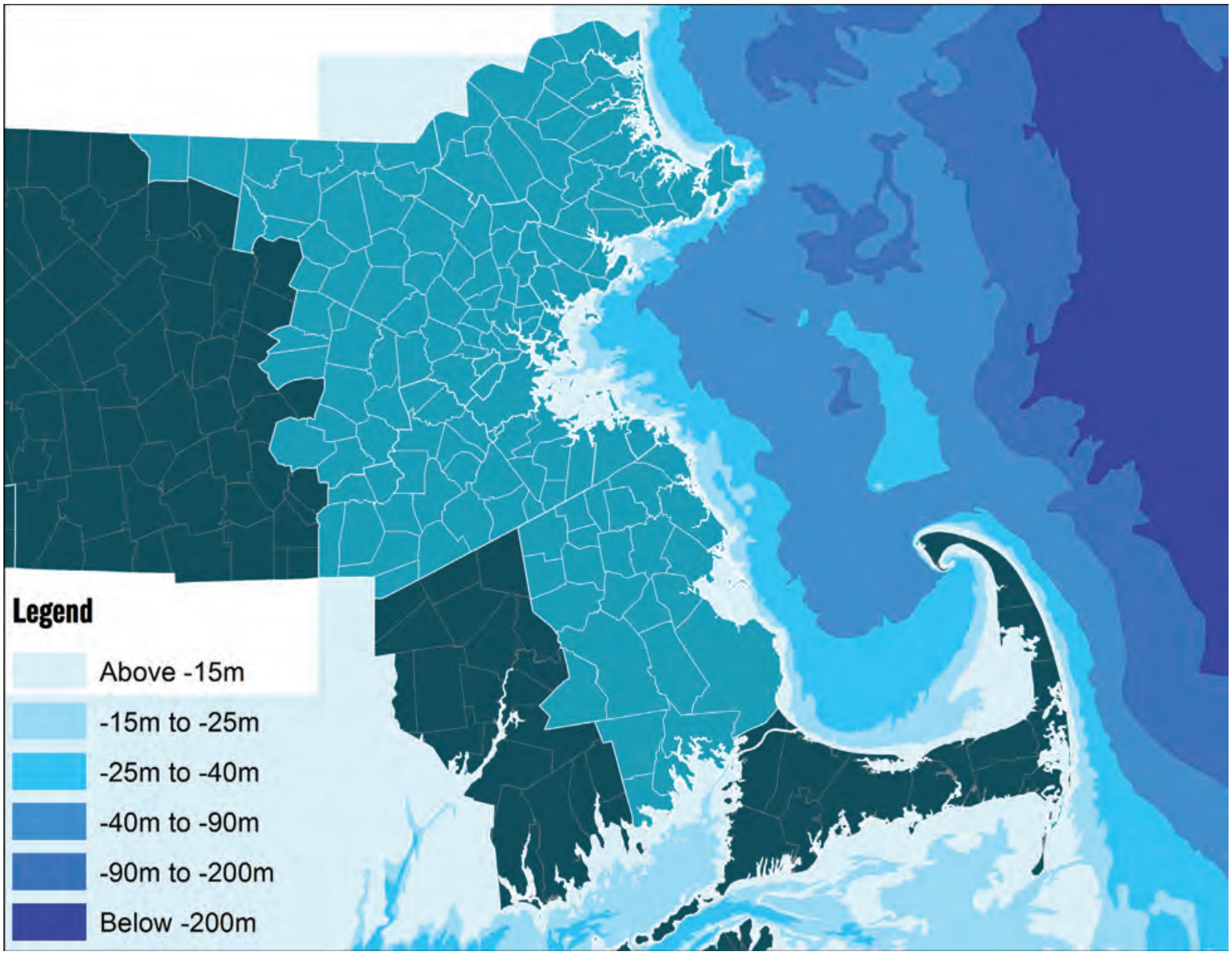
Most of our land mass is safe from sea-level rise, if not from storm surge. But as we will demonstrate in Chapter 4, the best climatologists suggest that sea-level rise is now inevitable and that a significant portion of the area around Boston Harbor and near the seacoast is vulnerable to flooding. We have only begun to consider how to make these areas resilient. **Map 2.1** shows the depth of ocean water off the coast of Massachusetts.

CONCLUSIONS

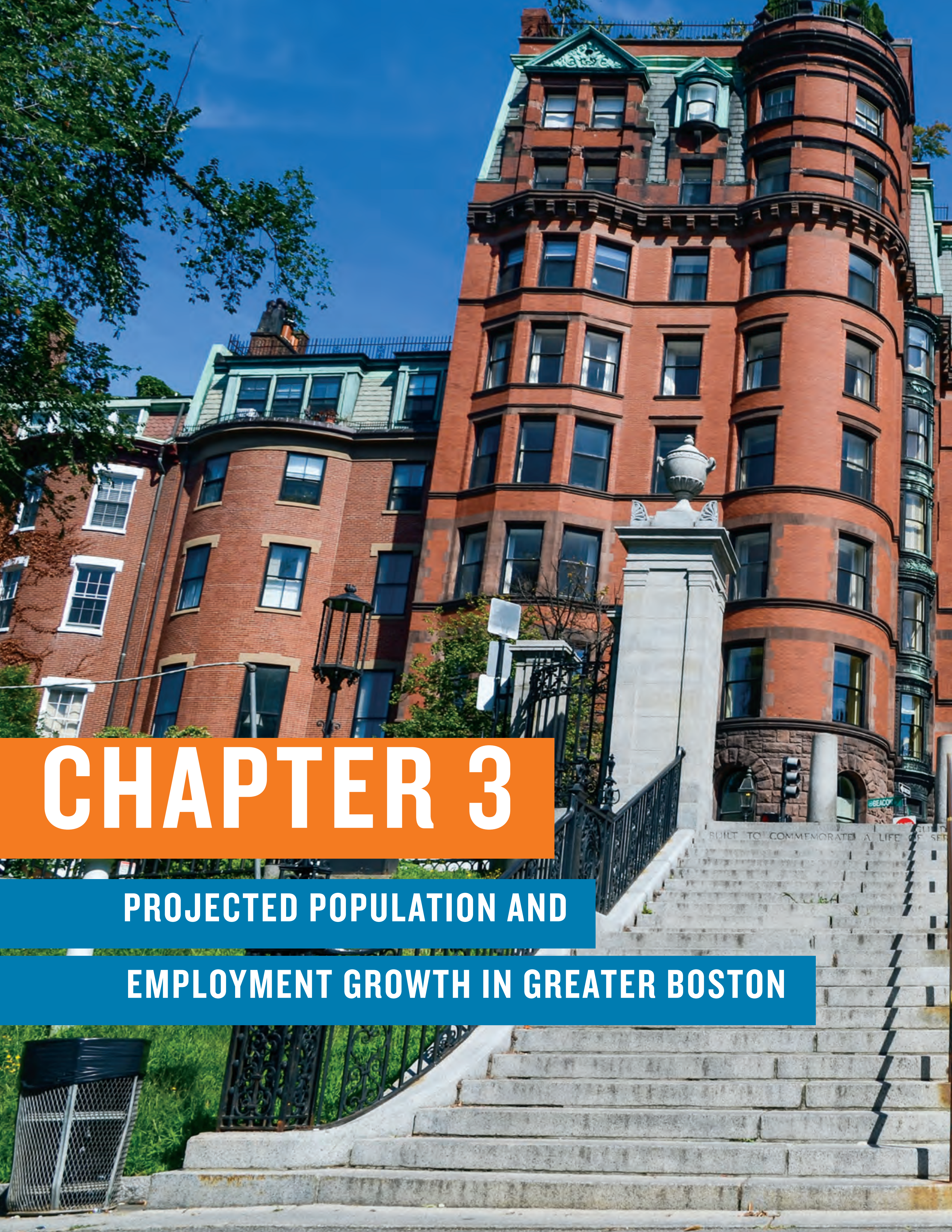
This chapter along with the following one provides the baseline data we need to project Greater Boston's infrastructure needs through 2030. The volume of data presented here provides a snapshot of the region's current use of and demand for infrastructure to support our population and our economy. As we will demonstrate, much must be done now to assure that we have adequate infrastructure so that the next generation can enjoy a better quality of life and greater economic security.

ASSURING A BETTER QUALITY OF LIFE AND GREATER ECONOMIC SECURITY.

MAP 2.1: Depth of Water Off the Coast of Massachusetts, 2016



Source: MassGIS



CHAPTER 3

PROJECTED POPULATION AND EMPLOYMENT GROWTH IN GREATER BOSTON


BEACON

CHAPTER 3

Greater Boston's future infrastructure needs depend primarily on anticipated population growth and economic development throughout the five-county region. The number of residents and the number of firms in Essex, Middlesex, Norfolk, Plymouth, and Suffolk Counties are the key determinants of future demand for transportation, water and sewerage, energy, and protected land. While conservation and efficiency measures and changes in transportation behavior can alter required additions to the region's built environment, demographic and economic growth will be the dominant factors in determining future infrastructure demand. For this reason, it is necessary to generate projections for Greater Boston's population and expected growth in firm output.

METHODOLOGY

Beginning with projections supplied by the Metropolitan Area Planning Council (MAPC) for its targeted 164 communities of "Metro Boston," we have estimated the population for the 147 communities in the Greater Boston's five counties through 2030.[20] MAPC projects population growth based on expected births, deaths, net migration, and immigration.[21] The Council produces two projections. The "Status Quo" scenario "is based on the continuation of existing rates of births, deaths, migration, and housing occupancy."[22] The "Stronger Region" forecast assumes that as a result of a stronger economy the Boston metro region will attract and retain more people, especially young people, and that younger householders (born after 1980) will be more inclined toward urban living than previous generations. MAPC's Stronger Region projection appears to be more consistent with the area's increased growth in population and employment since at least 2010. In fact, its projected Status Quo population estimate through 2020 had already been eclipsed by 2014, based on the retention and attraction of millennials (age 20-34) drawn to the region's economic success.[23]

To produce the population forecasts used here, we have therefore taken the following steps:

Step 1: Recalculated MAPC average annual population growth rates through 2020 and then through 2030 based on the 147 municipalities in the five counties of Greater Boston.

Step 2: Initiated the 2020 and 2030 projections based on the U.S. Census population estimates for Greater Boston for 2014.

Step 3: Aggregated the population growth projections into three sub-regions: the Inner Core, Regional Urban Centers, and Suburban communities.

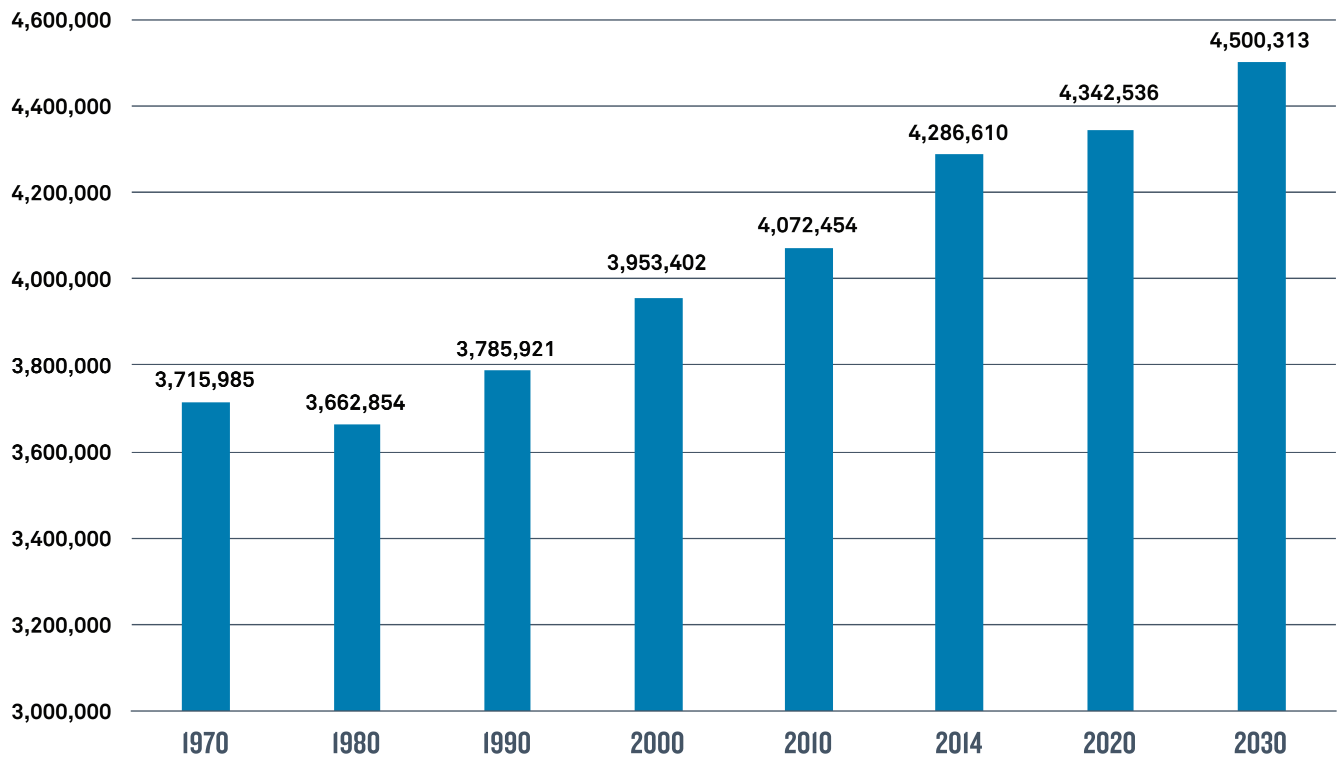
It is important to note that this projection technique attempts to measure population growth and the growth in economic output under the assumption that infrastructure constraints are not present to inhibit growth. Indeed, the whole point of this exercise is to demonstrate what infrastructure enhancements and what types of conservation measures and efficiencies may be necessary to permit the projected population levels and economic output forecast here. In this sense, our model is quite different from constrained transportation forecast models that attempt to show how inadequate infrastructure reduces the capacity for population growth and slows economic growth.[24] Here we attempt to measure the infrastructure we will need if expected population growth and economic output are to be accommodated.

PROJECTED POPULATION GROWTH (2010–2030)

Figure 3.1 provides Census data for the five-county Greater Boston region from 1970 through 2010, with five-county Adjusted MAPC Stronger Region projections through 2030, along with the latest Census data for 2014.[25]

As the figure reveals, the region's population actually declined between 1970 and 1980, and by 1990 the total population was less than 1 percent higher than the 1970 total. After that, the population grew substantially, increasing by 7.6 percent over the next two decades (1990–2010). The latest Census data suggest Greater Boston's population expanded even faster between 2010 and 2014, increasing by 5.2 percent in just four years. By 2030, we project the region's population will reach 4.5 million, an increase of another 214,000 residents or 5 percent over the 2014 figure. A larger population will almost inevitably require additional infrastructure to meet the region's needs for transportation, water and

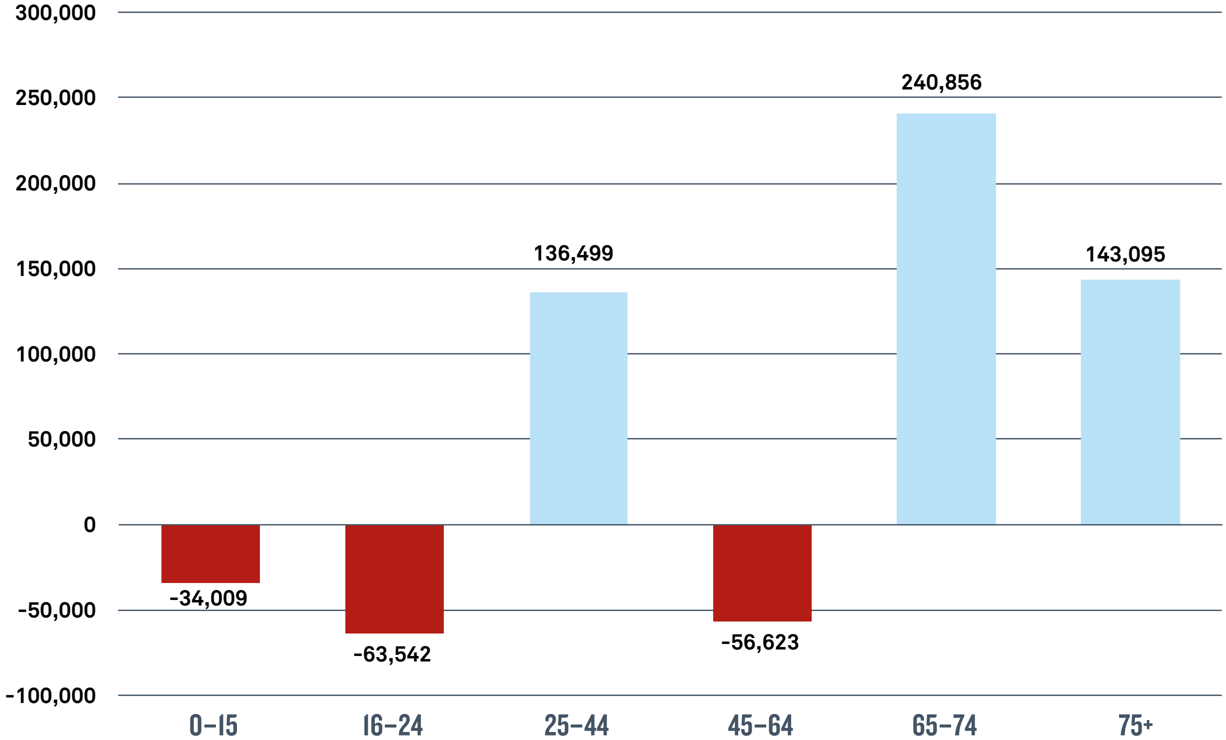
FIGURE 3.1: Greater Boston Population, 1970–2014 (2020–2030 Projected)



Sources: U.S. Census 1970–2014; MAPC 2020–2030 Stronger Region Projection (Adjusted)[26]

"WE ATTEMPT TO MEASURE THE INFRASTRUCTURE WE WILL NEED IF EXPECTED POPULATION GROWTH AND ECONOMIC OUTPUT ARE TO BE ACCOMMODATED."

FIGURE 3.2: Greater Boston Projected Popluation Growth by Age Cohort by 2030



Sources: U.S. Census 1970–2014; MAPC 2020-2030 Stronger Region Projection

sewerage, energy, and land use—unless there are substantial efficiencies attained in the use of the built environment.

As **Figure 3.2** confirms, projected additions to Greater Boston's population between 2010 and 2030 are dominated by two age cohorts—those aged 25 to 44 and those 65 plus. The former make up a large part of the expected growth in the labor force while the latter explains why the labor force will grow more slowly than the population.

PROJECTED LABOR FORCE GROWTH (2010–2030)

To estimate projected labor force growth, we used age-specific data from the U.S. Census Public Use Microdata Sample (PUMS data) to calculate labor force participation rates for each age cohort.[27] Based on this analysis for the five-year period 2010–2014, **Table 3.1** provides these rates.

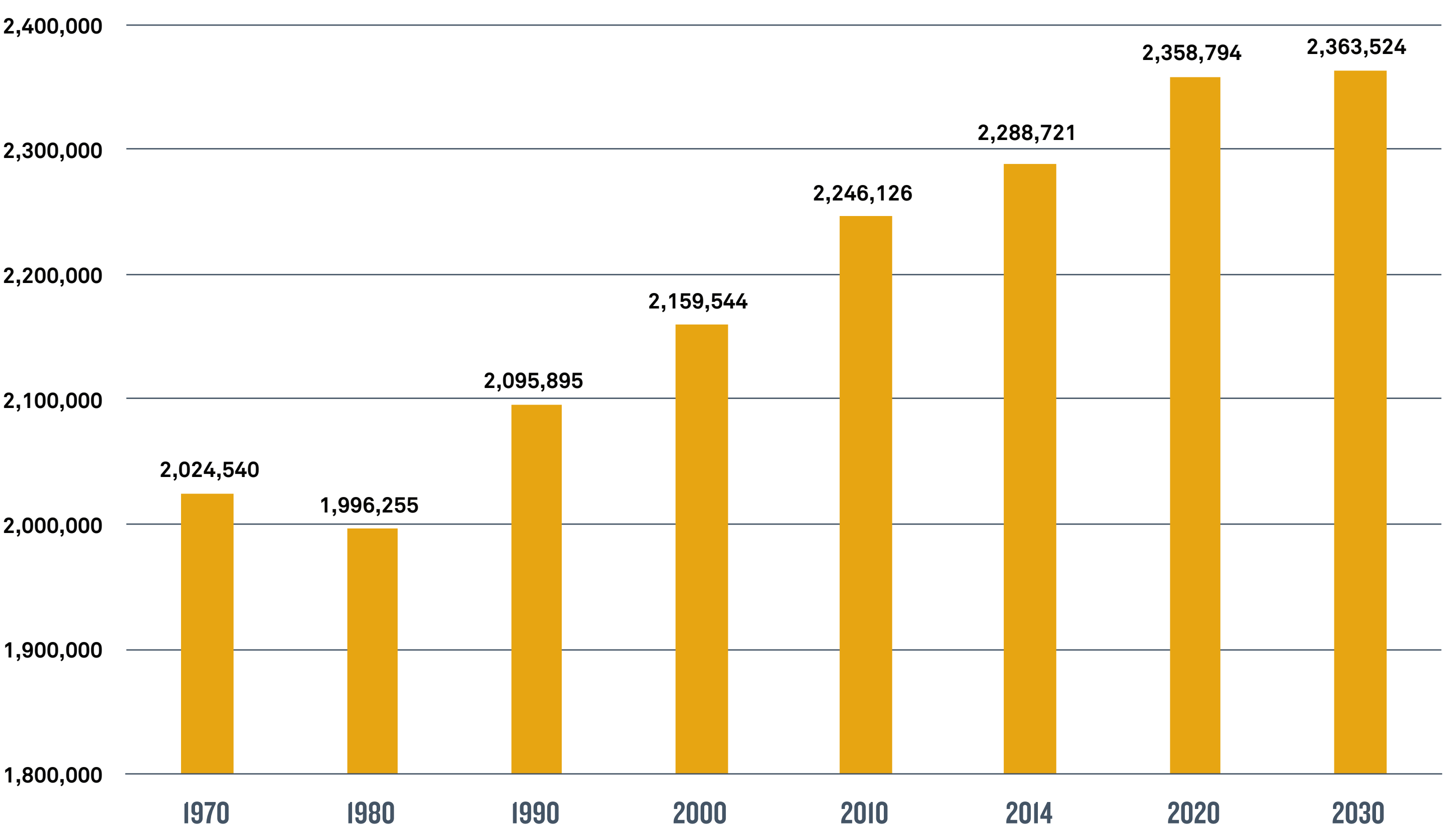
TABLE 3.1: Labor Force Participation Rates, 2010–2014

AGE COHORT	LABOR FORCE PARTICIPATION RATE
16–24	61.8%
25–44	85.8%
45–64	76.1%
65–74	30.6%
75+	6.0%
All Ages 16+	68.1%

Source: American Community Survey Public Use Microdata Sample for Greater Boston Metro Area, 2010–2014.

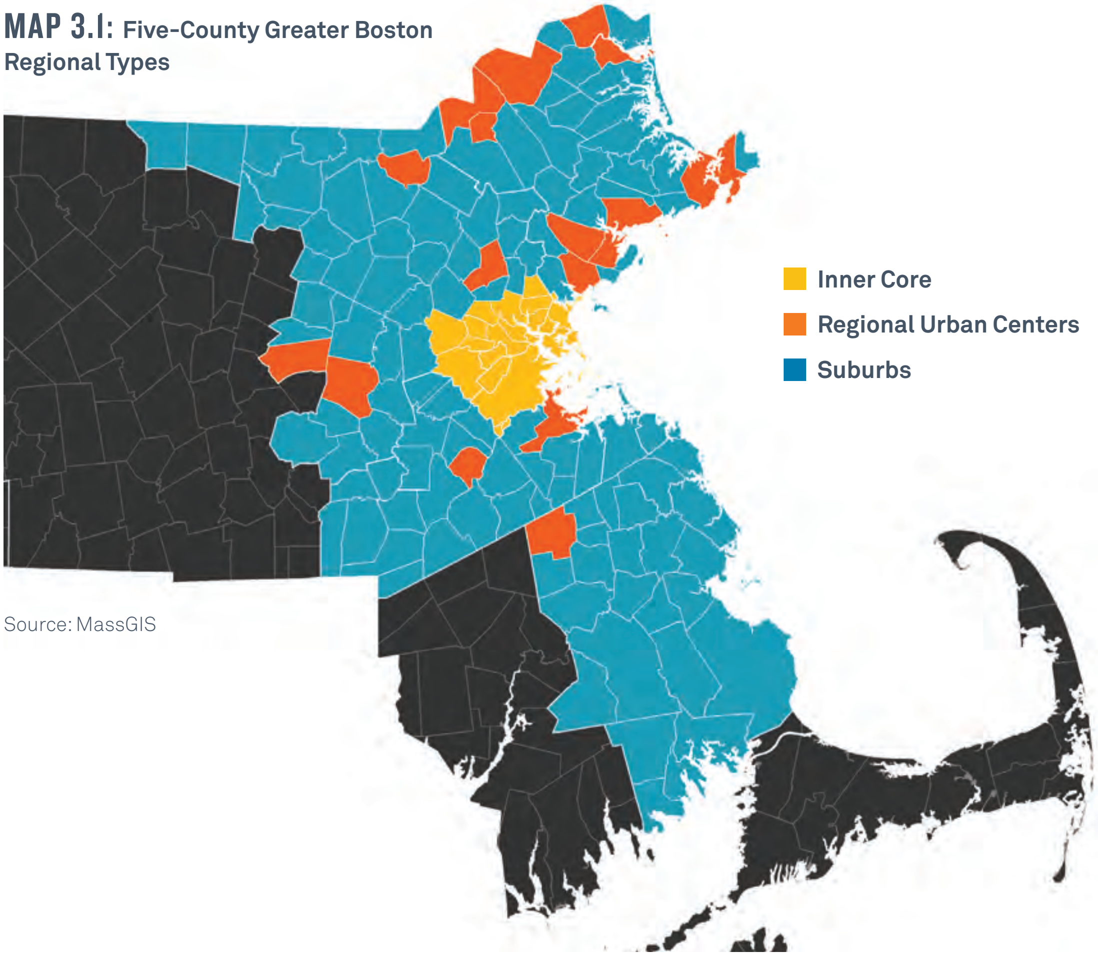
Given the aging of the region's population and assuming that age-specific labor force participation rates remain at current levels, **Figure 3.3** illustrates the expected slowdown in the region's labor force. Between 1990 and 2010, the labor force expanded by 7.2 percent. Our baseline projection for the following two decades (2010-2030) suggests that Greater Boston's labor force will increase by only 5.2 percent and much of this has already occurred. Between 2014 and 2030, the labor force is poised to grow by only 3.3 percent as a large cohort of current workers leaves the labor market for retirement. Indeed, between 2020 and 2030, retirements will claim even more workers so that labor force growth during this decade is predicted to come to a virtual halt, growing by a total of only 0.2 percent.

FIGURE 3.3: **Greater Boston Labor Force, 1970–2014 (2020–2030 Projected)**



Sources: U.S. Census 1970–2014; MAPC 2020–2030 Stronger Region Projection

MAP 3.1: Five-County Greater Boston Regional Types



Source: MassGIS

THE GEOGRAPHIC DISTRIBUTION OF INCREASED POPULATION AND LABOR FORCE

Population and labor force growth are not expected to expand at the same rate in all parts of the region. Based on MAPC definitions, we identify three key geographical sub-regions within Greater Boston's five counties. These are shown in **Map 3.1**.

These include:

- 16 *Inner Core* Communities—Arlington, Belmont, Boston, Brookline, Cambridge, Chelsea, Everett, Malden, Medford, Melrose, Newton, Revere, Somerville, Waltham, Watertown, and Winthrop
- 17 *Regional Urban Centers*—Amesbury, Beverly, Brockton, Framingham, Gloucester, Haverhill, Lawrence, Lowell, Lynn, Marlborough, Methuen, Newburyport, Norwood, Peabody, Quincy, Salem, and Woburn
- 114 *Suburbs*—See **Appendix 1** for the complete list of Greater Boston suburbs examined here

In 2010, the Greater Boston region was home to 63 percent of the Commonwealth's population.

Appendix 2 provides complete data on the population and labor force for 1990 through 2010 and projections for 2020 and 2030 for each age cohort in each Greater Boston sub-region, as well as the population and labor force estimates by age cohort for the five-county region as a whole.

As **Table 3.2** reveals, the region's ***inner core*** is expected to experience the fastest growth in both population and labor force between 2010 and 2030, as many young individuals and households choose to live in or near central cities. We project the inner core population to increase by nearly 240,000, a 17.5 percent increase over 2010. However, because of the large number of retiring Baby Boomers, the labor force will expand by less than half this number—by roughly 101,000 or 12.7 percent.

TABLE 3.2: **Projected Growth in the Population and Labor Force, 2010-2030**

GREATER BOSTON GEOGRAPHIC AREA	POPULATION GROWTH	PERCENTAGE POPULATION GROWTH	LABOR FORCE GROWTH	PERCENTAGE LABOR FORCE GROWTH
Inner Core	239,000	+17.5%	101,000	+12.7%
Regional Urban Centers	111,000	+12.1%	57,000	+11.5%
Suburbs	77,000	+4.3%	-41,523	-4.4%
5-County Greater Boston Region	428,000	+10.5%	117,000	+5.2%

Source: U.S. Census Bureau American Community Survey (2010); MAPC Stronger Region Projection (2010-2030)

In the *regional urban centers* throughout Greater Boston, the population is projected to increase by 111,000, an increase of 12.1 percent between 2010 and 2030. Here the labor force is expected to increase at almost the same rate as the population, climbing by an expected 57,000, or 11.5 percent. The addition of 25 to 44 year olds remaining in the region moving here by 2030 helps offset the decline in the labor force due to the growth in the number of older retirees.

The *suburbs* are expected to increase the least, with the population projected to expand by only 77,000 or 4.3 percent. But because of a large surge in Baby Boomer retirements, we project that the suburban labor force will actually shrink by nearly 42,000, a 4.4 percent decrease.

Overall, then, *Greater Boston* could experience an increase of nearly 430,000 residents by 2030, an increase of 10.5 percent over twenty years.

Meanwhile, the labor force across the entire region could swell by roughly 117,000 or 5.2 percent. As a result of the aging population, the overall labor force participation rate is expected to drop from 55.1 percent to 52.5 percent.

Areas within Greater Boston are expected to experience substantially different population demographics due to differences in the aging of their populations, different net domestic migration rates, and different rates of immigration. According to our projections, as **Table 3.3** demonstrates, only the inner core and regional urban centers will experience an increase in the number of children under age 16—presumably as a result of younger families remaining in or being attracted to these cities. All areas of the region will experience an increase in 25 to 44 year olds, although the suburbs will see only a small bump in this population. All parts of the region will experience a huge increase in Baby Boomers turning 65 or older. By 2030, we expect to see more than a 75 percent increase in this age cohort.

TABLE 3.3: **Percentage Change in Population by Age Cohort, 2010-2030**

	0–15	16–24	25–44	45–64	65+	ALL AGES
Inner Core	+23.2%	-7.7%	+19.5%	+8.3%	+38.7%	+17.5%
Regional Urban Centers	+6.0	-11.7	+15.5	+5.2	+81.0	+12.1
Suburbs	-23.9	-17.3	+1.2	-16.6	+97.0	+2.8
5-County Greater Boston Region	-2.8%	-10.5%	+13.5%	-3.6%	+76.8%	+10.5%

Sources: U.S. Census Bureau (2010); MAPC Stronger Region Projection (2010–2030)

PROJECTED GROWTH IN BUSINESS OUTPUT

The increase in the number of workers in Greater Boston will ultimately add to the need for more transportation but also portends a demand for additional infrastructure to meet the needs of the businesses that will employ them. Business demand for transportation, water, sewerage, electricity, natural gas, recycling, and appropriately zoned land use depends on the level of goods and services output. To forecast the growth in this demand, we can use the standard economics equation for output:

Total Output =
Output per Worker X Number of Workers

which translates into:

% Change in Output = %Change in Output per Worker + %Change in Number of Workers

Output per worker is what is commonly called labor productivity.

For the purposes of projecting increased business demand for infrastructure in Greater Boston, we will use what can be called "Output-Enhanced Labor Force" figures. These figures are calculated by adding together annual expected labor force growth rates and the expected increase in labor productivity, and multiplying this sum by the projected labor force for each year between 2010 and 2030. The projected annual increase in productivity used for these calculations is equal to the U.S. average growth in labor productivity for the decade between 2006 and 2015: 1.2 percent per year.[28]

As **Table 3.4** reveals, improved productivity is the key factor in increased business output. Between 2010 and 2020, the Greater Boston labor force is projected to increase by a grand total of 5 percent during the decade. With added productivity, however, business output is projected to increase by 13 percent over this decade. In the following decade, as noted earlier, the labor force grows very slowly, but productivity is assumed to continue increasing at 1.2 percent per year. As such, business output would expand at a

BUSINESS DEMAND FOR ELECTRICITY DEPENDS ON THE LEVEL OF GOODS AND SERVICES OUTPUT.

TABLE 3.4: Projected Labor Force and Business Output

	LABOR FORCE	BUSINESS OUTPUT
2010–2020	5.0%	13.1%
2020–2030	0.2%	12.9%
2010–2030	5.2%	27.7%

Source: U.S. Census Bureau (2010); MAPC Stronger Region Projection (2020–2030); U.S. Department of Labor, Bureau of Labor Statistics, Productivity Series

compounded rate of nearly 13 percent between 2020 and 2030. For the entire 2010–2030 period, we therefore project that business output will expand by nearly 28 percent. Not surprisingly this type of output growth will almost surely require substantially more infrastructure to meet business needs. If commensurate infrastructure is not forthcoming, business will likely not be able to continue growing at its current rate.

CONCLUSIONS

Projections of population, labor force, and output described in this chapter will form the basis for projecting future demands on Greater Boston's infrastructure through 2030. Underlying our projections are three key assumptions:

Assumption 1:
The relative accuracy of MAPC's projected "Stronger Region" rates for births, deaths, net internal migration, and net immigration for 2010 through 2030

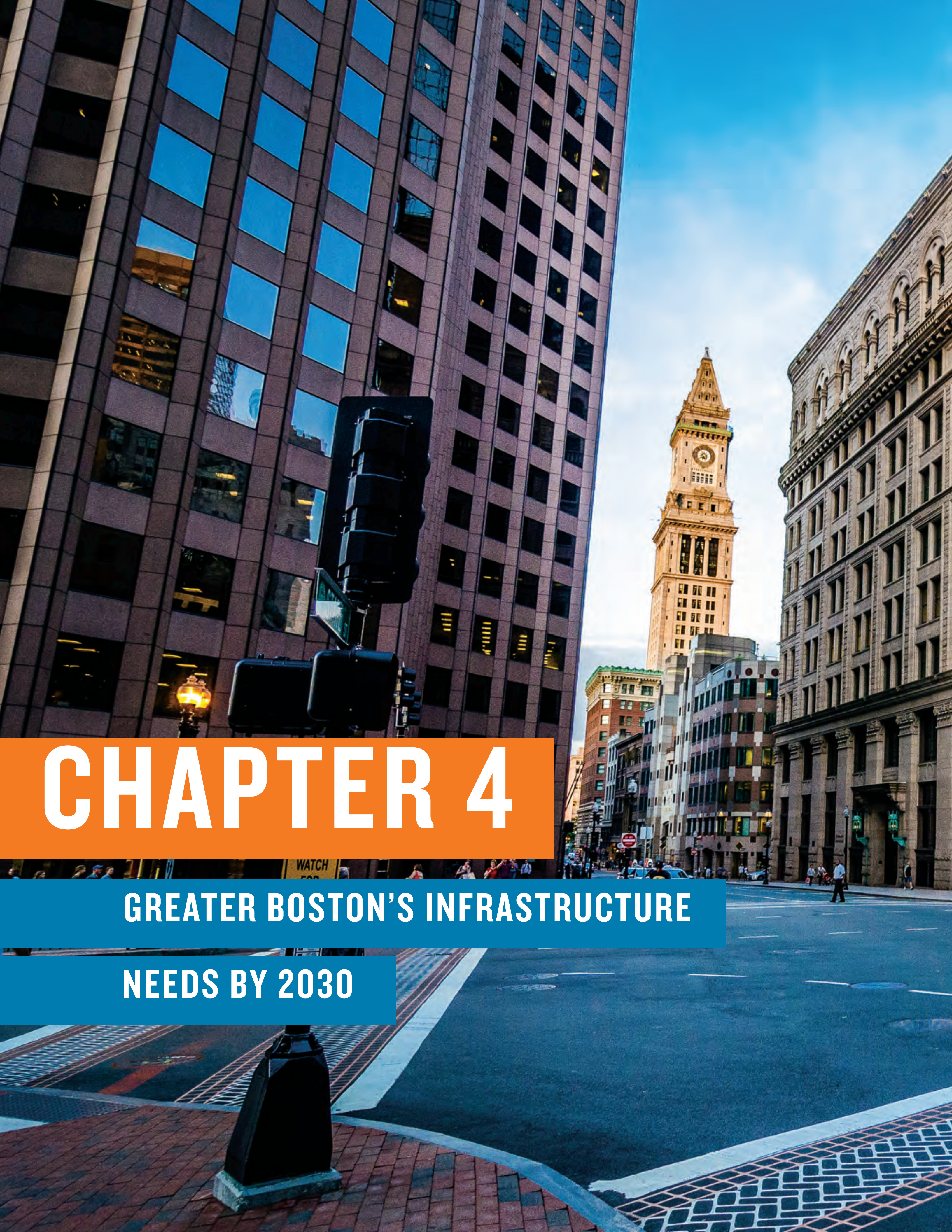
Assumption 2:
No change over time in age-specific labor force participation rates

Assumption 3:
Average productivity growth rate of 1.2 percent per year

The population projections will be used to estimate the increased demand for consumer use of energy and water resources. The labor force projections will be used to anticipate increased demand for commuter transport across all modes of transit. The business output projections will be used to forecast increased demand for commercial vehicle transit, water resources, and energy. Combining consumer and business demand for infrastructure will yield estimates of the future total demand placed on Greater Boston's built infrastructure through 2030.

CHAPTER 4

GREATER BOSTON'S INFRASTRUCTURE NEEDS BY 2030




CONGRESS
DEVONSHIRE
The First National Bank of Ipswich
NO TURN ON RED

CHAPTER 4

Even with greater conservation, it goes without saying that a growing population and a growing economy will require additions to the built environment. Based on the population, labor force, and economic output projections in the previous chapter, this section of the report will attempt to project how much additional infrastructure Greater Boston will need by 2030 in order to sustain our growing population and economy.

PROJECTION ASSUMPTIONS

These initial infrastructure projections are constructed on the basis of a number of "simulation" assumptions. These include:

- The ***birth, mortality, net domestic migration, and immigration rates*** implicit in the MAPC model will hold throughout the 2010–2030 period.
- ***Age-specific labor force participation rates*** will remain unchanged throughout the projection period. Hence, if approximately 62 percent of 16 to 24 years olds were participating in the labor force in the 2009–2014 period, the same proportion of 16 to 24 year olds will participate in the labor force in 2020 and 2030. This also means that older workers will continue to retire at the same rate throughout the projection period as they do now.
- ***Individuals*** and their ***households*** will consume the same amount of water, sewer, and energy resources per capita as they currently do.
- ***Commuters*** will continue to use the age-specific transit modes as currently used in the region.
- ***Economic output*** will require the same amount of water, sewer, and energy resources per unit of output as they do now.

In future reports, it will be possible to alter these behavioral assumptions, producing various "counterfactuals" or "what-if" projections. For example, if consumers and businesses engage in significant water and energy conservation so that fewer resources per capita and per output unit are needed, then there will be a corresponding reduction in required infrastructure. If a growing number of workers substitute alternative forms of transit for their daily commute—or increase their work from home—it would lead to a shift in the projected transportation infrastructure needed to meet demand. A battery of counterfactuals can be run once the basic simulation model is complete. Indeed, the projections here suggest that changes in behavior will almost surely be necessary—even with significant infrastructure improvements—if Greater Boston is to have a built environment that adequately supports its growing population and business enterprise over the next two decades.

PROJECTED TRANSPORTATION DEMAND—ROADS, HIGHWAYS, RAIL, AND FERRY

To begin to estimate the need for transportation infrastructure in Greater Boston in 2030, we have used Census PUMS data to ascertain the current transit mode that the region's commuters use as their main form of commuting to and from work.[29] PUMS provides data on the following transit modes by age of commuter for the Greater Boston region:

Auto/Truck	Bicycle
Bus/Streetcar	Taxi
Subway	Motorcycle
Rail	Ferryboat
Pedestrian	

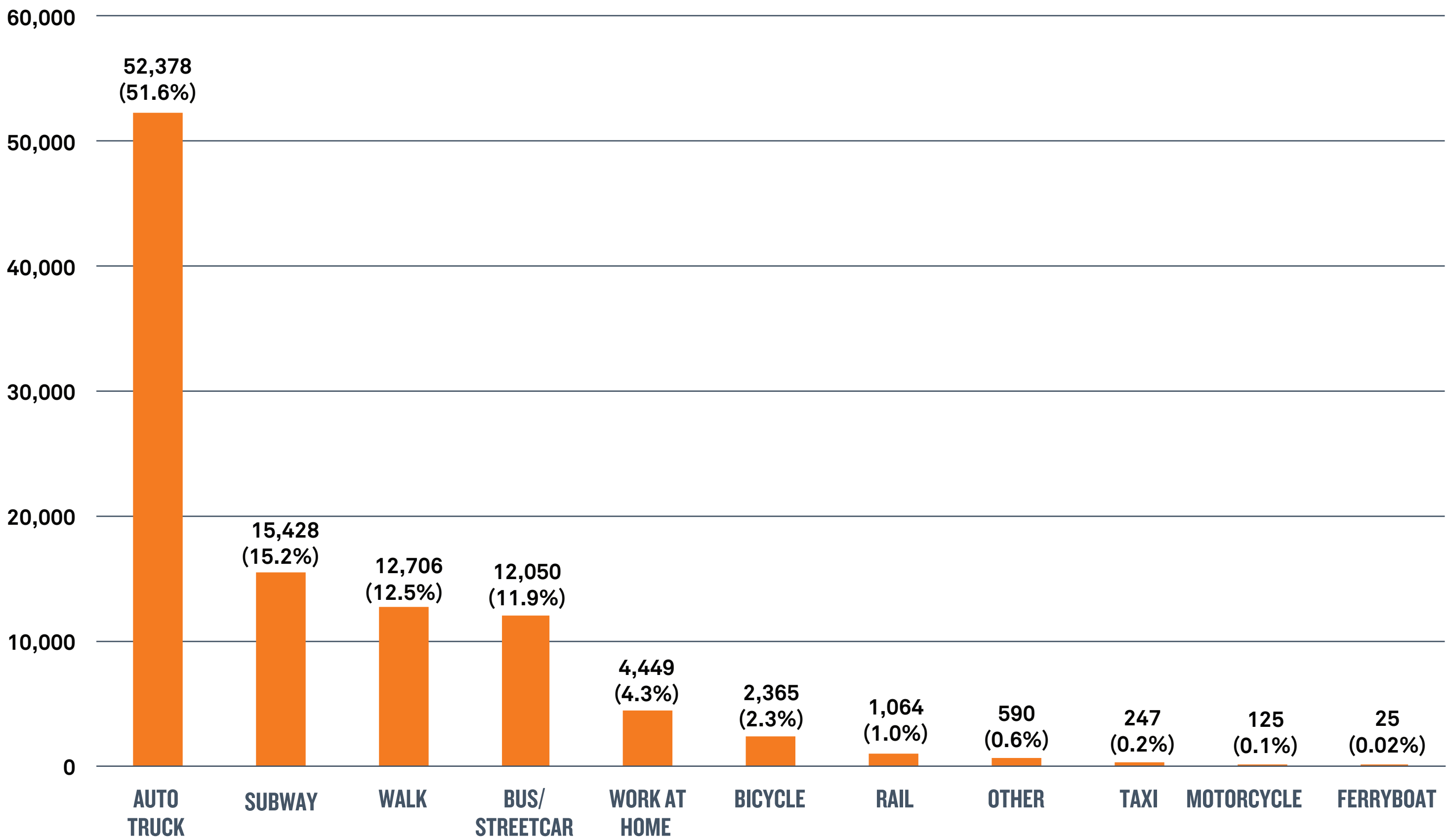
Using these data, we have estimated the current percentage of commuters in each age cohort in each of the three Greater Boston geographic areas (and for the five-county region as a whole) who commute using a given transit mode. **Appendix 3** provides the entire set of estimates.

We have applied existing commuting statistics (as shown in Chapter 2) to the expected growth in the labor force (as shown in Chapter 3) to arrive at estimates of how many more commuters will be using each form of transit in 2030. These are found in **Appendix 4**. Here we take into account projected changes in the age structure of the labor force but, as noted above, we assume that each age cohort within each region will continue to commute using their present transit mode.

INNER CORE

Figure 4.1 reveals the projected 2010-2030 increase in commuters by transit mode for those expected to reside in the 16 *Inner Core* municipalities within Greater Boston. The percentages refer to the percentage of residents expected to use each transit model. As such, we project that out of the roughly 101,000 additional Inner Core workers we expect by 2030, more than 52,000 of them will commute to work by auto or truck. An additional 15,000 will use the subway, with 12,000 more relying on buses or streetcars and 1,000 extra riders on commuter rail. As such, approximately 52 percent of the added commuters will choose to commute by auto or truck; 15 percent by subway; and nearly 12 percent by bus or streetcar. We also project an increase of nearly 13,000 pedestrians and more than 2,300 added bicyclists on Inner Core roads and bike paths. Of the 101,000 additional Inner Core workers, more than 4,400 are projected to "commute" to work by working at home.

FIGURE 4.1: Projected Increase in Commuters by Transit Mode, Inner Core, Greater Boston, 2010–2030 (% Share of Total Increase by Mode)



Source: Dukakis Center Labor Force Projections; U.S. Census PUMS data[30]

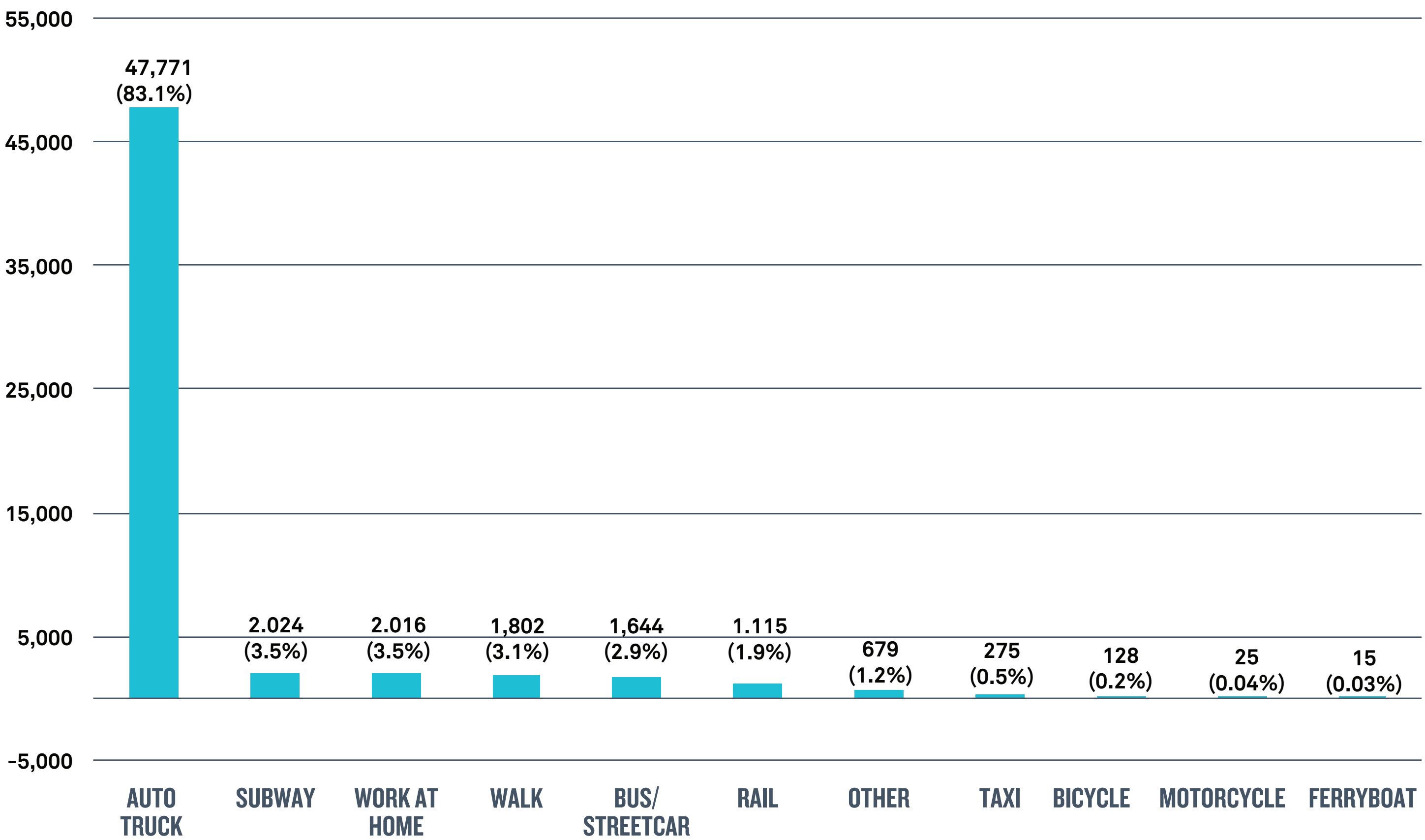
REGIONAL URBAN CENTERS

Figure 4.2 provides a similar projection for Greater Boston's 17 *Regional Urban Centers.* Here approximately 83 percent of the expected 57,000 additional commuters will commute by auto or truck (47,800) assuming no change in current transit choice. Another 4,800 workers in these regional centers will be added to the public transit system using commuter rail, subway, bus, streetcar, or ferryboat.

SUBURBS

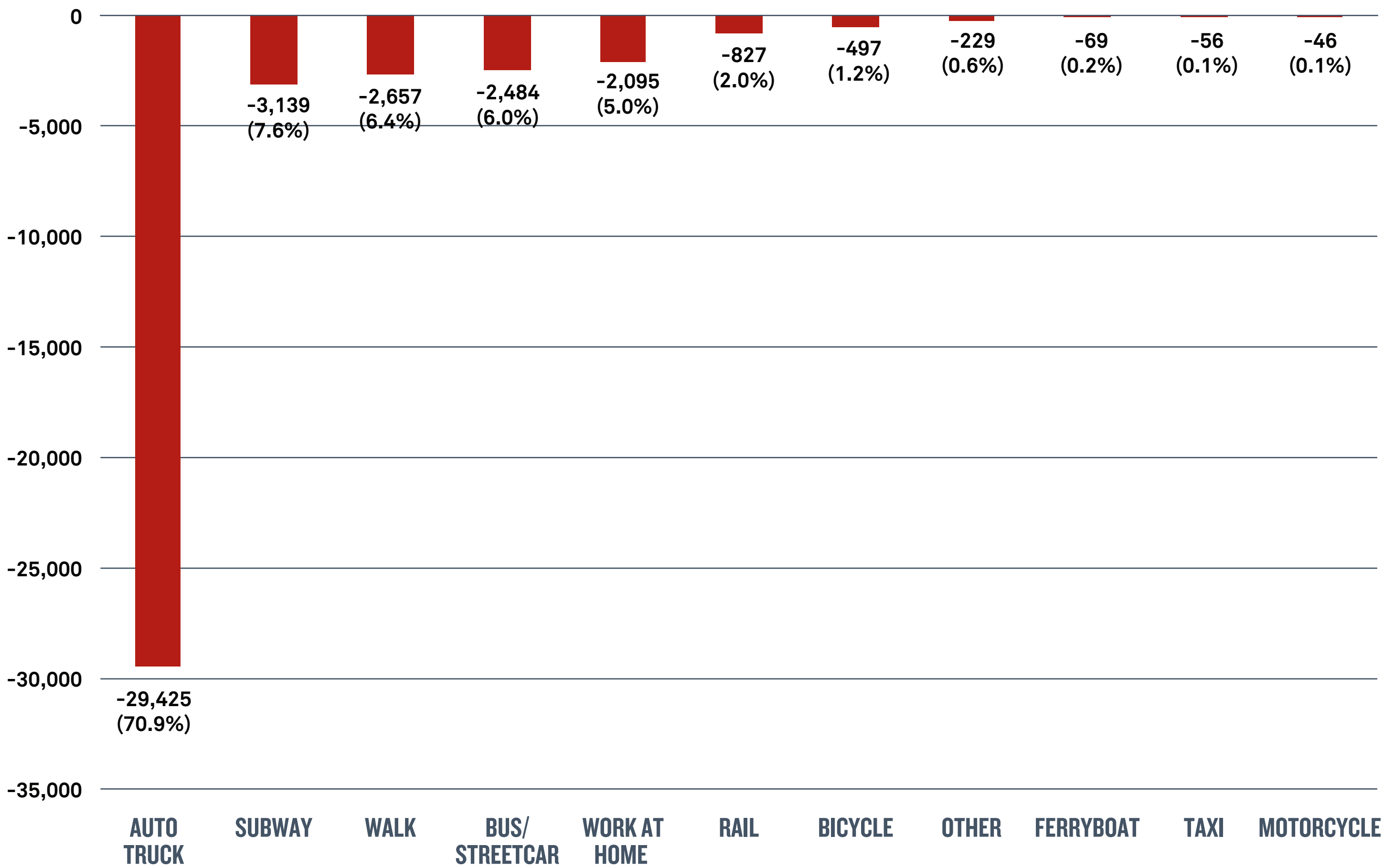
Figure 4.3 provides similar data for Greater Boston's *Suburbs*, but as demonstrated in Chapter 3, the number of suburbanites in the workforce is projected to decline between 2010 and 2030 as a rapidly aging population leaves the workforce in larger numbers than the cohort of younger workers coming up behind them grows. As such, the demand for transportation for suburban commuters is projected to decline across all transit modes including commuter rail. We project nearly 30,000 fewer auto/truck commuters, a reduction of more than 3,100 subway commuters, and nearly 2,500 fewer bus and streetcar riders. As such, our projections suggest only the suburbs will not put an added strain on the region's transportation infrastructure—at least for workday commuters. Many will rightly complain, however, that congested transit used by suburban commuters is already well beyond reason.

FIGURE 4.2: Projected Increase in Commuters by Transit Mode, Regional Urban Centers, Greater Boston, 2010–2030 (% Share of Total Increase by Mode)



Source: Dukakis Center Labor Force Projections; U.S. Census PUMS data

FIGURE 4.3: Projected Change in Commuters by Transit Mode, Suburbs, Greater Boston, 2010–2030 (% Share of Total Increase by Mode)



Source: Dukakis Center Labor Force Projections; U.S. Census PUMS data

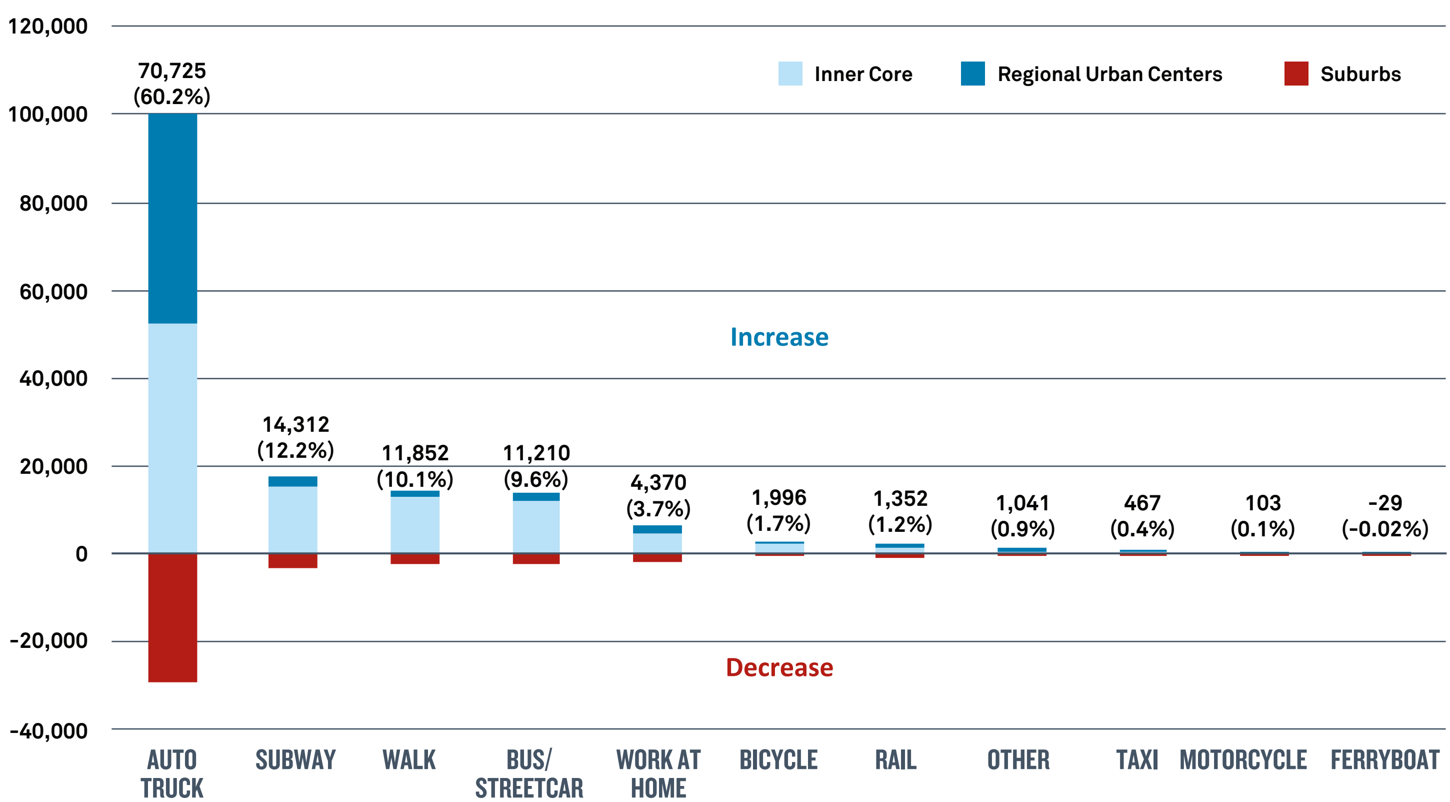
FIVE-COUNTY GREATER BOSTON

What these sub-region increases mean for the projected increase in transit use across the entire *Greater Boston region* is depicted in **Figure 4.4**. If there is no change in transit behavior and the labor force grows as projected in Chapter 3, there will be nearly **71,000 more auto/truck commuters** in 2030 than there were in 2010 in the five-county area. This represents more than three-fifths of all additional commuters. The MBTA will have to find a way to accommodate more than **14,000 more subway riders** and more than **11,000 bus and streetcar commuters,** while there will be a need to provide **commuter rail for another 1,100 riders** each workday. These numbers could increase as a result of constrained highways and roads as well as an increase in transit-oriented development.

There is also evidence that the need for additional transit capacity may in fact be even greater than we have projected here. The Boston Region Metropolitan Planning Organization (Boston MPO) recently adopted a Long Range Transportation Plan (LRTP) for the region which projects future transportation needs to the year 2040 using a travel demand model that accounts for travel time, congestion, cost, vehicle ownership, parking availability at workplace locations, and a variety of other factors. That model also utilizes MAPC's population, household, and employment scenarios as the basis for future land use, making the underlying demographic assumptions comparable to our analysis presented. Because the Boston MPO model covers a larger geographic area, extends the analysis out another ten years, and accounts for all trips, not just commuting, it suggests a substantially higher overall future demand for bus, rapid transit, and commuter rail.[31]

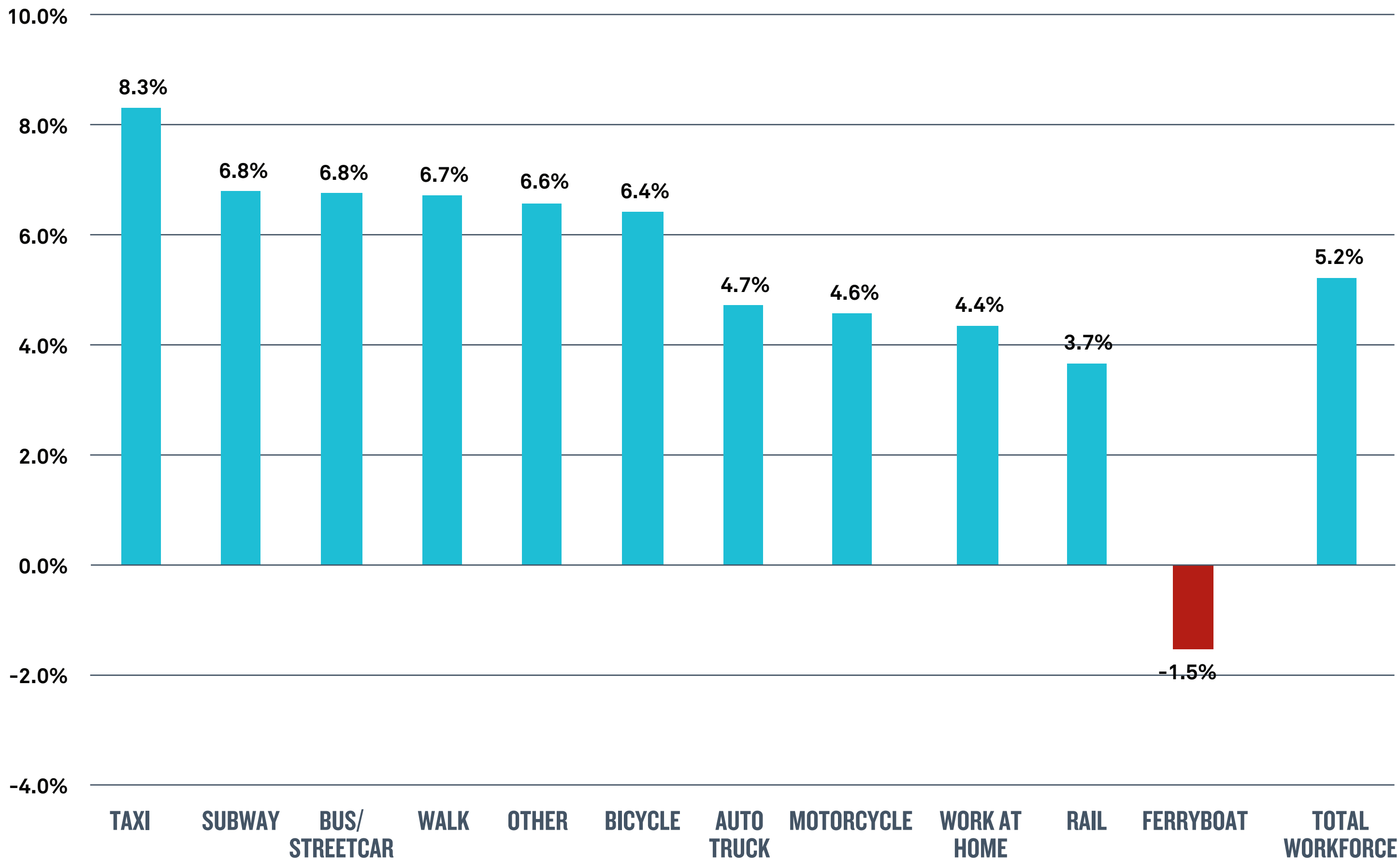
Figure 4.5 converts these figures into percentage increases in commuters by transit mode across all of Greater Boston. Mainly because of the projected growth of younger workers in the Inner Core, **we find the greatest additional pressure on Greater Boston's transit infrastructure will come in taxi use (e.g. Uber and traditional cab service), the MBTA subway system, and bus and streetcar ridership. All of these can be expected to see at least a 6 percent increase in demand.** Pedestrian and bicycle commuting can be expected to increase by nearly 7 percent as well. **Auto and truck commuting is projected to increase by nearly 5 percent,**

FIGURE 4.4: Projected Change in Commuters by Transit Mode, 5-County, Greater Boston Region, 2010–2030 (%Share of Total Increase by Mode)



Source: Dukakis Center Labor Force Projections; U.S. Census PUMS data

FIGURE 4.5: **Projected Percentage Change in Commuters by Transit Mode, 5-County, Greater Boston Region, 2010–2030**



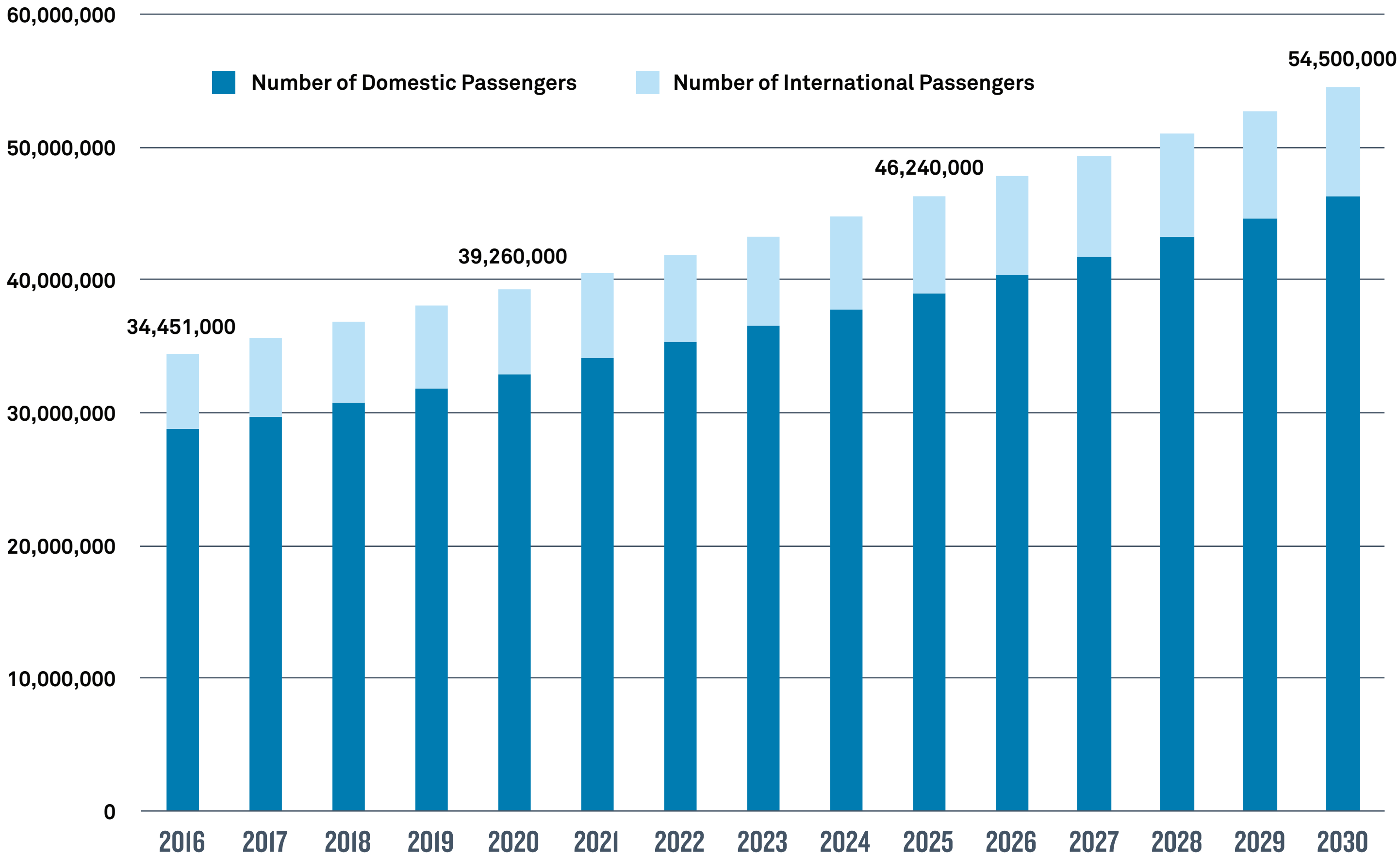
Source: Dukakis Center Labor Force Projections; U.S. Census PUMS data

likely enough to take many of the region's major thoroughfares from a state of heavy congestion to virtual gridlock. Only the decline in suburban commuters mitigates what could be an even more challenging outcome.

Yet the pressure on the highway and road system will be even greater, given an expected increase in commercial traffic as a result of a growing economy. In 2010 there were approximately 215,000 private sector establishments operating in Massachusetts, nearly 60 percent of which were located in the five-county Greater Boston region.[32] The Federal Highway Administration reports that in 2010 there were 14,092 tractor trucks registered in Massachusetts.[33] Assuming that Greater Boston accounts for 60 percent of these, the total number of these large trucks on the region's highways and roads is roughly 8,400. With our projected increase in economic output of nearly 28 percent between 2010 and 2030, we expect nearly 3,100 large tractor trailers will be added to the highways and roads in addition to more than 70,000 additional commuters in their autos and light trucks. Note that these projections do not include additional busses to accommodate the expected 7 percent increase in commuters using buses or streetcars, light trucks that are not used also for commuting, and out-of-state trucks traveling into Greater Boston.[34,35]

Altogether, then, the total number of additional vehicles on Greater Boston's roads and highways by 2030 could approach 80,000 or more—or nearly 5 percent more than in 2010. The forecasted transit trips can be further increased by the growth in transit-oriented development. For example, the 2012 *Hub and Spoke* report references an MAPC analysis which calculated that new transit-oriented development alone could generate more than 60,000 transit commute trips per weekday by 2035.

FIGURE 4.6: Projected Annual Air Passengers, Logan Airport, 2016–2030



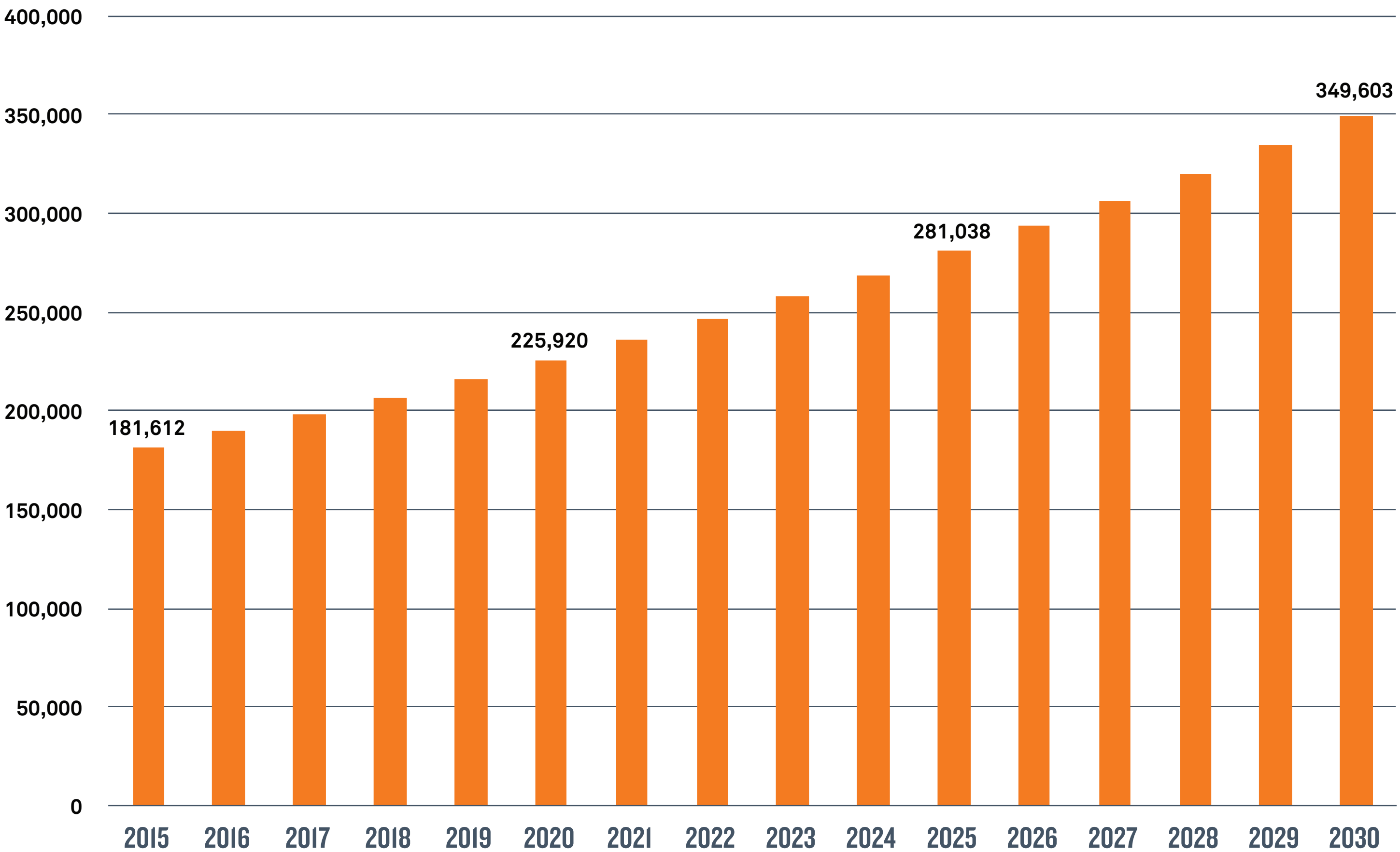
Source: Dukakis Center Projection based on MassPort Airline Passenger Data

PROJECTED TRANSPORTATION DEMAND—AIR TRAVEL AND THE SEAPORT

Not surprisingly, air travel has been expanding rapidly through Logan Airport for decades. So far, MassPort has been able to accommodate the growth in domestic and international passenger service with its fixed runways through the utilization of larger aircraft and higher load factors. But as **Figure 4.6** reveals, if the number of passengers using Logan increases in the future at the same annual rate as during the decade of 2005–2015 (Domestic Travel: 3.45%; International Travel: 2.68%), the number of domestic passengers will reach more than 46 million by 2030 while the number of passengers on international flights will swell to more than 8.2 million for a grand total of more than 54 million air travelers. Between 2015 and 2030, this amounts to a 66 percent increase in domestic travel and a 49 percent increase in international flights—63 percent overall. Whether Logan can handle such a load safely without major expansion seems questionable.

If the amount of container cargo handled by the Conley Seaport Terminal over the past two years is any indication of the potential growth in demand for sea-based cargo transport, **Figure 4.7** suggests that by 2030 the demand for import and export loadings could nearly double from its current 181,000 TEUs to nearly 350,000 TEUs, a 93 percent increase. One suspects that such an amount of cargo could be handled by the terminal only by substantial dredging of the harbor to permit larger container ships to dock in Boston—as they do now in Seattle—and increasing crane capacity. With a maximum TEU width of 17 in the current terminal, it is impossible for the Conley Terminal to accommodate the New–Panamax ships built for the expanded Panama Canal that are 20 TEU wide and the new Triple E container ships that first went into operation in 2013 with a capacity of 23 TEU width.[36]

FIGURE 4.7: **Projected Annual Seaport Cargo in TEUs, 2016–2030**



Source: Dukakis Center Projection based on MassPort Conley Terminal Data

PROJECTED ENERGY DEMAND

Like transportation, future demand for electricity and natural gas depend on population growth and the expected increase in economic output. Here we assume in our "simulation" projection that residential energy consumption per household remains constant through 2030 and that the future amount of electricity and natural gas required by industry is simply based on the rate of growth of the overall economy. Thus we base our energy infrastructure projection on three key assumptions:

- No increase in energy conservation in the household sector
- No increase in energy conservation in the industrial sector
- The use of energy per unit of industrial output remains at current levels regardless of changes in industry mix

RESIDENTIAL DEMAND

The data on electricity and natural gas consumption per residential household in Greater Boston are based on statistics obtained from Eversource.[37] We have adjusted the number of residential households to reflect the projected decline in the average size of households and therefore an expected decline in energy consumption per household. In 2010, the average household size throughout the five-county Greater Boston region was 2.54. By 2030, MAPC projects the average number of household members per household will have shrunk to 2.41.[38]

Tables 4.1 A and B provide the projection estimates for residential electricity and natural gas demand. According to Eversource, annual residential use currently runs from 5,470 kilowatt hours (kWh) in Suffolk County to nearly 9,370 kWh in Norfolk.[39] In 2010, we estimate that total residential electric use in all of Greater Boston amounted to 12.2 million megawatt hours (where 1,000 kWh = 1 MWh). Based on electricity use and size-adjusted household growth in each area within Greater Boston, we project an increased demand for approximately 1.2 million MWh by 2030, the equivalent of an 10.2 percent increase.

Tables 4.1A and B also provide equivalent data on residential demand for natural gas under the same assumptions we used to estimate future electricity demand. In this case, natural gas is measured in therms.[40] Currently, according to Eversource, the average household in Greater Boston consumes about 1,300 therms of natural gas energy per year, mostly for heat. This ranges from a little over 900 therms per year in Plymouth County to more than 1,950 in Norfolk. Since residential natural gas usage is assumed to increase with the number of size-adjusted households and we assume here no change over time in the amount of fuel used per household, we project the increase in demand for natural gas should mirror the increase in the number of size-adjusted households taking into account the redistribution of households across the five counties between 2010 and 2030. As such, we project the total amount of natural gas that could be needed in Greater Boston by 2030, assuming again no added conservation, is 10.5 percent higher than in 2010—an increase of nearly 215 million therms.

COMMERCIAL AND INDUSTRIAL DEMAND

As economic growth is expected to increase at a much faster rate than population growth, the growth rate for commercial and industrial electricity and natural gas will far eclipse that of households. **Appendix 5** provides our projections for commercial and industrial electric power through 2030.

According to current Eversource data, the average annual electric consumption by their commercial and industrial customers in Greater Boston is 67,000 kWh. Assuming this average holds for all such customers regardless of their generating and distributing company, we estimate total electric demand for the 128,000 establishments in the five-county region at roughly 8.6 million megawatt hours per year. Given our projected 27.7 percent economic output growth rate and assuming that any added commercial and industrial production is equally electric power-intensive, this translates into an average annual increase of just under 120,000 MWh. As such, by 2030, we project an increased demand for 2.4 million megawatt hours of power for these non-residential customers.

Adding together residential and commercial/industrial demand, we project the need for 3.6 million additional MWh of electric power by 2030, an increase of roughly 17 percent over the 20.8 million MWh consumed in 2010. These forecasts do not include energy mix changes or energy conservation measures in the residential, commercial/industrial sectors (see **Table 4.2**).

"WE PROJECT AN INCREASED DEMAND FOR 2.4 MILLION MEGAWATT HOURS OF POWER FOR THESE NON-RESIDENTIAL CUSTOMERS."

TABLE 4.1A: Projected Residential Electricity Demand, 2010–2030

	ESSEX	MIDDLESEX	NORFOLK	PLYMOUTH	SUFFOLK	GREATER BOSTON
Size-Adjusted Number of Households						
2010	282,768	569,917	255,039	163,992	289,503	1,561,219
2030	309,065	625,769	278,502	176,455	336,692	1,725,146
2010–2030	26,297	55,852	23,463	12,463	47,189	163,927
% Increase	9.3%	9.8%	9.2%	7.6%	16.3%	10.5%
Annual Residential kWh Use	6,875.4	8,860.5	9,369.7	7,726.7	5,469.7	7,856.6
2010 Total MWh	1,944,133	5,049,750	2,389,639	1,267,117	1,583,495	12,234,133
2030 Total MWh	2,124,935	5,544,626	2,609,480	1,363,415	1,841,604	13,484,060
Increase in MWh 2010–2030	180,801	494,877	219,841	96,298	258,110	1,249,927
% Increase	9.3%	9.8%	9.2%	7.6%	16.3%	10.2%
% Share of Greater Boston	14.5%	39.6%	17.6%	7.7%	20.6%	100.0%

TABLE 4.1B: Projected Residential Natural Gas Demand, 2010–2030

	ESSEX	MIDDLESEX	NORFOLK	PLYMOUTH	SUFFOLK	GREATER BOSTON
Size-Adjusted Household Change						
2010–2030	26,297	55,852	23,463	12,463	47,189	163,927
Annual Therms per Household Use	1,551.7	1,044.2	1,950.8	915.7	1234.7	1304
2010 Total Therms	438,771,106	595,107,331	497,530,081	150,167,474	357,449,354	2,035,829,576
2010-2030 Increase in Therms	40,805,055	58,320,658	45,771,620	11,412,369	58,264,258	214,573,961
% Increase	9.3%	9.8%	9.2%	7.6%	16.3%	10.5%
% Share of Greater Boston	19.0%	27.2%	21.3%	5.3%	27.2%	100.0%

Source: U.S. Census; Massachusetts Department of Labor and Workforce Development; MAPC Projections; Eversource

TABLE 4.2: Projected Residential and Commercial Demand for Electric Power in MWh, 2010–2030

	RESIDENTIAL	COMMERCIAL & INDUSTRIAL	TOTAL
2010	12,235,000	8,625,000	20,860,000
2030	13,480,000	11,015,000	24,495,000
2010–2030 Increase	1,245,000	2,390,000	3,635,000
2010–2030 % Increase	10.2%	27.7%	17.4%

Source: U.S. Census; Massachusetts Department of Labor and Workforce Development; MAPC Projections; Eversource

Projected increases in natural gas demand by commercial and industry firms are shown in **Appendix 6**. In 2010, there were nearly 88,000 commercial firms operating in Greater Boston and nearly 16,000 industrial firms.[41] Across the entire region, annual natural gas consumption for commercial firms averaged 5,800 therms while that of industrial enterprises averaged more than three times that much—21,000 therms.

Given our projected increase in economic output, the entire region may see a need for 234 million additional therms of natural gas on top of the 845 million currently used by business. Commercial and industrial firms in Middlesex County will account for close to half of the increased demand while Plymouth County less than 10 percent.

Adding together residential and commercial/industrial demand, **we project the need for nearly 419 million additional therm units of natural gas** in **Greater Boston, an increase of more than 14 percent over the amount used in 2010**. These forecasts do not include energy mix changes or energy conservation measure in the residential, commercial/industrial sectors (see **Table 4.3**).

TABLE 4.3: Projected Residential and Commercial Demand for Natural Gas in 1000s of Therms, 2010–2030

	RESIDENTIAL (IN 000'S)	COMMERCIAL & INDUSTRIAL (IN 000'S)	TOTAL (IN 000'S)
2010	2,080,000	845,000	2,925,000
2030	2,265,000	1,080,000	3,345,000
2010–2030 Increase	185,000	234,000	419,000
2010–2030 % Increase	8.9%	27.7%	14.3%

Source: U.S. Census; Massachusetts Department of Labor and Workforce Development; MAPC Projections; Eversource

PROJECTED WATER AND SEWER DEMAND

With the expected growth in population and economic output, we also anticipate an increase in demand for water and sewage infrastructure. Using data from the Massachusetts Water Resources Administration (MWRA), we estimate that in 2010 approximately 29.6 gallons of water were used per capita per day by residents in Greater Boston. On a per capita basis, this also required disposing of 19.5 gallons per day through the region's sewer system. As far as Greater Boston's businesses go, we estimate that the typical commercial firm used nearly 874 gallons of water per day and disposed of more than 183 gallons through the region's sewers while the typical industrial enterprise consumed 1,200 gallons of water per year and disposed of nearly 1,050 gallons of sewage.[42] We estimate that municipal governments and large nonprofit institutions in the aggregate consumed roughly 114 million gallons a day in 2010.[43]

Table 4.4 provides our 2030 projections for water and sewer assuming no change in consumption per capita or per firm. Consistent with our projected 10.5 percent increase in the Greater Boston population, we project increased residential water consumption of more than 12.6 million gallons of water per day and the need to dispose of nearly 8.2 million gallons of sewage. Assuming no change in water usage by commercial firms, we project an additional daily water demand of 26.3 million gallons for these enterprises and another 5 million gallons for industrial firms. The added sewer requirements for these companies amount to 5.4 million gallons and 4.6 million gallons a day, respectively. Assuming that municipal and institutional demand rises at the same rate as residential use, we project an increase of 12 million more gallons of water per day and nearly 8 million more gallons of sewage. In addition, we estimate that in 2010 rain and snow runoff added 343 million gallons to public sewers, an estimate for which we do not project any increase.[44]

Adding together all users in Greater Boston suggests the need for **an additional 44 million gallons of water per day by 2030,** nearly 14 percent more than current demand. **Total sewage is projected to increase by 26 million gallons** or nearly 5 percent.

TABLE 4.4: Projected Residential, Commercial, and Industrial Demand for Water and Sewer

WATER USAGE	WATER GALLONS PER UNIT	2010 POPULATION	2030 POPULATION	WATER GALLONS 2010	WATER GALLONS 2030	2010–2030 WATER GALLON INCREASE	2010–2030 PERCENTAGE INCREASE IN WATER USAGE
Residential	29.6	4,072,454	4,500,313	120,600,000	133,209,265	12,609,265	10.5%
Commercial	874.4	87,739	112,043	71,700,000	97,970,140	26,270,140	36.6%
Industrial	1,206.8	15,951	20,369	19,600,000	24,581,825	4,981,825	25.4%
Municipal & Institutional				114,000,000	125,970,000	11,970,000	10.5%
Total Water Usage				325,800,000	381,731,229	43,861,229	13.5%

SEWER USAGE	SEWER GALLONS PER UNIT	2010 POPULATION	2030 POPULATION	SEWER GALLONS 2010	SEWER GALLONS 2030	2010–2030 SEWER GALLON INCREASE	2010–2030 PERCENTAGE INCREASE IN SEWER USAGE
Residential	19.5	4,072,454	4,500,313	79,600,000	87,756,104	8,156,104	10.2%
Commercial	183.1	87,739	112,043	15,100,000	20,515,019	5,415,019	35.9%
Industrial	1,051	15,951	20,369	16,800,000	21,404,194	4,604,194	27.4%
Municipal & Institutional				75,300,000	83,206,500	7,906,500	10.5%
Rain & Snow Runoff				342,300,000	342,300,000		
Total Sewer Usage				529,100,000	555,181,816	26,081,816	4.9%

Source: Dukakis Center Analysis

PROJECTED GREENHOUSE GAS EMISSIONS

Given the recent success in reducing greenhouse gas emissions, Synapse Energy Economics, Inc. has produced a set of state climate targets for 2030. They suggest that Massachusetts could reduce its GHG output by 35–45 percent relative to 1990 through a combination of converting one-third of gasoline-powered light-duty vehicles to electric vehicles, replacing 44 percent of the region's residential oil heating consumption with efficient electric-power heat pumps, modernizing outdated gas furnaces to more efficient units, adding better insulation to homes and businesses, and adding 50,000 gigawatt-hours of new wind and solar electric generation.[45]

PROJECTED WASTE AND RECYCLING

A growing population and expanding economy also must find a way to dispose of waste. **Table 4.5** provides our estimates of current trash production by house-holds and firms in Greater Boston and our projections through 2030. In 2010, the residents of the region's five counties generated more than 1.6 million tons of trash of which one third (33%) was recycled. Assuming no change in behavior, by 2010 we project residents of the region will be disposing of more than 1.7 million tons of trash, an increase of 130,000 tons or 7.9 percent more.

Commercial and industrial firms combined are expected to generate another 141,000 tons of waste by 2030. Together, households and firms will there-fore generate nearly 272,000 additional tons of trash, nearly 13 percent more than in 2010.

TABLE 4.5: Projected Residential and Commercial/Industrial Demand for Trash Disposal and Recycling in tons

RESIDENTIAL			
5–County Region	Non-Recycled Trash	Recycled Trash	Total Trash
2010	1,102,931	543,473	1,646,404
2030	1,190,351	586,550	1,776,901
2010–2030 Increase	87,420	43,077	130,497
% Increase 2010–2030			7.9%
COMMERCIAL AND INDUSTRIAL			
5–County Region	Non-Recycled Trash	Recycled Trash	Total Trash
2010	341,909	168,477	510,386
2030	436,617	215,145	651,762
2010–2030 Increase	94,708	46,668	141,376
% Increase 2010–2030			27.7%
RESIDENTIAL, COMMERCIAL, AND INDUSTRIAL			
5–County Region	Non-Recycled Trash	Recycled Trash	Total Trash
2010	1,444,840	711,950	2,156,790
2030	1,626,968	801,695	2,428,663
2010–2030 Increase	182,128	89,745	271,873
% Increase 2010–2030			12.6%

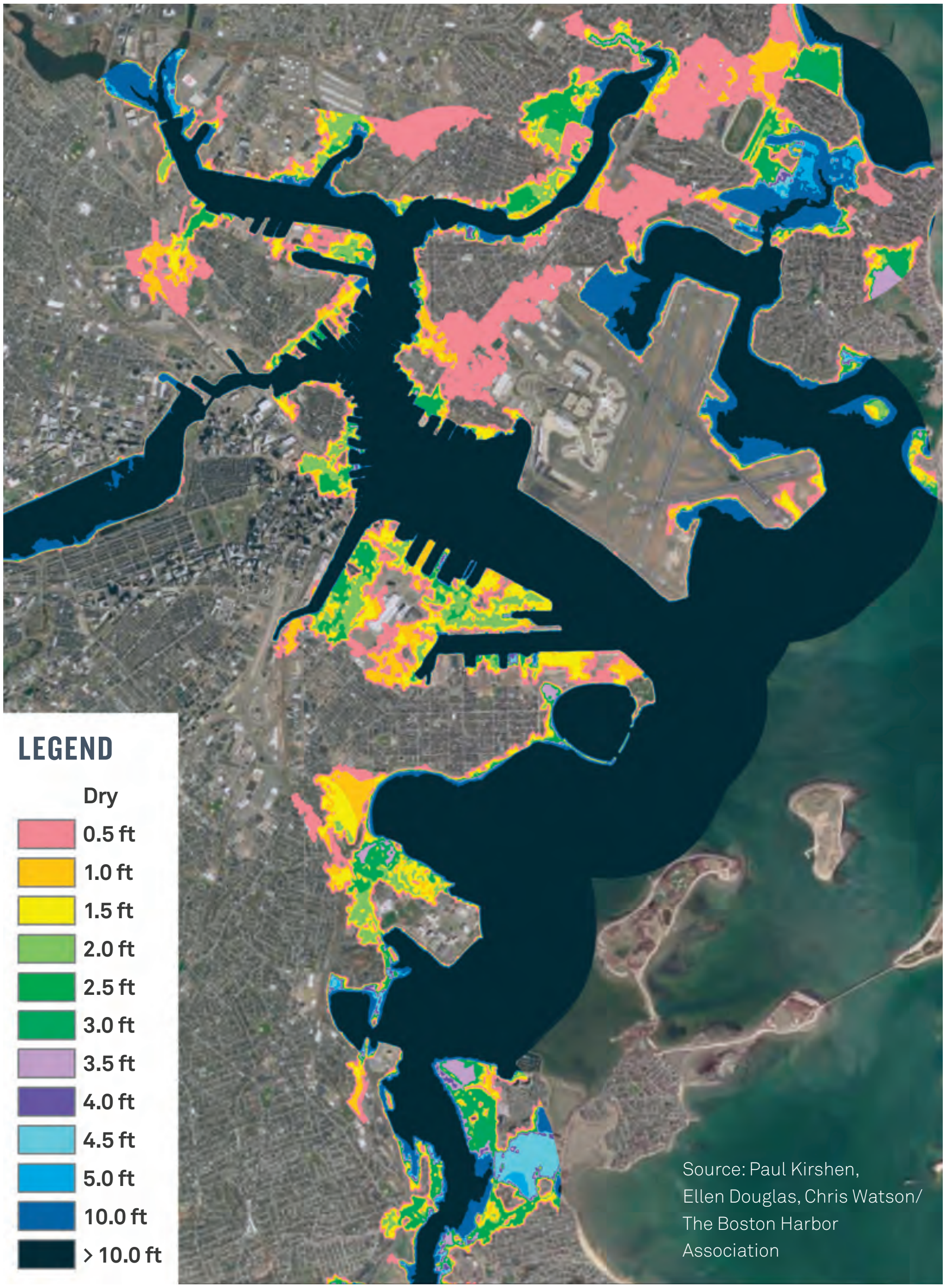
Source: Commonwealth of Massachusetts, Executive Office of Energy and Environmental Affairs, 2015 Municipal Solid Waste & Recycling Survey; MAPC Stronger Region Projections; Massachusetts Department of Labor and Workforce Development

PROJECTED SEA-LEVEL RISE

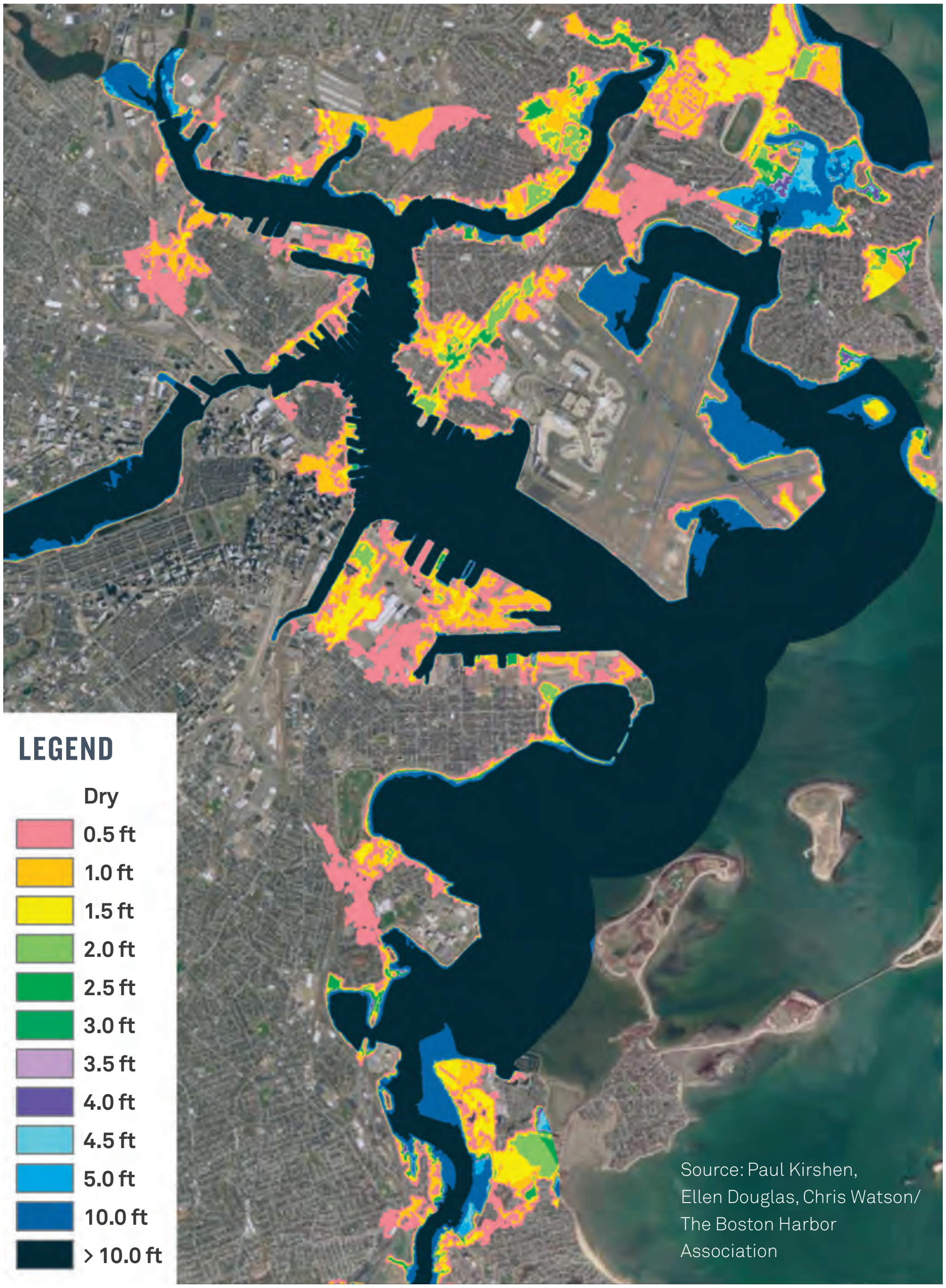
Finally, in addition to providing for additional infrastructure for transportation, energy, water and sewer, and waste disposal, Greater Boston will need to invest in building up resistance to sea-level rise and storm surge as shown in **Map 4.1** and **Map 4.2**. Paul Kirshen, Professor of Climate Adaptation in the School for the Environment at UMass Boston, working with his colleagues Ellen Douglas and Chris Watson, have prepared maps suggesting how much of the Boston region would be submerged under water by 2050 under scenarios of 2.5 feet, 5 feet, and 7.5 feet of flooding above mean high tide on the Boston Harbor coastline.[46] This flooding could occur as a result of: 1) sea-level rise, 2) astronomical high tides (when the moon and the sun align) and 3) storm surges. As they explain, astronomical high tides occur four to six times every year. As the impacts of climate change are increasingly felt, we can expect coastal flooding events to become more frequent and more severe, even during this century.

Clearly, this will call for major improvements in infrastructure to protect Greater Boston's subway system and to insure against the flooding of road and subway tunnels that connect various parts of the region. It will also call for making buildings in flood areas water resilient in terms of all of their mechanicals, including electric service, heat, and cooling. Additional steps will also need to be taken to address the public safety and response to such events.

MAP 4.1: Potential Land Mass under Storm Surge in Boston Region +0.1%



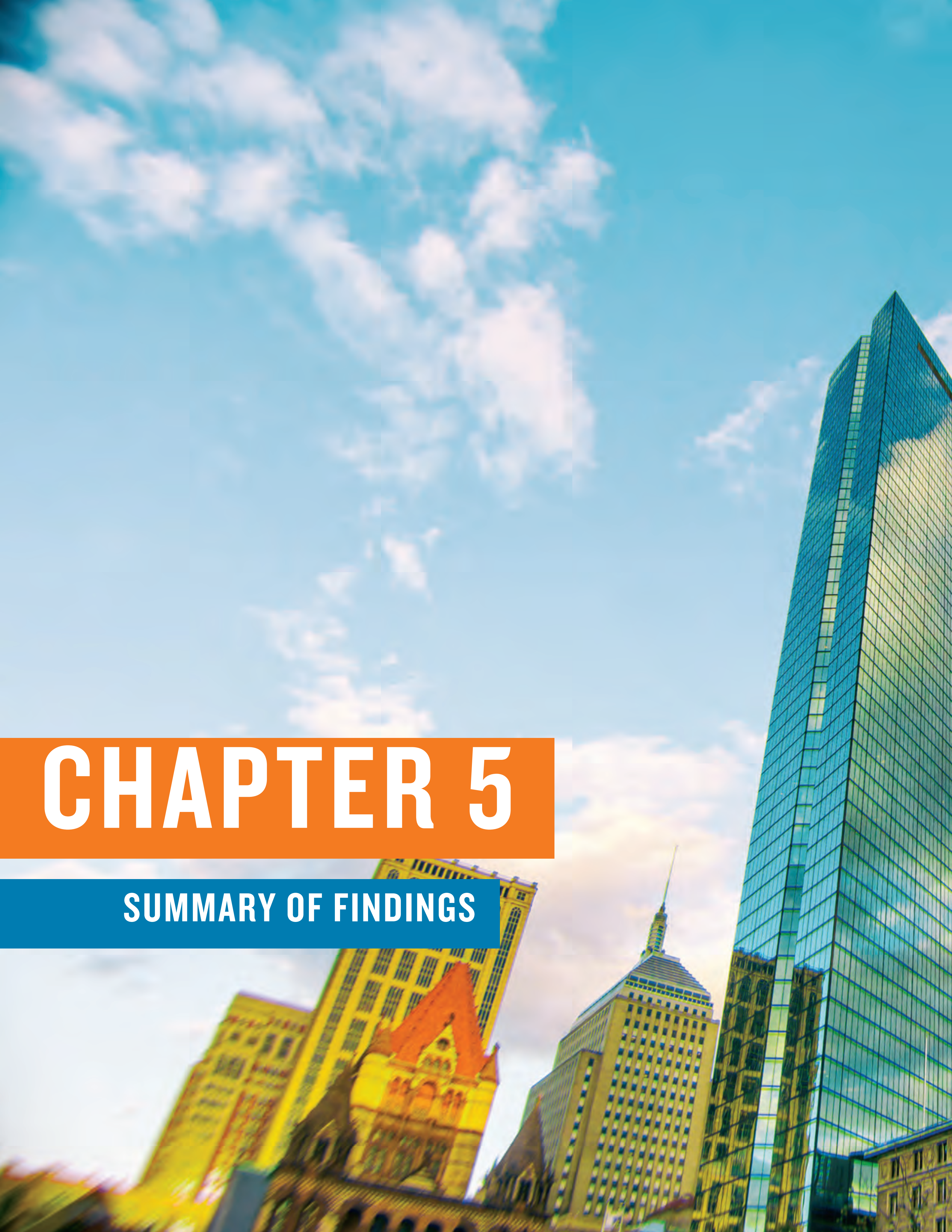
MAP 4.2: Potential Land Mass under Storm Surge in Boston Region +1%



CONCLUSIONS

The best data we have available at this time suggest that to serve its growing population and expanding economy, Greater Boston needs to consider how it will meet its infrastructure requirements for transportation, energy, water, sewerage, waste disposal, and sea-level rise through at least 2030 in light of projected growth in the region's population and its economic base.

The final chapter of this report will summarize all of our findings and suggest alternative approaches to assuring that we will have in place the built environment to sustain the residents of the region and provide the resources needed for continued development of Greater Boston's commercial and industrial base.



CHAPTER 5

SUMMARY OF FINDINGS

CHAPTER 5

The potential 2030 demand for infrastructure estimated in this report is based on a number of assumptions that we maintain are not unreasonable for a baseline simulation.

BEHAVIORAL ASSUMPTIONS

- The Greater Boston region will enjoy economic growth more or less in line with the 1.2 percent annual increase in productivity the U.S. enjoyed between 2006 and 2015, and small annual increases in the size of the labor force as the number of younger workers grows somewhat faster than the number of retiring Baby Boomers.
- The number of commuters will increase with the size of the labor force and, in this baseline projection, commuters continue to use the same age-specific and region-specific transit modes we utilize today.
- The consumption of energy, water, and sewage per household and per business enterprise will remain the same as today.
- Projected demand for air travel and seaport cargo will grow at the same annual rate as they have over the past decade.
- Sea-level rise and storm surge will match the best forecasts of regional climatologists.

"BETWEEN 2010 AND 2030, THERE WILL BE AN ADDITIONAL 117,000 COMMUTERS—5.2 PERCENT MORE THAN THE 2.25 MILLION IN THE LABOR FORCE IN 2010."

DEMOGRAPHIC AND ECONOMIC OUTPUT PROJECTIONS

Based on these assumptions, here is a summary of our main *demographic and economic projections:*

- The population of the five counties of Greater Boston (Essex, Norfolk, Middlesex, Plymouth, and Suffolk) will increase from a little less than 4.1 million in 2010 to 4.5 million in 2030: + 428,000. This amounts to an increase of 6.6 percent between 2010 and 2020, and another 3.6 percent between 2020 and 2030.
- While the region's young population (age 0–24) is projected to decline by nearly 100,000 between 2010 and 2030, along with a loss of 57,000 45 to 64 year olds, the number of 25 to 44 year olds is expected to increase by nearly 140,000. The number of older Baby Boom residents will skyrocket by more than 380,000.
- Overall, as a result of an increase in 25 to 44 year olds offset by the large increase in older residents who retire from the labor force, Greater Boston's labor force will grow much more slowly than its population. We project a total increase of 6.4 percent between 2010 and 2030 but less than 2 percent between 2020 and 2030.
- The population will not expand uniformly throughout Greater Boston. In the *Inner Core,* including Boston and the cities close by, we project the population to grow by 17.5 percent by 2030. In the *Regional Urban Centers,* such as Lawrence, Lowell, Lynn, and Quincy, the population is expected to increase by 12 percent. Meanwhile, in the *Suburbs* surrounding the Inner Core and Regional Urban Centers, the population is expected to increase by just 4.3 percent—as fewer young people choose to live there.
- Economic output by existing firms and new ones will expand by 13.1 percent between 2010 and 2020 and by 12.9 percent between 2020 and 2030. As such, over the full 2010–2030 period, we project a near 28 percent increase in economic activity in Greater Boston.

PROJECTED FUTURE INFRASTRUCTURE DEMAND

Based on these demographic and economic projections, here are our conclusions about the needed increase in infrastructure assuming no change in commuting behavior, no change in per capita, per household, and per business enterprise in the use of electricity, gas, and water, and continued increases in air travel and seaport activity based on current trends.

- **Commuting:** Across all of Greater Boston, we project that between 2010 and 2030, there will be an additional 117,000 commuters daily—5.2 percent more than the 2.25 million in the labor force in 2010.
- **Highway Use:** According to our projections, we expect to see 80,000 more autos, trucks, and tractor trailers on Greater Boston's roads and highways by 2030, an increase of nearly 5 percent.
- **Public Transit:** The region will need to accommodate more than 14,000 additional subway commuters, more than 11,000 additional bus and trolley commuters, and more than another 1,000 daily commuter rail customers. This represents a 6.8 percent increase in subway and bus/trolley use by commuters and nearly a 3 percent increase in commuter rail.
- **Air Travel:** If passenger air travel continues to grow at the same pace as it did over the 2005–2015 period, Logan Airport will have to find a way to handle 63 percent more passengers on domestic and international flights.
- **Seaport:** If the Conley Terminal is going to keep up with demand for seaport cargo, it will need to find a way to increase its container ship capacity by 93 percent—increasing its ability to handle TEU containers from its current 181,000 per year to 350,000 a year by 2030.

- **Electricity:** In terms of electricity demand in the five-county region, we project the need for adding 1.25 million megawatt hours of service to accommodate a 10.2 percent increase in residential service and a 27.7 percent increase in commercial and industrial use. This amounts to adding overall 17.4 percent more electric power to the Greater Boston grid.

- **Natural Gas:** In terms of natural gas for residents and businesses, we project increased demand of 14.3 percent between 2010 and 2030.

- **Water/Sewerage:** Similarly, we project increased water demand for residents, businesses, municipal governments, and large nonprofit institutions of nearly 13.5 percent. Total sewerage use will rise by only 5 percent since we project no increase in average daily rain and snow runoff between 2010 and 2030.

- **Trash/Recycling:** Overall, we will need trash disposal and recycling facilities to process an additional 130,000 tons of waste per year—7.9 percent more in 2030 than in 2010.

- **Sea-Level Rise:** We need to focus on making large parts of Greater Boston near Boston Harbor and along the sea coast more resilient to expected sea-level rise and storm surge that could inundate large swaths of the region.

CONCLUSIONS

Based on our methodology and forecast, Greater Boston will have to add a large quantity of new infrastructure to its current base to meet the needs of a growing population and a growing economy.

How we meet these infrastructure obligations will require a great deal of planning. Here are some of the issues we must face:

- How can we address the lack of capacity in Greater Boston's transportation systems to meet projected demand between now and 2030?
- How much of the increased need for transit infrastructure can be avoided through the efforts of workers to find housing closer to their jobs and therefore reduce the need for as much transit?
- To what extent can changes in transit mode reduce the need for expanding roads and highways to avoid turning severe congestion into outright gridlock?
- How do we ensure that the region's land use and zoning strategies will emphasize live, work, and play space to minimize impacts on transportation and provide for land conservation?
- To what extent can the MBTA increase ridership on its subways by improving the technology that permits more trainsets to operate per hour, especially during the AM and PM commute?
- Can other airports besides Logan be equipped to handle more domestic and perhaps even more international travel and more air cargo?
- How much energy demand can be met through more efficient use of electricity and natural gas and more use of other forms of electric generation including wind, solar, hydro, and perhaps tidal?
- What combined efforts can be developed to reduce greenhouse gas emissions and address the resiliency of the built environment?
- What solid waste strategies should be advanced to deal with rising demand due to population increase and economic growth?
- Are we ready to take sea-level rise seriously and begin to build infrastructure that will allow us to avoid the consequences of storm surge of the type that flooded New York City during Hurricane Sandy?

These ideas and others must be evaluated in terms of their cost effectiveness and the relative benefits they provide to meeting our future infrastructure needs. First, though, we must recognize the full extent to which we will have to add to Greater Boston's built environment. Only then can we balance investments in new infrastructure with conservation and efficiency measures in ways that meet the needs of a growing population and an expanding economy.

APPENDICES

APPENDIX I

GREATER BOSTON FIVE-COUNTY SUBURBS

ABINGTON
ACTON
ANDOVER
ASHBY
ASHLAND
AVON
AYER
BEDFORD
BELLINGHAM
BILLERICA
BOXBOROUGH
BOXFORD
BRAINTREE
BRIDGEWATER
BURLINGTON
CANTON
CARLISLE
CARVER
CHELMSFORD
COHASSET
CONCORD
DANVERS
DEDHAM
DOVER
DRACUT
DUNSTABLE
DUXBURY
EAST BRIDGEWATER
ESSEX
FOXBOROUGH
FRANKLIN
GEORGETOWN
GROTON
GROVELAND
HALIFAX
HAMILTON
HANOVER
HANSON
HINGHAM
HOLBROOK
HOLLISTON
HOPKINTON
HUDSON
HULL
IPSWICH
KINGSTON
LAKEVILLE
LEXINGTON
LINCOLN
LITTLETON
LYNNFIELD
MANCHESTER
MARBLEHEAD
MARION
MARSHFIELD
MATTAPOISETT
MAYNARD
MEDFIELD
MEDWAY
MERRIMAC
MIDDLEBOROUGH
MIDDLETON
MILLIS
MILTON
NAHANT
NATICK
NEEDHAM
NEWBURY
NORFOLK
NORTH ANDOVER
NORTH READING
NORWELL
PEMBROKE
PEPPERELL
PLAINVILLE
PLYMOUTH
PLYMPTON
RANDOLPH
READING
ROCHESTER
ROCKLAND
ROCKPORT
ROWLEY
SALISBURY
SAUGUS
SCITUATE
SHARON
SHERBORN
SHIRLEY
STONEHAM
STOUGHTON
STOW
SUDBURY
SWAMPSCOTT
TEWKSBURY
TOPSFIELD
TOWNSEND
TYNGSBOROUGH
WAKEFIELD
WALPOLE
WAREHAM
WAYLAND
WELLESLEY
WENHAM
WEST BRIDGEWATER
WEST NEWBURY
WESTFORD
WESTON
WESTWOOD
WEYMOUTH
WHITMAN
WILMINGTON
WINCHESTER
WRENTHAM

APPENDIX 2

POPULATION AND LABOR FORCE ESTIMATES FOR GREATER BOSTON REGIONAL TYPES

INNER CORE—POPULATION

AGE	1990	2000	2010	2020	2030	Change 2010–2030	
0–15	232,264	240,673	211,215	245,096	260,321	49,106	23.2%
16–24	224,894	206,354	239,142	211,754	220,711	-18,430	-7.7%
25–44	487,641	486,874	456,660	523,631	545,618	88,958	19.5%
45–64	222,030	262,956	305,277	312,886	330,481	25,204	8.3%
65–74	95,832	83,071	80,340	121,202	135,782	55,442	69.0%
75+	61,205	60,847	77,853	55,629	83,597	5,744	7.4%
All Ages	1,323,866	1,340,775	1,370,486	1,501,115	1,609,662	239,176	17.5%

REGIONAL URBAN CENTERS—POPULATION

AGE	1990	2000	2010	2020	2030	Change 2010–2030	
0–15	196,527	208,776	180,747	189,974	191,538	10,791	6.0%
16–24	122,407	105,687	115,336	102,869	101,856	-13,480	-11.7%
25–44	309,943	311,769	260,274	292,123	300,610	40,336	15.5%
45–64	162,140	201,914	243,699	268,224	256,410	12,711	5.2%
65–74	70,384	62,877	59,610	98,861	123,750	64,141	107.6%
75+	55,976	65,033	61,958	65,716	93,898	31,939	51.6%
All Ages	917,378	956,057	921,624	986,425	1,032,992	111,369	12.1%

SUBURBS—POPULATION

AGE	1990	2000	2010	2020	2030	Change 2010–2030	
0–15	327,955	381,041	392,651	312,289	298,630	-94,021	-23.9%
16–24	192,395	149,487	174,809	175,747	144,574	-30,234	-17.3%
25–44	519,819	503,492	427,602	409,433	432,592	4,990	1.2%
45–64	321,602	408,673	554,024	546,698	462,096	-91,928	-16.6%
65–74	105,979	110,803	132,291	206,719	251,726	119,436	90.3%
75+	76,927	103,372	98,967	139,943	203,808	104,840	105.9%
All Ages	1,544,677	1,656,869	1,780,344	1,854,996	1,857,658	77,314	4.3%

GREATER BOSTON—5 COUNTIES—POPULATION							
AGE	1990	2000	2010	2020	2030	Change 2010–2030	
0–15	729,409	761,734	784,613	759,992	762,469	-22,144	-2.8%
16–24	492,046	513,852	529,286	496,904	473,748	-55,538	-10.5%
25–44	1,064,008	1,111,161	1,144,536	1,246,452	1,298,342	153,806	13.4%
45–64	1,025,394	1,070,837	1,103,000	1,142,457	1,063,056	-39,944	-3.6%
65–74	253,086	264,302	272,240	432,012	517,213	244,973	90.0%
75+	221,978	231,816	238,778	264,719	385,484	146,706	61.4%
All Ages	3,785,921	3,953,702	4,072,454	4,342,536	4,500,313	427,859	10.5%

INNER CORE - LABOR FORCE							
AGE	1990	2000	2010	2020	2030	Change 2010–2030	
16-24	138,985	127,527	147,790	130,864	136,400	-11,390	-7.7%
25-44	418,396	417,738	391,814	449,276	468,140	76,326	19.5%
45-64	168,965	200,109	232,316	238,106	251,496	19,180	8.3%
65-74	29,325	25,420	24,584	37,088	41,549	16,965	69.0%
75+	3,672	3,651	4,671	3,338	5,016	345	7.4%
All Ages	759,342	774,445	801,174	858,671	902,601	101,427	12.7%

REGIONAL URBAN CENTERS—LABOR FORCE							
AGE	1990	2000	2010	2020	2030	Change 2010–2030	
16-24	75,648	65,314	71,278	63,573	62,947	-8,330	-11.7%
25-44	265,931	267,498	223,315	250,642	257,923	34,608	15.5%
45-64	123,389	153,657	185,455	204,119	195,128	9,673	5.2%
65-74	21,537	19,241	18,241	30,252	37,868	19,627	107.6%
75+	3,359	3,902	3,717	3,943	5,634	1,916	51.6%
All Ages	489,864	509,612	502,006	552,528	559,500	57,494	11.5%

SUBURBS—LABOR FORCE							
AGE	1990	2000	2010	2020	2030	Change 2010–2030	
16-24	118,900	92,383	108,032	108,612	89,347	-18,685	-17.3%
25-44	446,005	431,997	366,882	351,293	371,164	4,281	1.2%
45-64	244,739	311,000	421,612	416,037	351,655	-69,957	-16.6%
65-74	32,430	33,906	40,481	63,256	77,028	36,547	90.3%
75+	4,616	6,202	5,938	8,397	12,228	6,290	105.9%
All Ages	846,689	875,488	942,946	947,595	901,423	-41,523	-4.4%

GREATER BOSTON—5 COUNTIES—LABOR FORCE							
AGE	1990	2000	2010	2020	2030	Change 2010–2030	
16-24	333,532	285,224	327,099	303,049	288,694	-38,405	-11.7%
25-44	1,130,332	1,117,232	982,012	1,051,211	1,097,227	115,215	11.7%
45-64	537,093	664,766	839,383	858,262	798,280	-41,103	-4.9%
65-74	83,292	78,566	83,306	130,595	156,445	73,139	87.8%
75+	11,646	13,755	14,327	15,677	22,878	8,551	59.7%
All Ages	2,095,895	2,159,544	2,246,126	2,358,794	2,363,524	117,398	5.2%

Source: Dukakis Center Labor Force Projections, U.S. Census PUMS data

APPENDIX 3

TRANSIT MODE BY AGE COHORT AND GREATER BOSTON REGIONAL TYPE

INNER CORE

	16–24	25–44	45–64	65–74	75+	All Ages
Auto Truck	31.4%	50.7%	62.2%	62.5%	65.4%	51.6%
Motorcycle	0.1%	0.2%	0.1%	0.0%	0.0%	0.1%
Bus/Streetcar	15.6%	12.2%	10.1%	8.0%	6.2%	11.9%
Subway	18.3%	17.6%	10.6%	9.5%	4.9%	15.2%
Rail	0.7%	1.1%	1.1%	1.0%	0.6%	1.0%
Taxi	0.3%	0.3%	0.2%	0.1%	0.3%	0.2%
Ferryboat	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%
Bicycle	2.0%	2.8%	2.0%	1.1%	1.4%	2.3%
Walk	27.1%	11.4%	7.4%	8.4%	11.5%	12.5%
Other	0.8%	0.6%	0.5%	0.5%	0.0%	0.6%
Work at Home	3.7%	3.4%	5.8%	8.8%	9.7%	4.4%
Total Workforce	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

REGIONAL URBAN CENTERS

	16–24	25–44	45–64	65–74	75+	All Ages
Auto Truck	76.1%	83.4%	85.1%	83.3%	77.7%	83.1%
Motorcycle	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%
Bus/Streetcar	5.0%	2.9%	2.3%	1.9%	3.6%	2.9%
Subway	2.4%	4.3%	3.1%	3.1%	0.0%	3.5%
Rail	1.3%	2.5%	1.6%	1.0%	0.0%	1.9%
Taxi	1.1%	0.4%	0.3%	0.7%	0.0%	0.5%
Ferryboat	0.0%	0.0%	0.0%	0.0%	1.4%	0.0%
Bicycle	0.2%	0.2%	0.2%	0.2%	0.0%	0.2%
Walk	9.3%	2.2%	2.3%	2.4%	7.2%	3.1%
Other	2.5%	1.0%	1.0%	0.8%	0.0%	1.2%
Work at Home	2.0%	3.0%	4.0%	6.6%	10.2%	3.5%
Total Workforce	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

SUBURBS

	16–24	25–44	45–64	65–74	75+	All Ages
Auto Truck	60.1%	70.9%	74.7%	72.6%	72.2%	70.9%
Motorcycle	0.0%	0.2%	0.1%	0.0%	0.0%	0.1%
Bus/Streetcar	7.9%	6.5%	5.3%	4.7%	3.9%	6.0%
Subway	9.4%	9.5%	5.8%	5.5%	3.1%	7.6%
Rail	1.2%	2.4%	2.0%	1.5%	1.3%	2.0%
Taxi	0.2%	0.1%	0.1%	0.1%	0.2%	0.1%
Ferryboat	0.0%	0.2%	0.2%	0.1%	0.0%	0.2%
Bicycle	1.2%	1.5%	1.0%	0.7%	0.9%	1.2%
Walk	16.4%	6.3%	4.3%	5.4%	8.0%	6.4%
Other	0.7%	0.6%	0.5%	0.3%	0.5%	0.6%
Work at Home	2.8%	4.0%	6.0%	9.0%	9.8%	5.0%
Total Workforce	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

5-COUNTY GREATER BOSTON REGION

	16–24	25–44	45–64	65–74	75+	All Ages
Auto Truck	52.3%	65.9%	74.0%	72.4%	72.3%	67.6%
Motorcycle	0.0%	0.1%	0.1%	0.0%	0.0%	0.1%
Bus/Streetcar	10.3%	7.6%	5.8%	5.0%	4.3%	7.1%
Subway	11.4%	11.2%	6.4%	6.0%	2.6%	9.1%
Rail	1.0%	1.9%	1.7%	1.2%	0.8%	1.7%
Taxi	0.5%	0.2%	0.2%	0.2%	0.2%	0.3%
Ferryboat	0.0%	0.1%	0.1%	0.0%	0.4%	0.1%
Bicycle	1.3%	1.6%	1.1%	0.7%	0.8%	1.3%
Walk	19.1%	7.1%	4.6%	5.5%	8.5%	7.6%
Other	1.2%	0.7%	0.6%	0.5%	0.3%	0.7%
Work at Home	3.0%	3.5%	5.5%	8.4%	9.9%	4.5%
Total Workforce	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Source: U.S. Census Bureau, American Community Survey Office, American Community Survey 2010–2014 ACS 5-Year PUMS Files, January 2016.

APPENDIX 4

NUMBER OF COMMUTERS BY TRANSIT MODE, 2010–2030

2010–2030 INNER CORE—CHANGE IN NUMBER OF WORKERS BY TRANSIT MODE

	16–24	25–44	45–64	65–74	75+	All Ages	
Auto Truck	-3,578	38,665	11,931	10,611	226	52,378	51.6%
Motorcycle	-6	127	20	0	0	125	0.1%
Bus/Streetcar	-1,772	9,280	1,929	1,364	21	12,050	11.9%
Subway	-2,079	13,426	2,028	1,614	17	15,428	15.2%
Rail	-84	837	220	165	2	1,064	1.0%
Taxi	-39	192	37	18	1	247	0.2%
Ferryboat	-6	18	3	0	0	25	0.0%
Bicycle	-228	2,108	375	184	5	2,365	2.3%
Walk	-3,082	8,673	1,426	1,417	40	12,706	12.5%
Other	-91	435	97	90	0	590	0.6%
Work at Home	-425	2,564	1,114	1,501	34	4,449	4.4%
Total Workforce	-11,390	76,326	19,180	16,965	345	101,427	100.0%

2010–2030 REGIONAL URBAN CENTERS—CHANGE IN NUMBER OF WORKERS BY TRANSIT MODE

	16–24	25–44	45–64	65–74	75+	All Ages	
Auto Truck	-6,341	28,847	8,229	16,357	1,489	47,771	83.1%
Motorcycle	-4	5	8	0	0	25	0.0%
Bus/Streetcar	-416	986	221	379	69	1,644	2.9%
Subway	-202	1,495	298	602	0	2,024	3.5%
Rail	-109	879	155	187	0	1,115	1.9%
Taxi	-89	148	33	131	0	275	0.5%
Ferryboat	0	11	0	0	26	15	0.0%
Bicycle	-20	80	21	42	0	128	0.2%
Walk	-777	755	218	481	137	1,802	3.1%
Other	-204	350	101	150	0	679	1.2%
Work at Home	-168	1,051	390	1,298	196	2,016	3.5%
Total Workforce	-8,331	34,608	9,673	19,627	1,917	57,494	100.0%

2010–2030 SUBURBS—CHANGE IN NUMBER OF WORKERS BY TRANSIT MODE

	16–24	25–44	45–64	65–74	75+	All Ages	
Auto Truck	-11,222	3,037	-52,233	26,523	4,544	-29,425	-70.9%
Motorcycle	-8	7	-72	6	0	-46	-0.1%
Bus/Streetcar	-1,482	276	-3,728	1,713	248	-2,484	-6.0%
Subway	-1,764	408	-4,083	2,024	192	-3,139	-7.6%
Rail	-216	104	-1,369	564	84	-827	-2.0%
Taxi	-39	6	-86	27	15	-56	-0.1%
Ferryboat	-8	10	-112	21	0	-69	-0.2%
Bicycle	-227	63	-720	254	56	-497	-1.2%
Walk	-3,067	269	-2,983	1,982	506	-2,657	-6.4%
Other	-137	26	-346	122	31	-229	-0.6%
Work at Home	-514	170	-4,227	3,295	614	-2,095	-5.0%
Total Workforce	-18,685	4,282	-69,957	36,547	6,290	-41,523	-100.0%

2010–2030 5-COUNTY TOTAL—CHANGE IN NUMBER OF WORKERS BY TRANSIT MODE

	16–24	25–44	45–64	65–74	75+	All Ages	
Auto Truck	-21,142	70,549	-32,073	53,491	6,259	70,725	60.2%
Motorcycle	-18	139	-44	6	0	103	0.1%
Bus/Streetcar	-3,670	10,543	-1,579	3,457	338	11,210	9.5%
Subway	-4,045	15,330	-1,757	4,241	209	14,312	12.2%
Rail	-409	1,820	-994	916	86	1,352	1.2%
Taxi	-168	345	-15	176	16	467	0.4%
Ferryboat	-14	39	-109	21	26	-29	0.0%
Bicycle	-475	2,252	-325	481	61	1,996	1.7%
Walk	-6,926	9,697	-1,338	3,880	683	11,852	10.1%
Other	-433	811	-147	361	31	1,041	0.9%
Work at Home	-1,107	3,785	-2,723	6,094	844	4,370	3.7%
Total Workforce	-38,406	115,216	-41,104	73,139	8,552	117,398	100.0%

Source: Dukakis Center Labor Force Projections; U.S. Census PUMS data

APPENDIX 5

PROJECTED COMMERCIAL/INDUSTRIAL ELECTRICITY CONSUMPTION IN MWH

	ESSEX	MIDDLESEX	NORFOLK	PLYMOUTH	SUFFOLK	5-COUNTY
kWh Use per Customer	18,929	93,359	75,876	29,964	68,823	67,005
2010 Establishments	20,933	47,865	23,820	13,688	22,397	128,703
2016 Current Total MWh	396,232	4,468,630	1,807,356	410,146	1,541,432	8,623,796
Output Growth Rate: 19.4%	473,101	5,335,544	2,157,983	489,714	1,840,470	10,296,812
2016-2030 MWh Increase	76,869	866,914	350,627	79,568	299,038	1,673,016
Annual 2010-2030 MWh Increase	5,491	61,922	25,045	5,683	21,360	119,501
Total 2010-2030 MWh Increase	109,813	1,238,449	500,896	113,669	427,197	2,390,023
Total 2010-2030 MWh % Increase						27.7%
% Share of Total	4.6%	51.8%	21.0%	4.8%	17.9%	100.0%

Source: Eversource, Dukakis Center Analysis

APPENDIX 6

PROJECTED INCREASE IN COMMERCIAL AND INDUSTRIAL GAS CONSUMPTION

COMMERCIAL & INDUSTRIAL NATURAL GAS CONSUMPTION (THERMS)						
	Essex	Middlesex	Norfolk	Plymouth	Suffolk	5-County
Industrial Firms	3,016	6,403	2,960	2,273	1,299	15,951
Commercial Firms	13,890	33,655	15,052	8,687	16,455	87,739
AVERAGE GAS CONSUMPTION BY ACCOUNT TYPE BY COUNTY (THERMS/ACCOUNT)						
	Essex	Middlesex	Norfolk	Plymouth	Suffolk	5-County
Industrial Firms	21,045	25,481	15,876	21,776	21,045	21,045
Commercial Firms	5,805	6,766	6,979	3,670	5,805	5,805
TOTAL THERMS (IN MILLIONS)						
	Essex	Middlesex	Norfolk	Plymouth	Suffolk	5-County
Industrial Firms	63.5	163.2	47.0	49.5	27.3	335.7
Commercial Firms	80.6	227.7	105.0	31.9	95.5	509.3
Commercial + Industrial Firms	144.1	390.9	152.0	81.4	122.9	845.0
2010-2030 Projected Increase	39.9	108.3	42.1	22.5	34.0	234.1
County Share of Increase	17.1%	46.2%	18.0%	9.6%	14.5%	100.0%

Source: U.S. Census; Massachusetts Department of Labor and Workforce Development; MAPC Projections; Eversource

ENDNOTES

1 See MAPC, *Population and Housing Demand Projections for Metro Boston* (January 2014), which updates features of the regional planning agency's MetroFuture Regional Plan extending from 2000 through 2030.(*http://www.mapc.org/sites/default/files/MetroBoston%20Projections%20Final%20Report_1_16_2014_0.pdf*, *http://www.mapc.org/sites/default/files/MetroFuture_Goals_and_Objectives_1_Dec_2008.pdf.*

2 MAPC also brings together many streams of data for each of the 164 Metro Boston communities it covers, a level of detail we do not offer in this report.

3 U.S. Census Bureau, Decennial 2000 Census; American Community Survey (ACS) (2010–2014).

4 MassDOT, Report of the Performance and Asset Management Advisory Council: Progress by MassDOT Highway Division on Integrated Asset Management, January 15, 2016.

5 Phineas Baxandall, "Maintaining an Effective Transportation System," Massachusetts Budget and Policy Center, March 17, 2016.

6 Massachusetts Bay Transit Authority "Ridership Services Statistics, 2014 Edition."

7 Massachusetts Bay Transit Authority "SGR & Capital Working Group Initial Overview," August, 2015.

8 Governor's Special Panel to Review the MBTA, "Back on Track: An Action Plan to Transform the MBTA," April 8, 2015.

9 Urban Land Institute Boston, "*Hub and Spoke:* Core Transit Congestion and the Future of Transit and Development in Greater Boston," June, 2012.

10 See Massachusetts Department of Transportation, "Ridership and Service Statistics: 14th Edition" 2014.

11 About one-sixth of rail miles are listed by Mass GIS as having no specified owner. Further research will be needed to document ownership.

12 A standard shipping container is 20 feet long, 8 feet wide, and 9 feet high, thus capable of holding up to 1,440 cubic feet of cargo. Such a container is called a TEU which stands for "Twenty Foot Equivalent Unit."

13 Data on the size of container ships is available from Hofstra University, "The Geography of Transport Systems," *https://people.hofstra.edu/geotrans/eng/ch3en/conc3en/containerships.html*.

14 *http://www.mass.gov/eea/docs/doer/rps-aps/rps-aps-2014-annual-compliance-report.pdf*

15 Methodological note: Due to a lack of total water and sewer demand data for all five counties, we assumed that water and sewer demand is about the same, per capita, by user type (residential, commercial, and industrial) in all counties. Given this assumption, we modeled per capita demand based on data in Middlesex County, for which we had the most complete data, to generate demand rates for both sewer and water demand for all three user types. Using these per capita rates, we calculated demand for each missing user type in each county. From these estimates and real data, we created an average demand rate for all five counties, weighted by the population share of each county.

16 For information on the Quabbin Reservoir, we relied on Wikipedia, which provides a historical overview of this water resource.

17 See Massachusetts Water Resources Authority (MWRA) "A History of the Sewer System" and Center for Land Use Interpretation, "Deer Island Sewerage Treatment Plant," May 2005.

18 Massachusetts Executive Office of Energy and Environmental Affairs, Massachusetts Department of Environmental Protection, "Massachusetts Annual Greenhouse Gas Emissions Inventory: 1990–2011," 2014.

19 City of Boston, "Community Greenhouse Gas Inventory 2005–2013, 2014.

20 Tim Reardon and Meghna Hari, *Population and Housing Demand Projections for Metro Boston: Regional Projections and Provisional Municipal Forecasts* (Boston: Metropolitan Area Planning Council, January 2014).

21 MAPC uses a sophisticated methodology to estimate population growth based on a cohort survival model with age- and race-specific fertility, mortality, and migration rates. Births are based on 2007–2009 Census data; deaths are projected on the basis of 2006–2008 data. Migration flows are based on county flow data from the American Community Survey for 2005–2009. For further information on the MAPC methodology, see Reardon and Hari, *Population and Housing Demand Projections for Metro Boston: Regional Projections and Provisional Municipal Forecasts,* Appendix B "Methodology," pp. B1-B5.

22 MAPC, Executive Summary, *Population and Housing Demand Projections for Metro Boston: Regional Projections and Provisional Municipal Forecasts, op. cit.*, p. 1.

23 According to the U.S. Census, the total population for the five counties of Greater Boston (Essex, Middlesex, Norfolk, Plymouth, and Suffolk) was 4,305,936 in 2014. The MAPC 2020 Status Quo projected estimate was just 4,227,509—nearly 2 percent lower than the 2014 Census estimate for the five counties of 4,305,936. Even the MAPC Stronger Region forecast for 2020 is just 20,000 higher than the 2014 Census estimate. Much of this increase is due to young people staying in the region or being attracted to it. Between 2000 and 2010 the number of 20-34 year-old residents in the combined inner city region of Boston, Cambridge, and Somerville increased by nearly 28,500. This increase accounted for more than 93 percent of the growth in this three-city region over this ten-year period. See American Factfinder, *http://factfinder.census.gov/faces/nav/jsf/pages/community_facts.xhtml*.

24 For an extended treatment of the relationship between infrastructure investment and economic growth, see David Bannister and Joseph Berechman, *Transport Development and Economic Development* (London: UCL Press, 2000).

25 The MAPC region is somewhat larger than the five-county Greater Boston region since it includes portions of Bristol and Worcester Counties. Altogether, MAPC tracks 164 communities. The five-county Greater Boston region includes 147 municipalities. We have adjusted the MAPC population estimates to the five-county region by subtracting the Worcester and Bristol County estimates from the total. The five-county region represents approximately 93 percent of the population of the MAPC "Metro Region."

26 The MAPC 2010-2030 published population projections for the five counties of Greater Boston differ slightly from the "adjusted" projections presented here. The Census population estimate for 2010 is 1.2 percent higher than the MAPC figure for this year—perhaps as a result of a Census re-estimate since the completion of the 2010 Census. Based on this small difference, small adjustments were made to the 2020 and 2030 projections. Our adjusted 2020 estimate is 1.1 percent higher than the MAPC estimate. The 2030 estimate is within .02 percent of the MAPC projection. These small differences are well within forecast errors.

27 Age-specific labor force participation rates for Greater Boston were calculated from the U.S. Census Bureau, American Community Survey Office, *American Community Survey 2010–2014 ACS 5-Year PUMS Files,* January 2016.

28 The annual labor productivity growth rate for the U.S. is calculated from data in the statistical appendix to the Council of Economic Advisors, *Economic Report of the President 2016* (Washington, D.C.: U.S. Government Printing Office, February 2016), Table B-16, p. 419.

29 See U.S. Census Bureau, American Community Survey Office, *American Community Survey 2010-2014 ACS 5-Year PUMS Files*, January 2016.

30 The "Other" category of transit mode presumably includes such means as skateboard, roller blade, motor scooter, unicycle, hoverboard, pod racer, broomstick, and Segway.

31 The geographic area in the Boston MPO analysis is slightly larger than ours as it includes portions of Bristol and Worcester Counties. Specifically, the Long Range Transportation Plan modeling indicates the following changes in travel demand by the year 2040:

The numbers of transit person trips in Eastern MA is projected to increase by 27% from 2012 to 2040, a growth of over 250,000 person trips. Non-motorized (walking and biking) person trips are projected to increase by about 32%, or over 675,000 person trips. Increases in linked transit trips are projected as follows:

- Local buses up 75,000 linked trips
- Rapid transit up 196,000 linked trips
- Commuter rail up 18,000 trips

The substantially higher transit and non-motorized travel anticipated by these projections can be accounted for by a number of "not business as usual" factors: the MPO model anticipates greater concentration of homes and jobs near transit, as has been observed in recent years; increased congestion on major highways will result in more workers shifting to transit; creation of specific new transit service (such as the Green Line Extension) and off-road walking and biking facilities will provide rapid transit and non-motorized options to residents who do not currently have them; and increased cost of parking and tolls may deter vehicle commuting.

For more information, see *http://bostonmpo.org/data/html/plans/lrtp/charting/2040_LRTP_Chapter5_final.html.*

32 See Massachusetts Department of Labor and Workforce Development, Labor Market Information, Employment and Wages ES-202 Data, *http://www.mass.gov/lwd/economic-data*.

33 See Federal Highway Administration, "Highway Statistics," Table MV-9.

34 Besides heavy trucks, the Federal Highway Administration reports that in 2010 there were 555,000 light trucks registered in Massachusetts. If roughly 60 percent of these are in Greater Boston, the total in the region was 332,000. To accommodate the expected 27.7 percent in commerce would presumably require another 92,000 such vehicles. However, since we could not ascertain how many of these are actually used for commuting (and they are included in our auto/truck projections), we have taken the prudent route of not including these as additions to highway and road use.

35 In addition, there likely will be added buses and streetcars on the roads to accommodate the expected increase in commuters. Presently, the MBTA operates 1,052 buses on routes throughout the region. To accommodate 7 percent more passengers will require 73 more buses. See Massachusetts Bay Transit Authority, MBTA Vehicle Inventory, April 2016.

36 For data on container ship capacity, see Hofstra University, "The Geography of Transport Systems," *https://peopole.hofstra.edu/geotrans/eng/ch3en/conc3en/containerships.html.*

37 The data supplied by Eversource include statistics on average annual kWh consumption by commercial/industrial customers, residential customers, and for municipal street lights. We assume for our projection here that the demand for electricity for street lights remains constant through 2030.

38 The household adjustment factors are:

Essex County:	.919
Middlesex County:	.934
Norfolk County:	.928
Plymouth County:	.889
Suffolk County:	.960

39 Electricity is measured in kilowatt-hours (kWh). One kWh of energy is equal to 1000 watt hours and will power a 100 watt light bulb for 10 hours (100 watts x 10 hours = 1,000 watt-hours = 1 kWh).

One kilowatt-hour of electricity is enough to:

- watch television for 10 hours
- vacuum for an hour
- wash 12 pounds of laundry
- cook breakfast for a family of 4
- listen to the radio for 20 hours
- work on a computer for 5–10 hours

Source: *www.duke-energy.com.*

40 The therm is a unit of heat energy equal to 100,000 British thermal units (BTU). It is approximately the energy equivalent of burning 100 cubic feet (often referred to as 1 CCF) of natural gas.

A BTU is the amount of heat required to raise the temperature of a pound of water by one degree Fahrenheit. Also, 1 therm is equal to about 29.3 kWh.

See *http://mapawatt.com/2010/02/17/what-therm*.

41 *Industrial Firms:* Mining, Construction, Manufacturing, and Utilities

Commercial Firms: Wholesale Trade, Retail Trade, Transportation and Warehousing, Information, Real Estate and Rental and Leasing, Professional and Technical Services, Management Companies and Enterprises, Administrative and Waste Services, Educational Services, Health Care and Social Assistance, Arts, Entertainment, and Recreation, and Accommodation and Food Services. Other Non-Public Services and Government Services are not included in this total.

42 Due to the lack of total water and sewer demand data for all five counties, it is assumed that water and sewer demand is about the same, per capita, by user type (residential, commercial, and industrial) in all counties. Given this assumption, we have modeled per capita demand based on data in Middlesex County to generate demand rates for both sewer and water demand for all three user types. Using these per capita rates, we calculated demand for each missing user type in each county. From these estimates and real data, we created an average demand rate for all five counties, weighted by the population share of each county.

43 The estimate of water and sewage usage by municipal governments and non-profit institutions is based on taking the total amount of water usage per day and subtracting residential, commercial, and industrial daily consumption.

44 The amount of rain and snow runoff entering the Greater Boston sewer system is based on an analysis of total sewage demand in the MRWA district and subtracting residential, commercial, industrial, municipal, and institutional consumption.

45 Elizabeth A. Stanton, et.al., *The RGGI Opportunity 2.0,* Synape Energy Economics, Inc., Cambridge, Massachusetts, March 4, 2016.

46 See The Boston Harbor Association, Boston Harbor Sea Level Rise Maps, *http://tbha.org/boston-harbor-sea-level-rise-maps.*

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