

Choices for Stewardship: Background Books – Facts, Trends, & Issues

VOLUME II

Submitted Pursuant to
Executive Orders 579 and 580

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Introduction

The Commission's work is grounded in what was learned through extensive reading of articles and reports, public input both written and from five Listening Sessions, expert presentations, and the knowledge, experience and expertise of the Commission members themselves. The Commission cast a wide net for information so as not to limit its thinking on the disruptive forces facing Massachusetts' transportation network and on the potential approaches that will best enable the Commonwealth to be ready for them. Early on, the Commission determined that the creation of Background Books (collectively presented here as Volume II of this report) on the five key topics charted by the Governor would be an effective way to capture, provide and present this wealth of information. The Commission believes that this work will be a valuable resource for other states as they consider ways to prepare themselves for the changes that they are sure to face in the future.

DEMOGRAPHICS AND LAND USE

Why do demographics and land use matter?

1. The makeup of Massachusetts' population is changing due to immigration and aging.
2. While Baby Boomers will continue to play a large role in the economy and politics...
3. ...younger generations live and travel differently, which is significantly affecting land use and transportation options...
4. ...though some very broad trends are expected to ignore generational boundaries.
5. Transportation will play a significant role in future land-use plans.
6. In addition to where one lives, a person's job is also an important factor in transportation mode choice.
7. While transportation is a universal concern, it is experienced very differently across socioeconomic groups.

Summary

1. The makeup of Massachusetts' population is changing due to immigration and aging.

- [Massachusetts has seen declining births, net negative domestic migration, and increases in international migration.](#)
- [In the short term, international immigrants in the U.S. have lower auto usage, though this effect diminishes depending on where they live.](#)
- [While international migration has grown, Massachusetts' current population remains the biggest factor for future population growth, with decreased mortality rates and a large aging Baby Boomer generation resulting in an older overall population.](#)
- [Americans are living longer \(increased lifespan\) but are in poorer health \(over half of the increase is spent living with a disability\).](#)
- [Senior citizens \(aged 65+\) grew in population by 35 percent in the U.S. between 2011 and 2016 \(6.6 to 8.9 million\) and are projected to be the fastest-growing segment of the workforce through 2024.](#)
- [Massachusetts has developed the Governor's Council to Address Aging in Massachusetts to promote healthy aging in the state. The Council released blueprint recommendations focusing on mobility in suburban and rural areas and the "last 50 feet" of transportation.](#)

2. While Baby Boomers will continue to play a large role in the economy and politics...

- [Instead of fleeing the suburbs, many Baby Boomers in the U.S. are "aging in place," limiting the supply of suburban homes available for sale to Millennial households seeking to move to suburbs.](#)
- [Baby Boomers in the U.S. still hold great purchasing power, with median incomes more than twice that of Millennials \(\\$56k and \\$26k, respectively\) and median net worth more than 15 times that of Millennials \(\\$333k and \\$21k, respectively\).](#)
- [While combined Millennial and Gen X votes in the U.S. in 2016 were more than the combined votes of the Baby Boomers and the Silent Generation, Baby Boomers still accounted for the most votes of any single age group in the U.S.](#)
- [Baby Boomers make up the vast majority of Congress.](#)

3. ...younger generations live and travel differently, which is significantly affecting land use and transportation options...

- [In 2040, projections show that 84 percent of the Massachusetts labor force and 58 percent of Massachusetts head of households will have been born after 1980. Families, who have different transportation needs than other households, will make up a declining portion of the population.](#)
- [94 percent of Americans aged 18-29 own smartphones, compared to only 46 percent of those aged 65+.](#)
- [In the U.S., optimization is the biggest consideration for Millennials in choosing transportation modes, and they rely heavily on technology to make those choices.](#)
- [While there has been much reporting about Millennials in the U.S. driving less than older generations, a portion of this decrease is likely due to the recession and delayed lifecycle milestones, rather than solely different attitudes and lifestyle preferences.](#)
- [Millennial inclination for non-ownership \(e.g., Uber, rental housing\) may be due to affordability issues rather than preference.](#)
- [Millennials demonstrate the same long-term interest in becoming homeowners as previous generations, though they appear to have a new interest in “urban-lite,” as opposed to true suburban communities \(e.g., more active, walkable communities with accessible dining and retail\).](#)

4. ...though some very broad trends are expected to ignore generational boundaries.

- [The population growth in Massachusetts has been declining in rural areas in favor of growth in urban and suburban areas, a trend that has become more pronounced since the recession.](#)
- [In Massachusetts, the population has been shifting to the east and is predicted to continue to do so through 2040 \(excluding the Cape\).](#)
- [In the U.S., suburbanization is on the rise; since 2012 the population growth rate of urban cores has decreased by half, while the exurban county rate has quadrupled.](#)
- [While suburban growth exceeds city growth nationally, out of the 53 metro areas with populations over 1 million, Boston is one of 17 where the primary city growth rate is higher than the suburban growth rate.](#)
- [Without influx of younger households, slow-growing towns may become “senior suburbs.”](#)
- [Most of the housing stock and most of the land area of America’s metros is comprised of relatively low-density suburban homes, with growth potential restricted due to current zoning regulations.](#)
- [The causes of vehicle miles traveled \(VMT\) declines in the U.S. are controversial; Gross Domestic Product appears to correlate most strongly with VMT, but density, diversity, design, destination accessibility, and distance to transit all typically have an effect on decreasing VMT as well.](#)

5. Transportation will play a significant role in future land-use plans.

- [In the U.S., active transportation infrastructure in the form of bike lanes, paved trails for pedestrians and cyclists, and bike-friendly features in residential and commercial properties is increasing and is sometimes referred to as trail-oriented development.](#)
- [Across the U.S., homes in more walkable areas can charge a premium; in Boston an increase of one Walk Score point \(where walkability based on access to amenities is scored on a 1 – 100 scale\) raises the median home price by \\$3,927.](#)
- [Reducing parking demand and increasing parking density in New England will contribute to less land needed for parking in the future.](#)
- [Curbside management in the U.S. will likely become a significant issue due to bike-share stations, bike lanes, e-commerce delivery, and ride-hailing pick-up and drop-off.](#)
- [Access to new and emerging transportation modes in the U.S. will be heavily influenced by land-use policy, such as parking requirements and zoning laws that dictate density.](#)
- [MassDOT and MBTA are focusing on transit oriented development \(TOD\), which features compact, walkable mixed-use developments at or near transit stations...](#)
- [... which in Gateway Cities can support higher population and more jobs than would be present with the status-quo development.](#)
- [By improving transit service and focusing on TOD, Gateway Cities can “borrow size” from Boston to mitigate both congestion and cost of sprawling infrastructure, while also improving their economic development and regional mobility competitiveness.](#)
 - [Communities with high-frequency subway service accounted for 42 percent of Massachusetts’ net job growth in the last decade, up from only 6 percent in the previous decade for those same communities.](#)

6. In addition to where one lives, a person’s job is also an important factor in transportation mode choice.

- [Driving alone is the most common means of transportation to work in Massachusetts as a State and Suffolk County, specifically.](#)
- [Working from home has become increasingly common, with nearly 3 percent \(3.9 million employees\) of the U.S. workforce working from home at least half of the time, which has more than doubled since 2005...](#)
- [...making telecommuting a more common method of commuting to work than public transit in more than half of the top U.S. metro areas.](#)
- [However, telecommuting is not an option for registered nurses, home health aides, and personal care aides, all of which are projected to have the highest job growth in Massachusetts through 2024.](#)

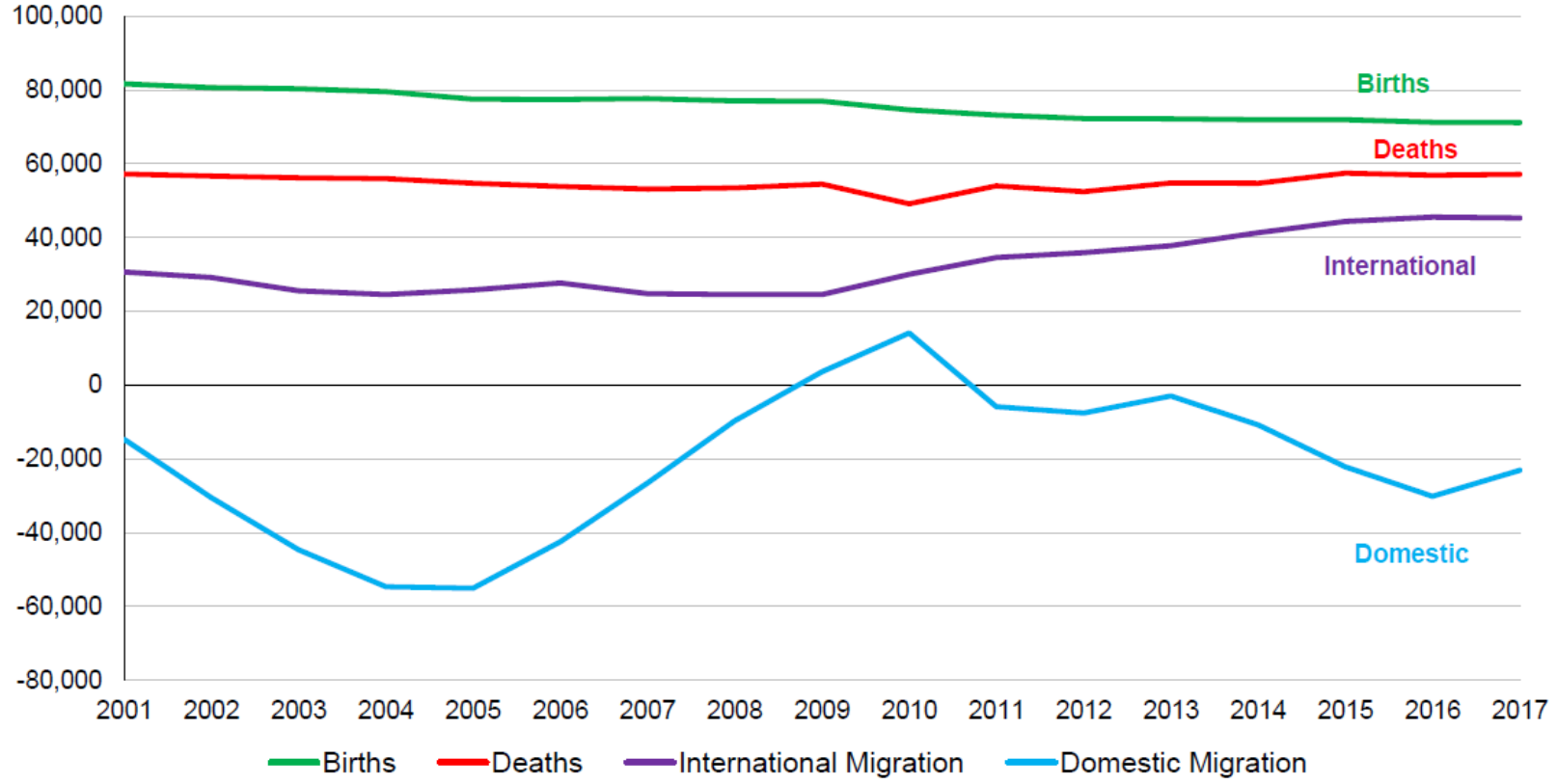
7. While transportation is a universal concern, it is experienced very differently across socioeconomic groups.

- [Americans making less than \\$14,000 per year spend on average 28 percent of their annual income on transportation.](#)
- [In the U.S., Lyft is filling transportation gaps in low-income areas; those living in low-income areas made more Lyft trips per person compared to middle-income and high-income communities.](#)
- [However, personal vehicle ownership is the most important factor for determining ride-hailing use.](#)
- [A Los Angeles study confirmed what other studies have shown: race still plays a factor in ride-hailing services, as African American riders are subjected to longer wait times.](#)

1. The makeup of Massachusetts' population is changing due to immigration and aging.

- [Massachusetts has seen declining births, net negative domestic migration, and increases in international migration.](#)¹
- [In the short term, international immigrants in the U.S. have lower auto usage, though this effect diminishes depending on where they live.](#)²

Components of Population Change in Massachusetts 2000-2017¹



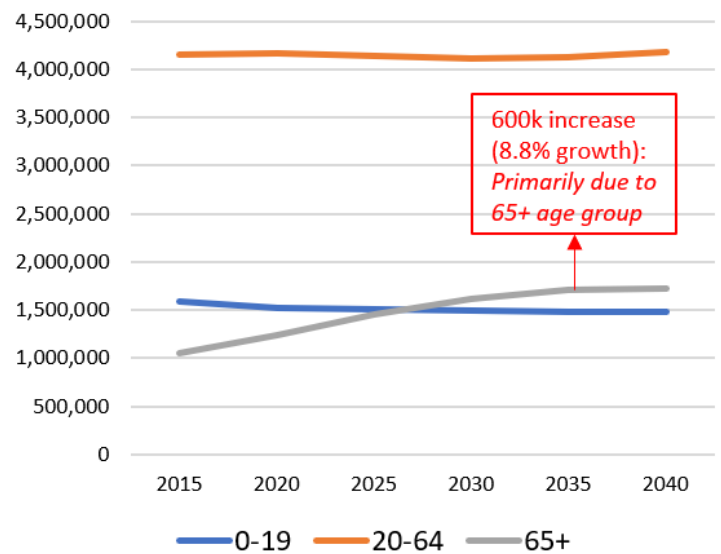
ST-2000-7; CO-EST2010-ALLDATA; and NST-EST2017-ALLDATA, U.S. Census Bureau Population Division

1. University of Massachusetts (UMass) Donahue Institute. (2018). *Long-Term Population Projections for Massachusetts Regions and Municipalities: Method Overview, Recent Updates, and the Components of Change in Massachusetts*. <https://www.mass.gov/doc/long-term-population-projections-umass-donahue-may-2-2018>
2. Transportation (2014). *Explaining The "Immigrant Effect" on Auto Use: The Influence of Neighborhoods and Preferences*. <https://rd.springer.com/article/10.1007/s11116-013-9475-4>

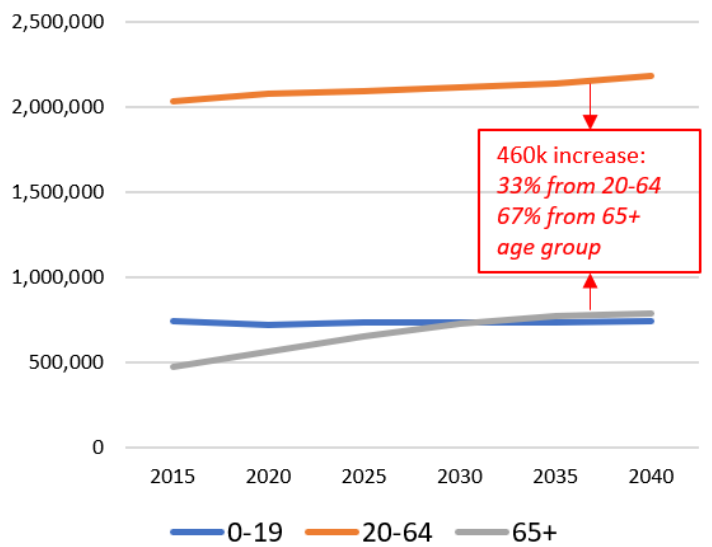
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Massachusetts Population by Age Group: 2015-2040¹



MAPC Region Population by Age Group: 2015-2040¹



*Rates of births, deaths, and immigration stay constant. Potential disruptors (e.g., technology, policies, land use) not taken into account.

1. UMass Donahue Institute. (2018). *Long-Term Population Projections for Massachusetts Regions and Municipalities: Method Overview, Recent Updates, and the Components of Change in Massachusetts*. <https://www.mass.gov/doc/long-term-population-projections-umass-donahue-may-2-2018>

2. Science Daily. (2016). *Americans Live Longer but With Disabilities or Health Issues, Study Shows*. <https://www.sciencedaily.com/releases/2016/04/160415103502.htm>

3. Society for Human Resource Management (SHRM). (2018). *Number of Older Americans at Work Has Grown 35 Percent*. <https://www.shrm.org/resourcesandtools/hr-topics/employee-relations/pages/older-workers-.aspx>

4. Commonwealth of Massachusetts. (2018). *Governor's Council to Address Aging in Massachusetts*. <https://www.mass.gov/orgs/governors-council-to-address-aging-in-massachusetts>

5. Executive Office of Health and Human Services: Governor's Council to Address Aging (2018). *Initial Blueprint Recommendations*. <https://www.mass.gov/files/documents/2018/04/10/Council%20to%20Address%20Aging%20in%20Massachusetts%20Initial%20Blueprint%20Recommendations-April-2018.pdf>

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Financial Statistics about U.S. Adults, by Generation²

Based on profiles created from Epsilon data assets, including its cooperative database Abacus,[®] compiled file TotalSource Plus, and proprietary self-reported database Shopper’s Voice.[®]

March 2017

	Median Income	Median Net Worth	Average spend per household per month	Credit Card Usage	Homeowner	Average Length of Residence
Millennials (15-35)	\$25,759	\$21,620	\$508	25%	28%	4.25 years
Gen Xers (35-50)	\$63,832	\$171,212	\$709	63%	66%	10.8 years
Baby Boomers (50-70)	\$55,928	\$332,944	\$765	76%	79%	16.3 years
Silents (70+)	\$41,538	\$360,448	\$675	79%	77%	16.4 years

MarketingCharts.com | Data Sources: Epsilon

1. Urban Land Institute (ULI). (2018). *Defying Expectations for Master-Planned Communities*. <https://urbanland.uli.org/development-business/defying-expectations-master-planned-communities/>

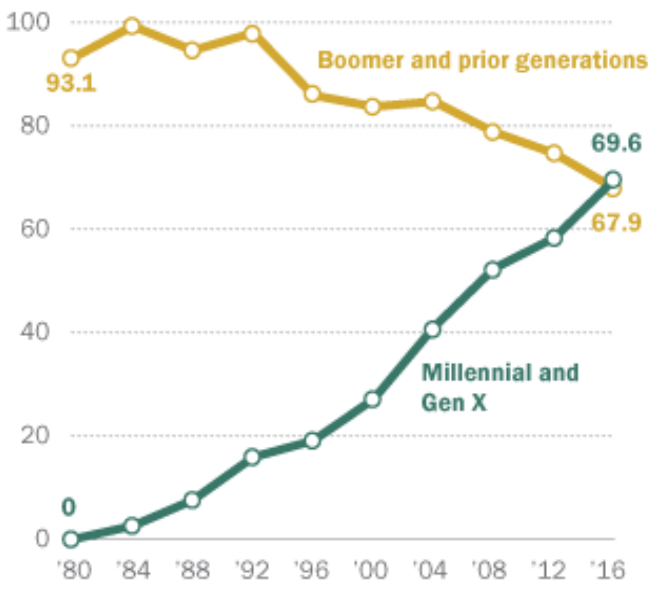
2. Marketing Charts. (2017). *These Financial Stats Show Why Brands Shouldn’t Focus Too Much on Millennials*. <https://www.marketingcharts.com/demographics-and-audiences/boomers-and-older-75298>

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Millennial and Gen X Voters Edged Out Older Generations in 2016 Vote¹

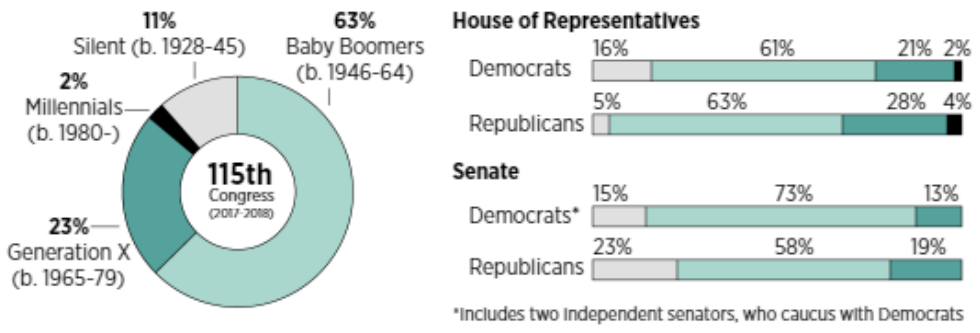
Reported votes cast in presidential elections, in millions



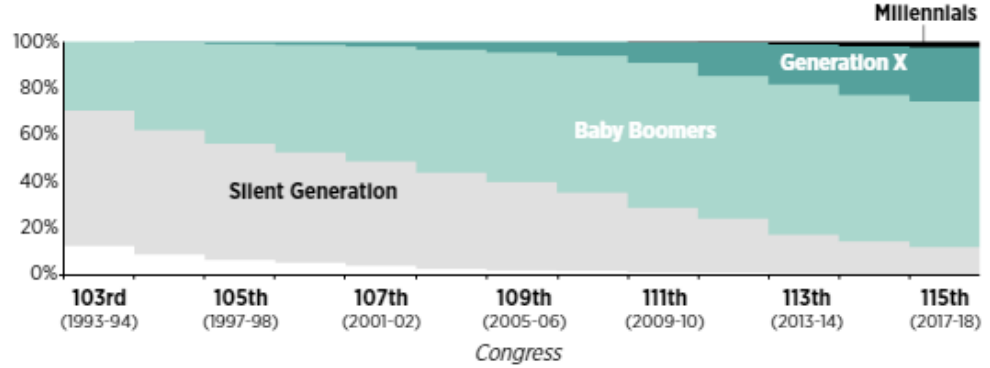
Source: Pew Research Center tabulations of the 1980-2016 Current Population Survey November Supplements.

PEW RESEARCH CENTER

A Generational Breakdown of the Current Congress²



Generational Shifts Since 1993



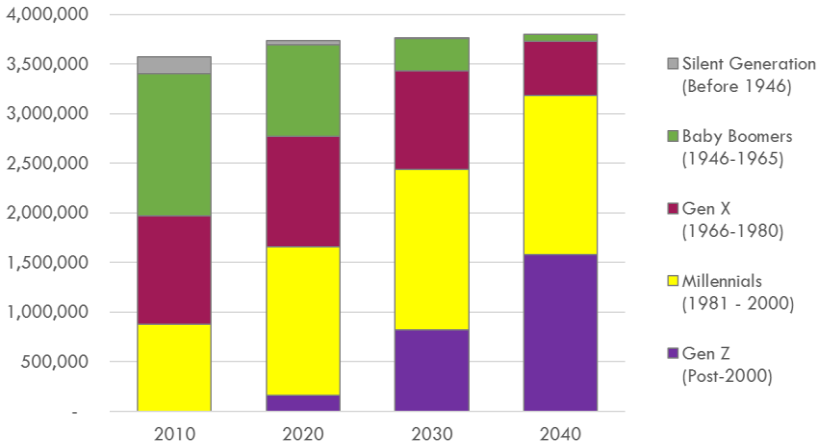
Source: CQ Members data
Ryan Kelly/Roll Call

1. Pew Research Center. (2017). *Millennials and Gen Xers outvoted Boomers and Older Generations in 2016 Election*. <http://www.pewresearch.org/fact-tank/2017/07/31/millennials-and-gen-xers-outvoted-boomers-and-older-generations-in-2016-election/>
 2. Roll Call. (2017). *Senior Class: Members of Congress Getting Older*. <https://www.rollcall.com/news/politics/seniority-rules-members-getting-older>

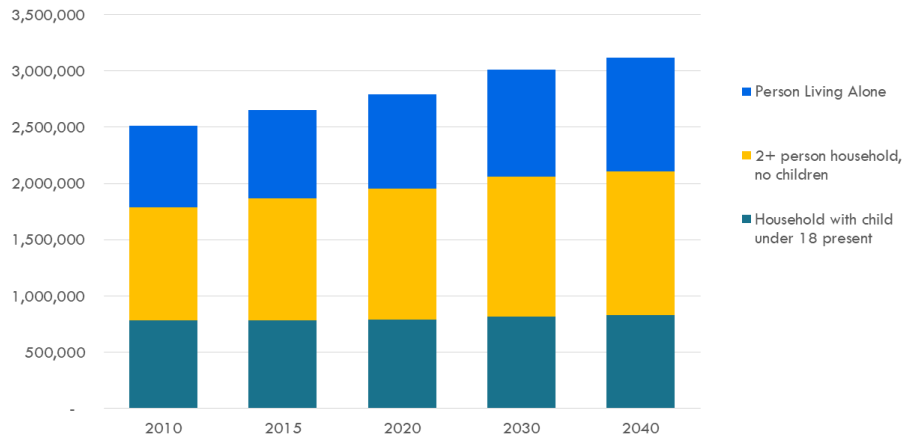
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Labor Force by Year Born, Massachusetts Metropolitan Planning Organizations: 2010-2040¹



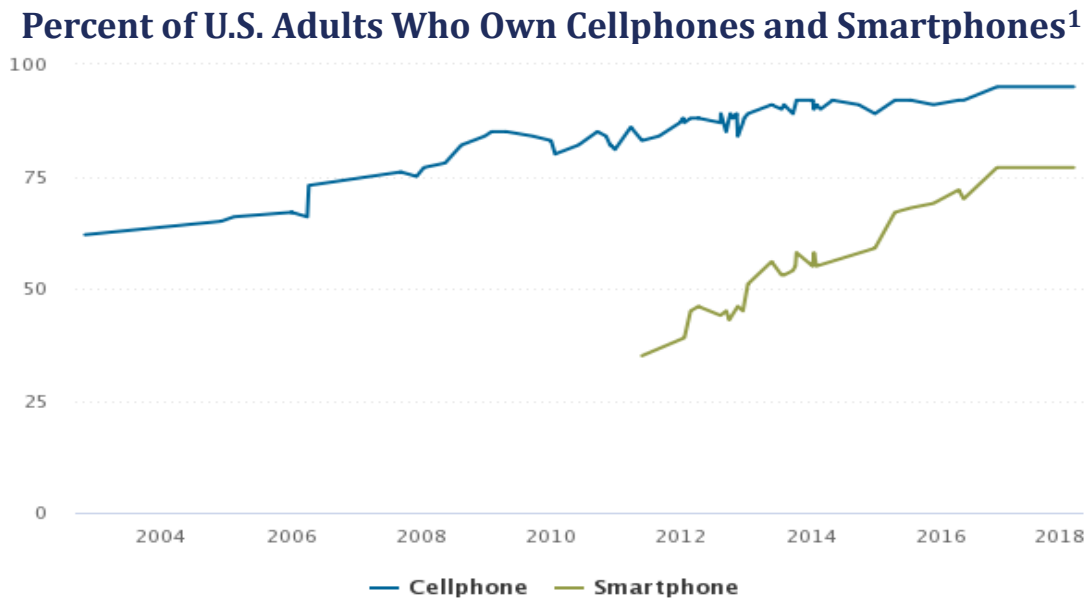
Households by Household Type, Massachusetts, 2010 - 2040¹



1. Metro Area Planning Council (MAPC). (2018). *Demographics and land use factors affecting future transportation demand*. <https://www.mass.gov/doc/demographics-and-land-use-factors-affecting-future-transportation-demand-mapc-may-2-2018>

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1. Pew Research Center. (2018). *Mobile Fact Sheet*. <http://www.pewinternet.org/fact-sheet/mobile/>

2. American City & Country. (2017). *Millennials in Transit*. <http://americancityandcountry.com/public-transit/millennials-transit>

3. Georgia Tech. (2016). *Will millennials transform the future of transportation? Maybe not as much as we thought*. <https://ce.gatech.edu/news/will-millennials-transform-future-transportation-maybe-not-much-we-thought>

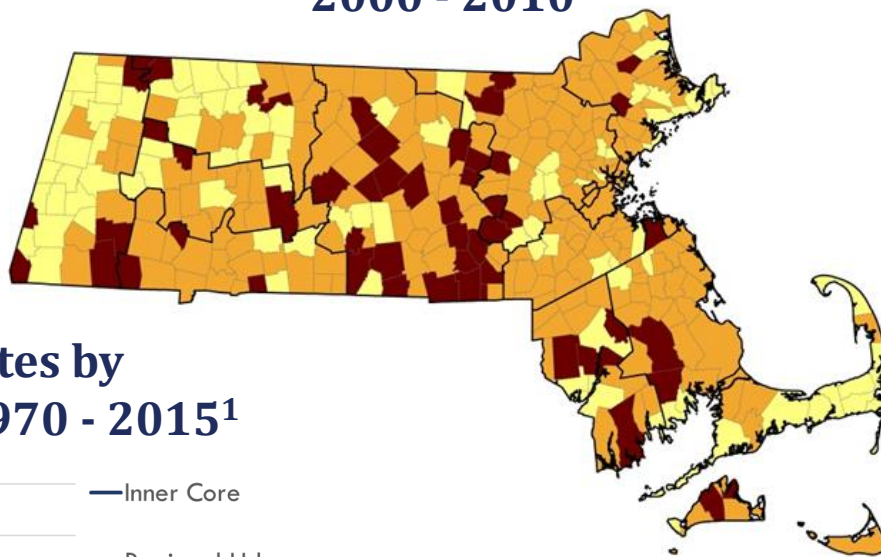
4. Time. (2015). *Millennials Will Outgrow the Sharing Economy*. <http://time.com/money/3957652/sharing-economy-millennials/>

5. ULI. (2018). *Defying Expectations for Master-Planned Communities*. <https://urbanland.uli.org/development-business/defying-expectations-master-planned-communities/>

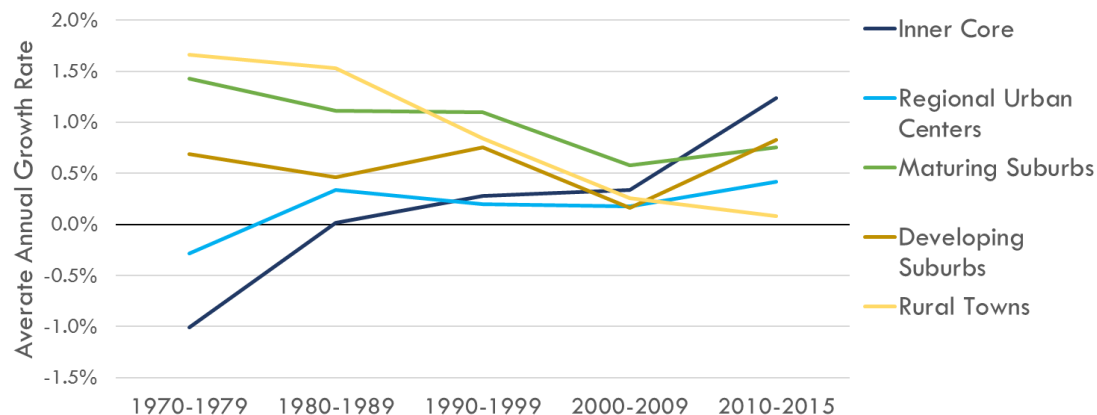
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Population Change by Municipality, Massachusetts 2000 - 2010¹



Annual Population Growth Rates by Community Type, Massachusetts 1970 - 2015¹



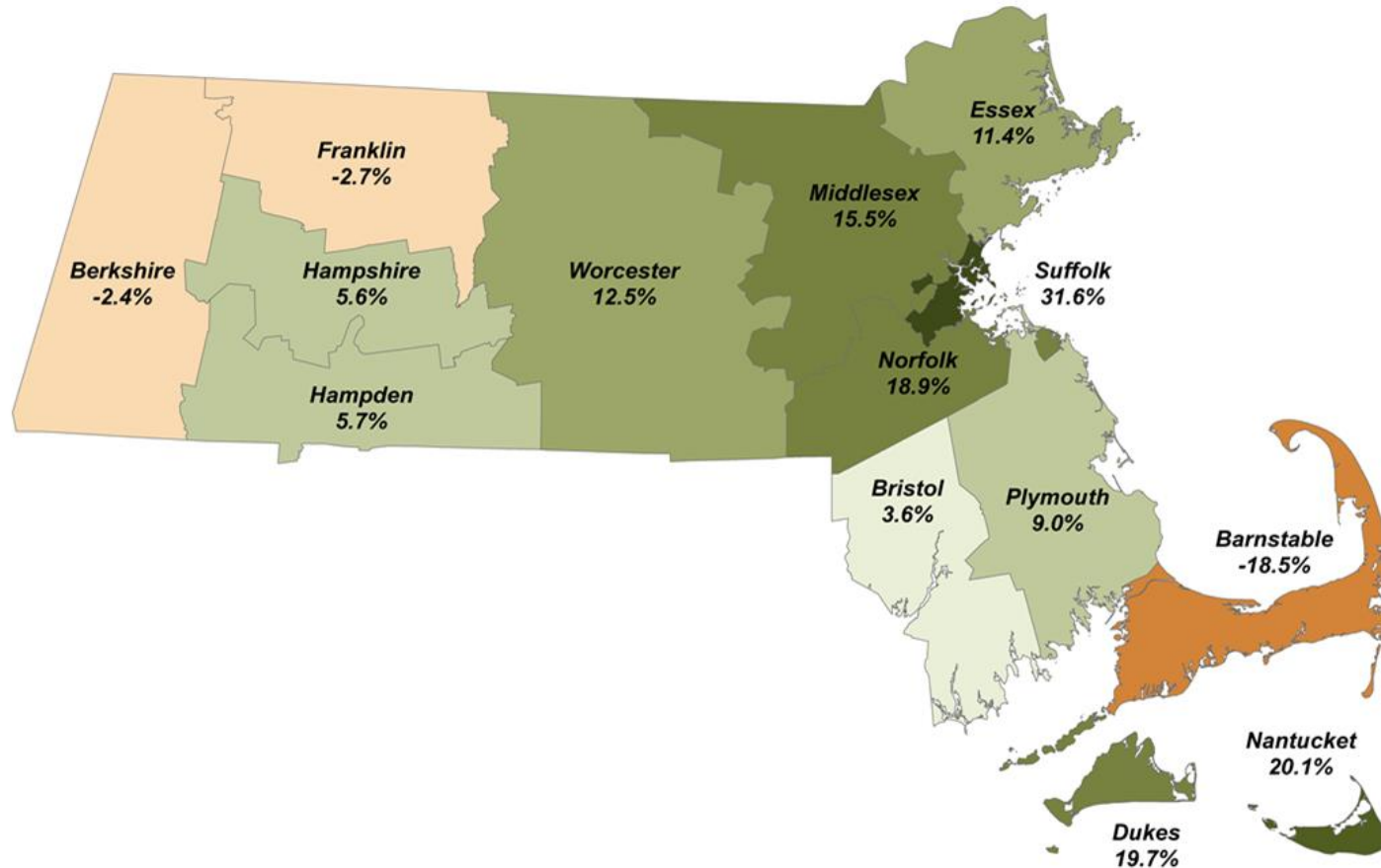
Source: U.S. Census, Decennial Census and Population Estimates

1. MAPC. (2018). *Demographics and land use factors affecting future transportation demand*. <https://www.mass.gov/doc/demographics-and-land-use-factors-affecting-future-transportation-demand-mapc-may-2-2018>

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Percent Change in Population by County: 2010- 2040¹

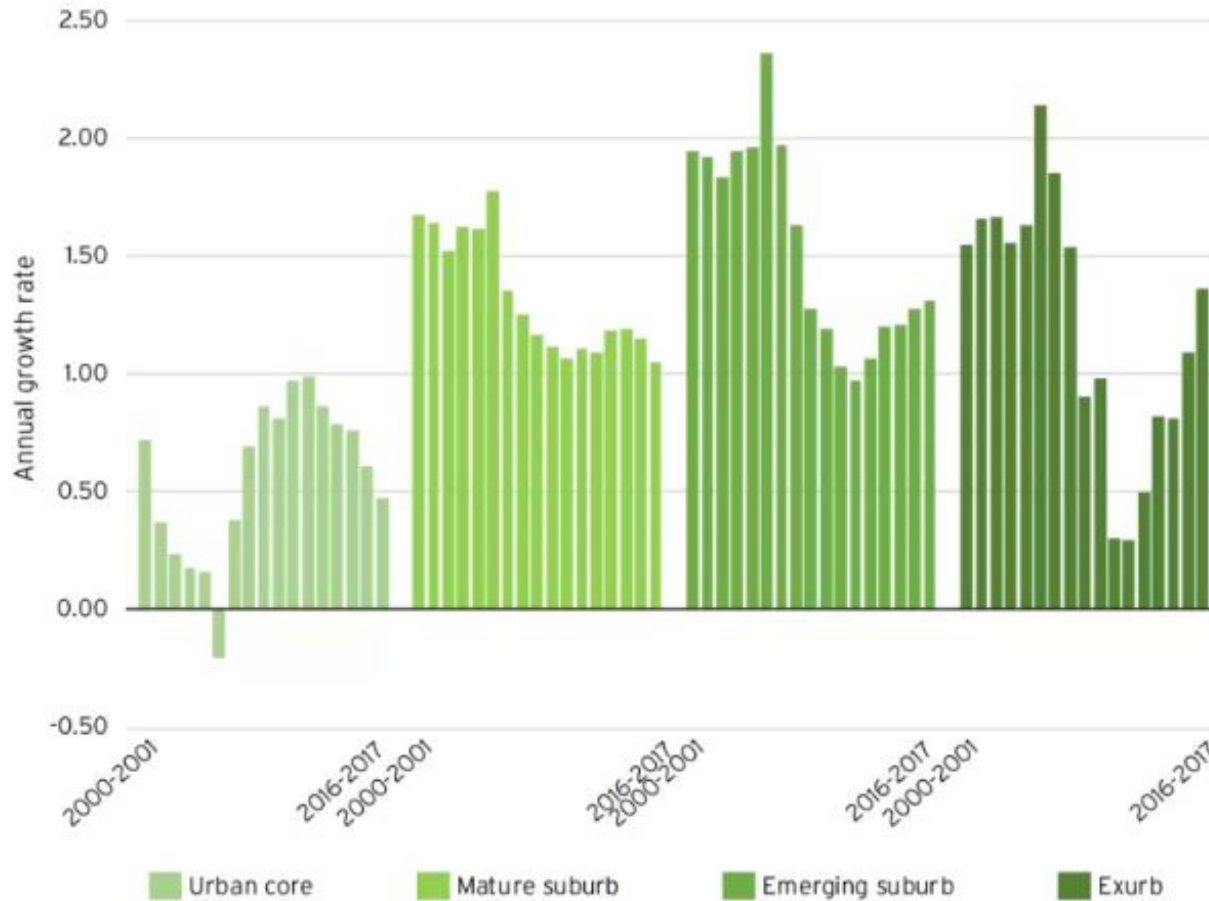


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Annual Growth Rates for Urban and Suburban Counties: 2000-2017*1



*Counties in metropolitan areas over 500,000 using Brookings classification system.

1

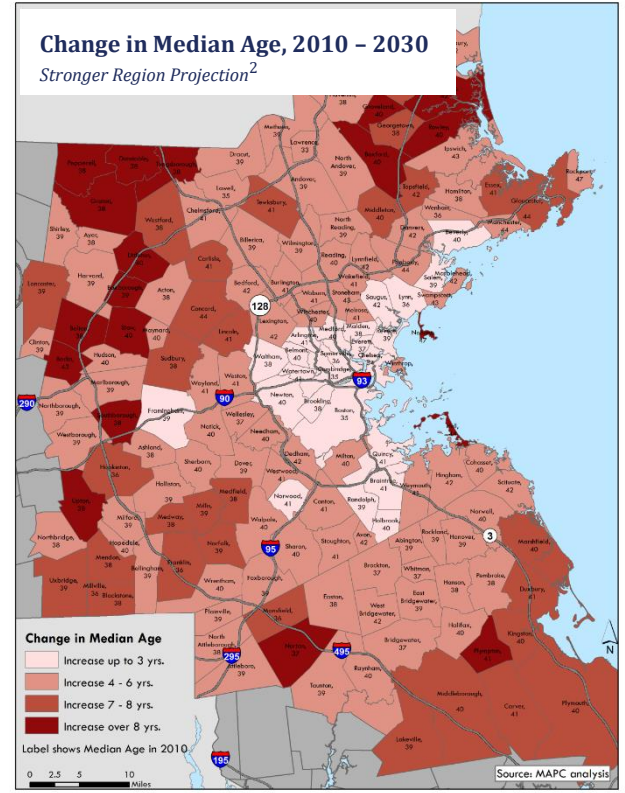
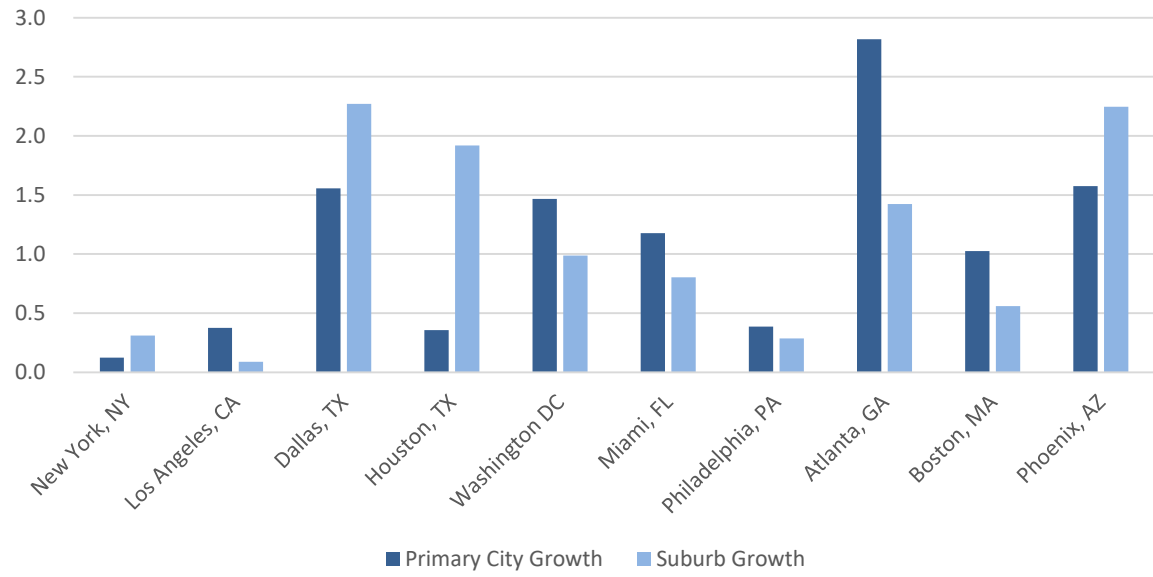
1. Brookings Institute. (2018). *US population disperses to suburbs, exurbs, rural areas, and "middle of the country" metros*. <https://www.brookings.edu/blog/the-avenue/2018/03/26/us-population-disperses-to-suburbs-exurbs-rural-areas-and-middle-of-the-country-metros/>

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2016-2017 Growth Rates for Primary Cities and Suburbs

Large Metropolitan Areas (ranked by size)¹



1. Brookings Institute. (2018). *Early decade big city growth continues to fall off, census shows.* <https://www.brookings.edu/blog/the-avenue/2018/05/25/early-decade-big-city-growth-continues-to-fall-off-census-shows/>

2. MAPC. (2018). *Demographics and land use factors affecting future transportation demand.* <https://www.mass.gov/doc/demographics-and-land-use-factors-affecting-future-transportation-demand-mapc-may-2-2018>

3. CityLab. (2018). *Density's Next Frontier: The Suburbs.* <https://www.citylab.com/equity/2018/02/densitys-next-frontier-the-suburbs/552065/>

4. CityLab. (2017). *What Drove the Driving Downturn?* <https://www.citylab.com/transportation/2017/04/what-drove-the-driving-downturn/518601/>

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Development Profiles for Bike-Friendly Communities¹

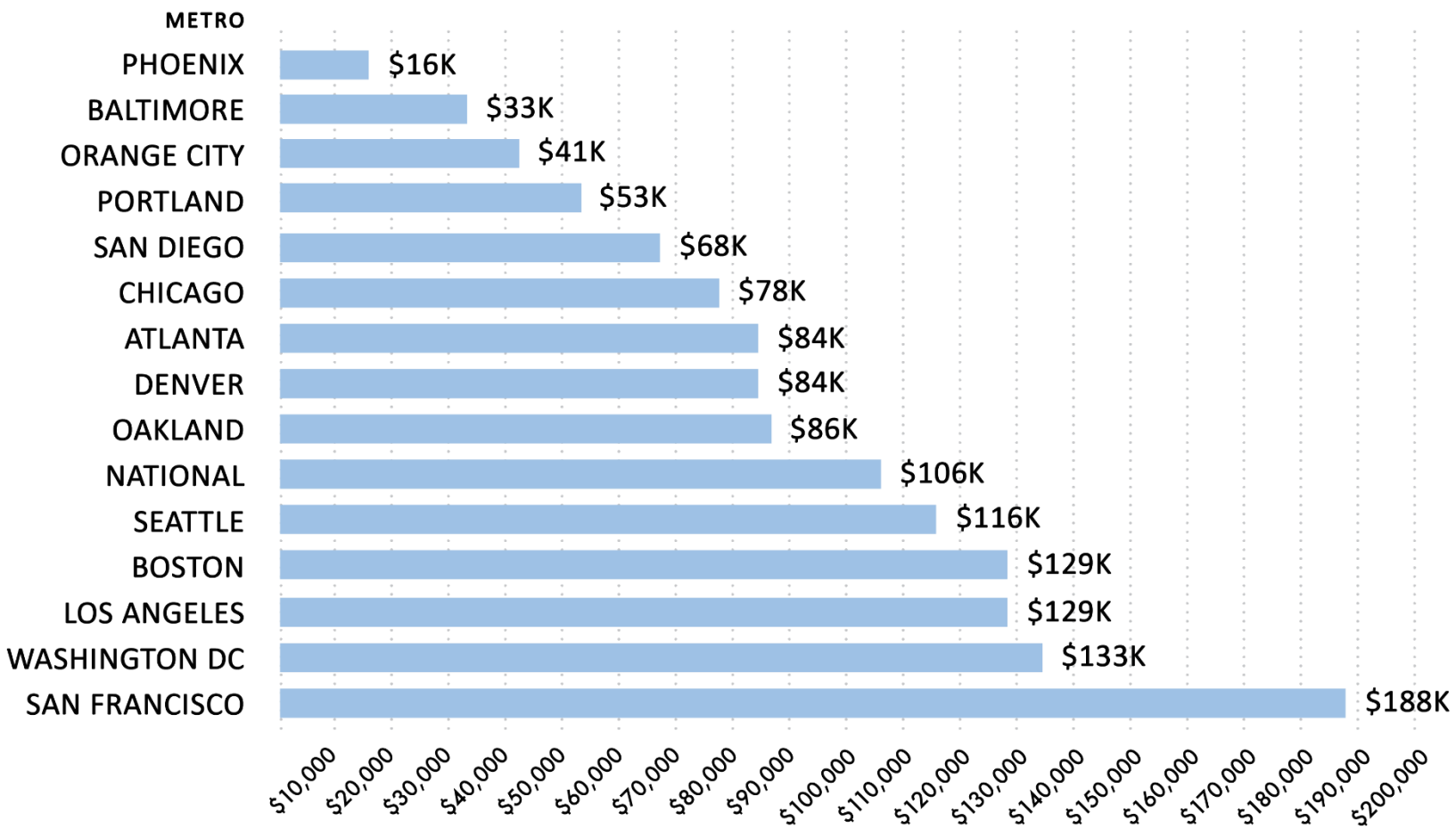
	DEDICATED BICYCLE STORAGE AREAS	EXTRA-WIDE HALLWAYS OR BIKE ELEVATORS	BICYCLE WORKROOM	BICYCLE WASHING STATION	BIKE VALET	SHOWER AND/OR LOCKER FACILITIES	BICYCLE PARTS OR MECHANIC AVAILABLE ON-SITE	INVESTMENT IN ON-SITE BIKE RENTALS OR BIKE SHARE	BIKE PARK AND RIDE	INVESTMENT IN PUBLIC ACTIVE TRANSPORTATION AND INFRASTRUCTURE
BICI FLATS DES MOINES, IA MULTIFAMILY	●	●	●	●						
CIRCA INDIANAPOLIS, IN MULTIFAMILY	●		●	●				●		
FLATS AT BETHESDA AVE BETHESDA, MD MIXED USE	●	●							●	●
GOTHAM WEST NEW YORK, NY MIXED USE	●				●		●	●		
HASSALC ON EIGHTH PORTLAND, OR MIXED USE	●		●	●	●	●	●			
MOZAIC MINNEAPOLIS, MN MIXED USE	●					●				●
PONCE CITY MARKET ATLANTA, GA MIXED USE	●	●	●		●	●				●
SILVER MOON LODGE ALBUQUERQUE, NM MIXED USE	●		●					●		
250 CITY ROAD LONDON, UK MULTIFAMILY	●	●	●	●				●		●
WESTWOOD RESIDENCES SINGAPORE MULTIFAMILY	●		●	●						●

1. ULI. (2016). *Active Transportation and Real Estate: THE NEXT FRONTIER*. <http://uli.org/wp-content/uploads/ULI-Documents/Active-Transportation-and-Real-Estate-The-Next-Frontier.pdf>

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Home Price Premiums for Increases in Walk Score from 60 to 80¹



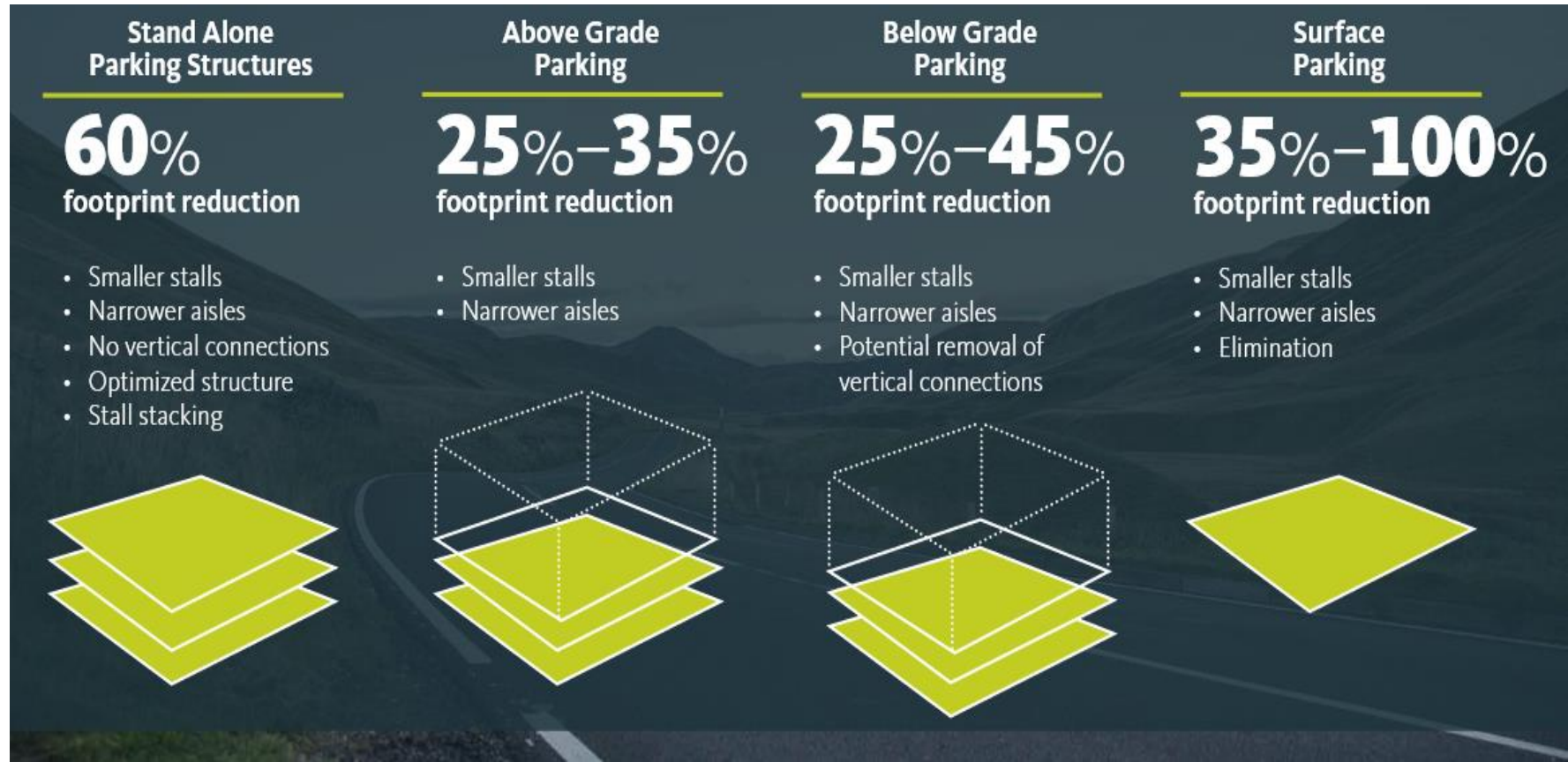
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- [Reducing parking demand and increasing parking density in New England will contribute to less land needed for parking in the future.](#)¹

Impacts of the Driverless Car on Real Estate¹

Parking Typologies - Project Footprint Reduction

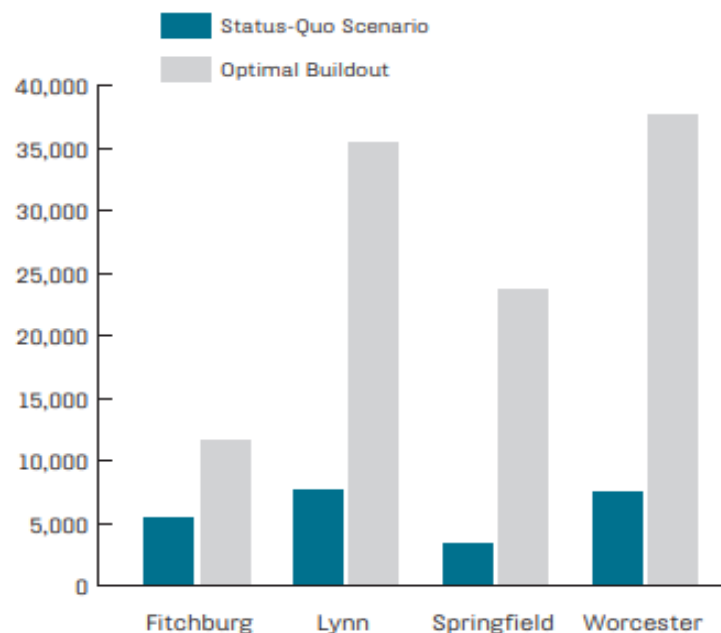


1. ULI. (2018). *ULI Boston/New England Infrastructure Council Presents: The Future of Parking.* <https://www.mass.gov/doc/the-future-of-parking-urban-land-institute-january-23-2018>

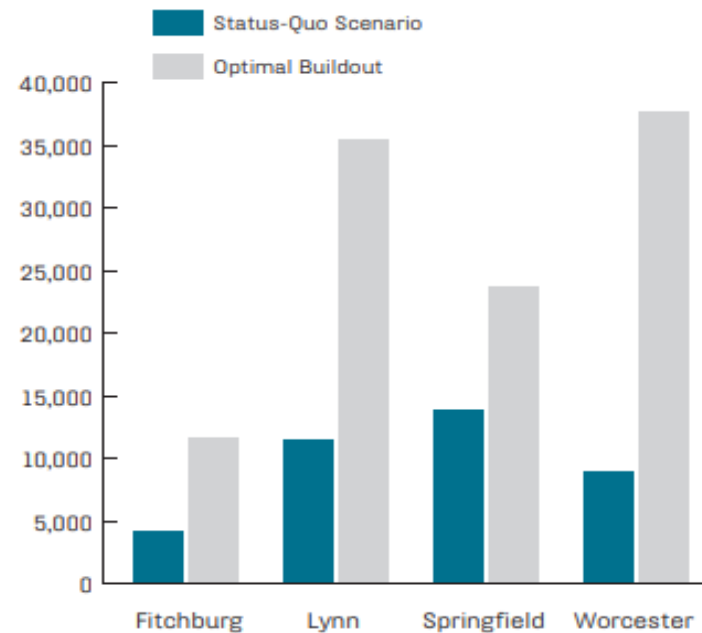
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- [Curbside management in the U.S. will likely become a significant issue due to bike-share stations, bike lanes, e-commerce delivery, and ride-hailing pick-up and drop-off.](#)¹
- [Access to new and emerging transportation modes in the U.S. will be heavily influenced by land-use policy, such as parking requirements and zoning laws that dictate density.](#)¹
- [MassDOT and MBTA are focusing on transit oriented development \(TOD\), which features compact, walkable mixed-use developments at or near transit stations...](#)²
- [... which in Gateway Cities can support higher population and more jobs than would be present with the status-quo development.](#)³

Population in TOD Districts³ Status Quo Scenario vs. Optimal Buildout



Jobs in TOD Districts³ Status Quo Scenario vs. Optimal Buildout



Source: RKG Associates and Hodge Economic Consulting

1. Wired. (2017). *TO SEE THE FUTURE OF CITIES, WATCH THE CURB. YES, THE CURB.* <https://www.wired.com/story/city-planning-curbs/>

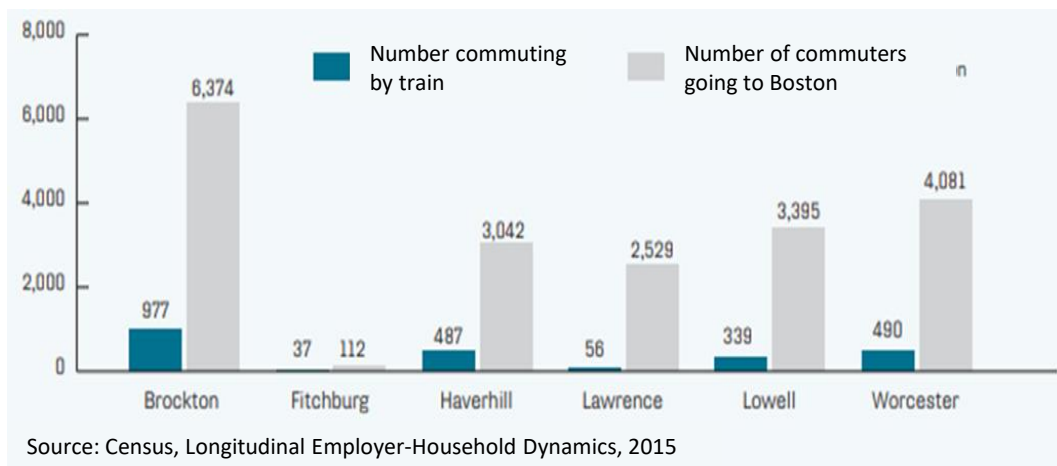
2. Massachusetts Realty Group. (2018). *Transit Oriented Development.* <https://www.mbtarealty.com/transit-oriented-development/>

3. Massachusetts Institute for a New Commonwealth (MassINC). (2018). *The Promise and Potential of Transformative Transit-Oriented Development in Gateway Cities.* <https://massinc.org/research/the-promise-and-potential-of-transformative-transit-oriented-development-in-gateway-cities/>

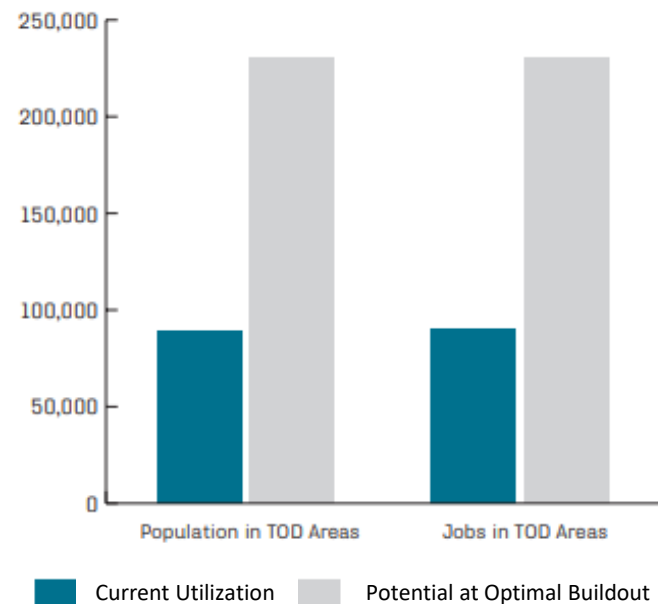
5. Transportation will play a significant role in future land-use plans.

- By improving transit service and focusing on TOD, Gateway Cities can “borrow size” from Boston to mitigate both congestion and cost of sprawling infrastructure, while also improving their economic development and regional mobility competitiveness.¹
 - Communities with high-frequency subway service accounted for 42 percent of Massachusetts’ net job growth in the last decade, up from only 6 percent in the previous decade for those same communities.¹

Number of Gateway City Residents Commuting to Boston by Mode¹



Growth in Population and Jobs in TOD Areas with Optimal Buildout¹ 13 Gateway Cities

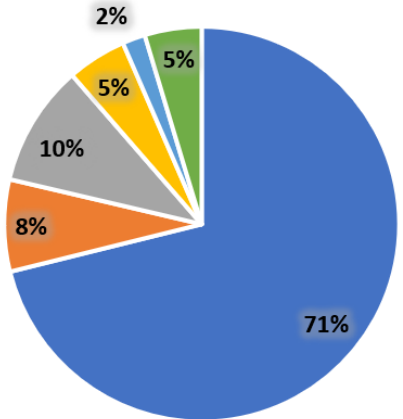


1. MassINC. (2018). *The Promise and Potential of Transformative Transit-Oriented Development in Gateway Cities*. <https://massinc.org/research/the-promise-and-potential-of-transformative-transit-oriented-development-in-gateway-cities/>

6. In addition to where one lives, a person's job is also an important factor in transportation mode choice.

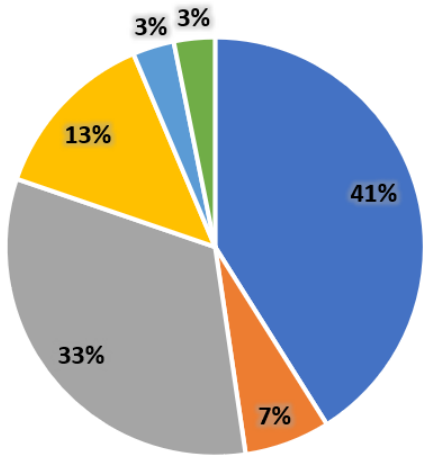
- [Driving alone is the most common means of transportation to work in Massachusetts as a State and Suffolk County, specifically.](#)¹

Means of Transportation to Work – Massachusetts¹



- Car, truck, or van - drove alone
- Car, truck, or van - carpooled
- Public transportation (excluding taxicab)
- Walked
- Taxicab, motorcycle, bicycle, or other means
- Worked at home

Means of Transportation to Work – Suffolk County¹



- Car, truck, or van - drove alone
- Car, truck, or van - carpooled
- Public transportation (excluding taxicab)
- Walked
- Taxicab, motorcycle, bicycle, or other means
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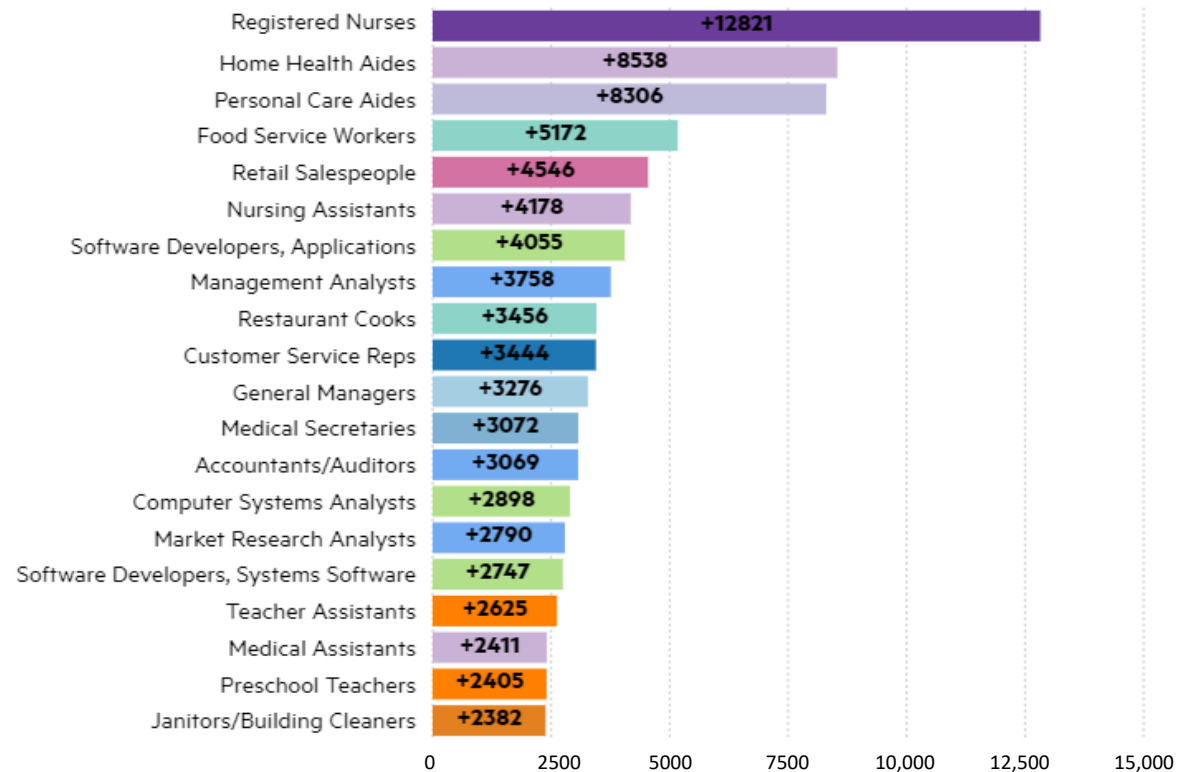
1. U.S. Census. (2018). 2012-2016 American Community Survey 5-Year Estimates. <https://factfinder.census.gov/faces/nav/jsf/pages/index.xhtml>

6. In addition to where one lives, a person's job is also an important factor in transportation mode choice.

- [Working from home has become increasingly common, with nearly 3 percent \(3.9 million employees\) of the U.S. workforce working from home at least half of the time, which has more than doubled since 2005...](#)¹
- [...making telecommuting a more common method of commuting to work than public transit in more than half of the top U.S. metro areas.](#)¹
- [However, telecommuting is not an option for registered nurses, home health aides, and personal care aides, all of which are projected to have the highest job growth in Massachusetts through 2024.](#)²

Massachusetts Biggest Job Growth in Raw Numbers: 2014-2024²

- ↔ Healthcare Practitioners and Technical
- ↔ Healthcare Support
- ↔ Personal Care and Service
- ↔ Food Preparation and Serving
- ↔ Sales and Related
- ↔ Computer and Mathematical
- ↔ Business and Financial Operations
- ↔ Office and Administrative Support
- ↔ Management
- ↔ Education, Training, and Library
- ↔ Building and Grounds Cleaning and Maintenance



*Some job title labels have been edited for clarity.

Source: Massachusetts Office of Labor and Workforce Development

1.1 Million for Work Flexibility (1MFWF). (2017). *The State of Telecommuting in the U.S. in 2017*. <https://www.workflexibility.org/state-of-telecommuting-us-2017/>

2.WBUR. (2017). *What The Data Tell Us About The Future Of Work In Mass.* <http://www.wbur.org/bostonmix/2017/10/30/future-jobs-data-massachusetts>

7. While transportation is a universal concern, it is experienced very differently across socioeconomic groups.

- [Americans making less than \\$14,000 per year spend on average 28 percent of their annual income on transportation.](#)¹

Portion of Income Spent on Basic Needs¹

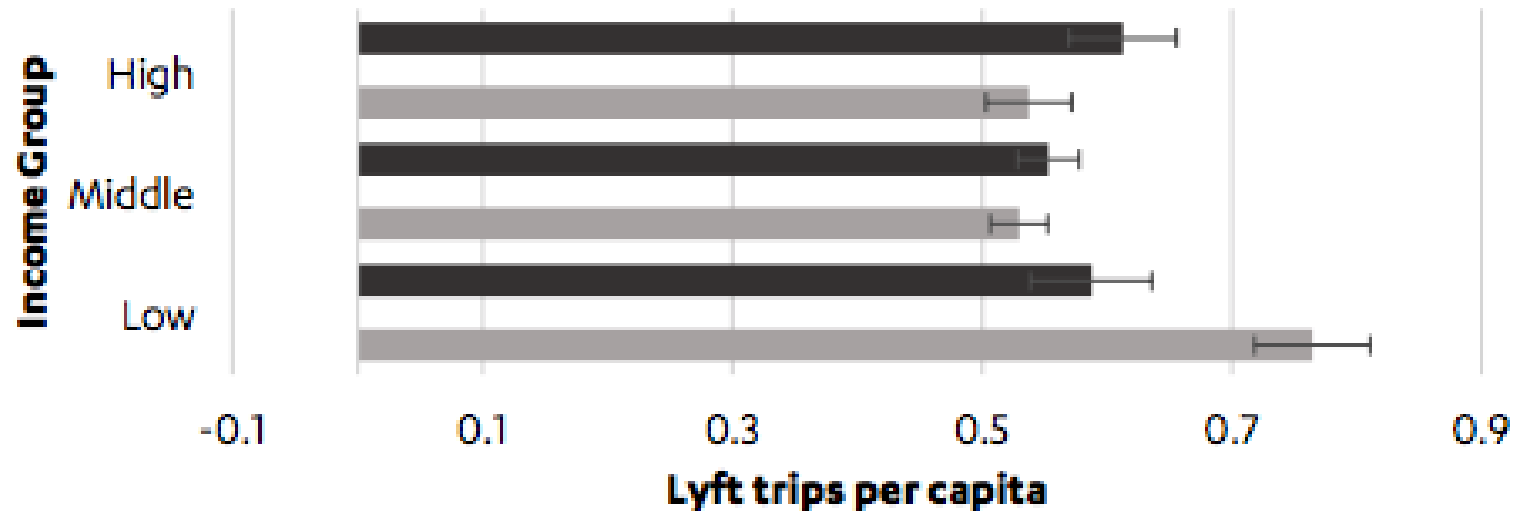


1. CNN. (2015). *It's expensive to be poor*. <https://money.cnn.com/2015/04/23/news/economy/poor-spending/index.html>

7. While transportation is a universal concern, it is experienced very differently across socioeconomic groups.

- [In the U.S., Lyft is filling transportation gaps in low-income areas; those living in low-income areas made more Lyft trips per person compared to middle-income and high-income communities.](#)¹
- [However, personal vehicle ownership is the most important factor for determining ride-hailing use.](#)¹
- [A Los Angeles study confirmed what other studies have shown: race still plays a factor in ride-hailing services, as African American riders are subjected to longer wait times.](#)¹

Comparison of Lyft Trips Across Income Groups¹



- ↔ Neighborhood with 10 percent zero car households
- ↔ Neighborhoods where all residents own vehicles

1. CityLab. (2018). *Lyft Is Reaching L.A. Neighborhoods Where Taxis Wouldn't*. <https://www.citylab.com/transportation/2018/06/lyft-is-reaching-la-neighborhoods-where-taxis-wouldnt/563810/>

TRANSIT, ACTIVE TRANSPORTATION, AND MOBILITY SERVICES

Why do transit, active transportation, and mobility services matter?

1. [Transit usage is changing.](#)
2. [Active transportation and micro-mobility are becoming more prevalent.](#)
3. [The use of transportation network companies \(TNCs\) is growing.](#)
4. [Mobility as a Service \(MaaS\) looks to change how people plan, pay for, and take trips.](#)
5. [New trends and technology will affect congestion, as will attitudes towards ride and vehicle sharing.](#)
6. [These new transportation options potentially play a big role in improving mobility.](#)
7. [Density impacts, but does not need to define, transit options.](#)

Summary

1. Transit usage is changing.

- [Total U.S. transit ridership has decreased overall, but the pattern is not consistent:](#)
 - [Light and commuter rail ridership are at an all-time high,](#)
 - [Heavy rail \(subway\) ridership is down only slightly, and](#)
 - [Bus ridership is at its lowest in almost 20 years.](#)
- [Summing the benefits associated with travel time savings, travel cost, crashes avoided, and reduced vehicular emissions, MBTA transit services provide an approximately \\$11.4 billion benefit to the greater Boston region annually – the annual MBTA budget is approximately \\$2 billion, demonstrating a significant return on investment.](#)
- [However, MBTA ridership, along with most other transit agencies in the U.S., is trending down.](#)
- [Almost all of Massachusetts' Regional Transit Authorities \(RTAs\) are experiencing ridership declines, in line with nationwide trends.](#)

2. Active transportation and micro-mobility are becoming more prevalent.

- [While almost half of all trips in the U.S. are three miles or fewer \(a distance that could generally be completed in under 20 minutes walking or biking\), only 10 percent are completed by walking or biking...](#)
- [...and many of those trips would actually take less time via active transportation or micro-mobility modes.](#)
- [Americans would like to see more money spent on active transportation.](#)
- [MassDOT is planning to improve walkability and bike networks for communities statewide.](#)
- [Bike-share trips have seen enormous growth in the last six years in the Boston area, exceeding 1 million in 2017.](#)
- [Other new forms of micro-mobility, such as E-Scooters, are showing rapid adoption across the U.S.](#)
- [Major automobile companies are entering the market – GM is launching a line of E-bikes and Ford bought an E-scooter company for close to \\$100 million.](#)

3. The use of transportation network companies (TNCs) is growing.

- [TNCs connect passengers with drivers through a mobile application \(e.g. ,Uber, Lyft\) to provide services referred to as ride-hailing.](#)
- [In major cities, 21 percent of adults have used ride-hailing services, but only one-quarter use them on a weekly basis.](#)
- [Frequent TNC users in the U.S. have lower household vehicle ownership.](#)
- [TNCs in the U.S. tend to be more popular in high-density areas, including college campuses.](#)
- [TNC riders in the U.S. are on average younger and have higher education levels and higher average incomes.](#)
- [In 2017, Massachusetts saw 64.8 million ride-hailing trips...](#)
- [...compared to 408 million trips on public transit and 5.9 million by taxi...](#)
- [...however these trips are not evenly distributed; ride-hailing trips accounted for nearly one out of every 25 trips made in Boston, but barely more than one out of every 100 trips over the entire MAPC region.](#)
- [In Massachusetts, almost half of ride-hailing trips would have been completed on transit if TNCs were not available, and 30 percent of those trips occurred during rush hour.](#)
- [Weekend nights dominate usage, although rush hour usage varies across locations in the U.S.](#)
- [This trend in usage is likely because parking concerns and alcohol consumption are two of the top reasons for using TNCs in the U.S.](#)
- [Massachusetts signed legislation in 2016 regulating and taxing TNCs.](#)
- [Massachusetts assesses TNCs a \\$0.20 per-ride fee on every trip started in the state.](#)
- [After factoring in the impact on transit ridership and the per-ride TNC fee, there was about \\$10 million net revenue loss to the state's transportation system in 2017 due to TNCs.](#)
- TNCs are rapidly gaining mode share at Logan Airport.
- [TNCs generally do not share their data freely; however, legislatures and public agencies may mandate that they provide some of the data.](#)

4. Mobility as a Service (MaaS) looks to change how people plan, pay for, and take trips.

- [MaaS provides mobility options without requiring the user to own the means of transportation \(ride-hailing, bike-sharing etc.\), though some definitions go further specifying it as the integration of various forms of transport services into a single mobility service that is accessible on demand \(i.e. use one app to plan and pay for a door-to-door trip using multiple modes – both public and private\).](#)
- [Integrated MaaS is available in some forms today. Europe leads the U.S. in adoption.](#)
- [Even as ride-hailing grows, TNCs are beginning to invest in micro-mobility options, which are becoming more popular, especially as travelers try to avoid rush-hour congestion.](#)
- [Transit agencies see MaaS as a way to increase the mobility options they can offer to travelers \(e.g., bike-share, micro-transit\).](#)
- [Founder of MaaS-provider Whim \(the “Netflix of transportation” based in Finland\) wants to “prove that we can beat the service level of a car. Or at least be comparable to it.”](#)
- [Uber is adding bike-sharing, car-sharing, transit start-ups, and, more recently, scooters in an effort to expand mobility options.](#)
- [While micro-transit start-ups have not always panned out, they may have a place as part of a bigger system like MaaS.](#)

5. New trends and technology will affect congestion, as will attitudes towards ride and vehicle sharing.

- [Many studies find TNCs are contributing to congestion.](#)
- [TNCs look to reduce car ownership, but their use may reduce congestion only if rides are shared, and “deadhead” miles may increase congestion.](#)
- [Consumers interested in vehicle subscription services still see personal vehicles as their primary mode of transportation.](#)
- [The potential for MaaS to reduce congestion is predicated on it minimizing the reliance on private vehicles for transportation. It needs to incorporate public transit and shared rides.](#)
- [Automated Vehicles \(AVs\) will play a large role in the adoption of TNCs and MaaS, with predictions of up to 80 percent of miles in urban areas being completed by shared AVs.](#)
- [Despite the fact that ridesharing is common feature in many predictions for the future, carpooling in the U.S. has been declining in recent years.](#)
- [Uber contends that the complexity of carpooling is a major reason it is not more prevalent; services like Uberpool and Lyftline will reduce complexity and have seen significant ridership increases since their launch...](#)
- [...however, other analysis in the U.S. indicates that most ridepool users are actually drawn away from transit and active transportation modes rather than single occupant trips.](#)
- [Some cities, such as Portland, are rolling out new approaches to allocating street spaces to reduce congestion – Portland’s effort calls for removing parking spaces in the congested downtown to increase the land area set aside for bus and bike lands from 4 to 6 percent and increase total people-carrying capacity of downtown street by an average of 60 percent.](#)

6. These new transportation options potentially play a big role in improving mobility.

- [Automation will make TNCs and MaaS more cost-efficient and improve adoption, though public transit will still be the least expensive option for users.](#)
- [New mobility options are prompting parking professionals to view themselves as “transportation mobility professionals” who figure out how best to use current parking facilities given new trends and technology.](#)
- [These technologies and innovations are not solely for private transportation, but can improve and reshape public transit as well.](#)
- [A rural Ontario town of 36,000 provided 26,700 transit trips in eight months, and saved hundreds of thousands of dollars by partnering with Uber, instead of adding fixed bus routes.](#)
- [The MBTA is running a pilot program with Uber and Lyft to offer on-demand transit service to RIDE customers at a subsidized rate, which helps provide more rides and lower costs.](#)

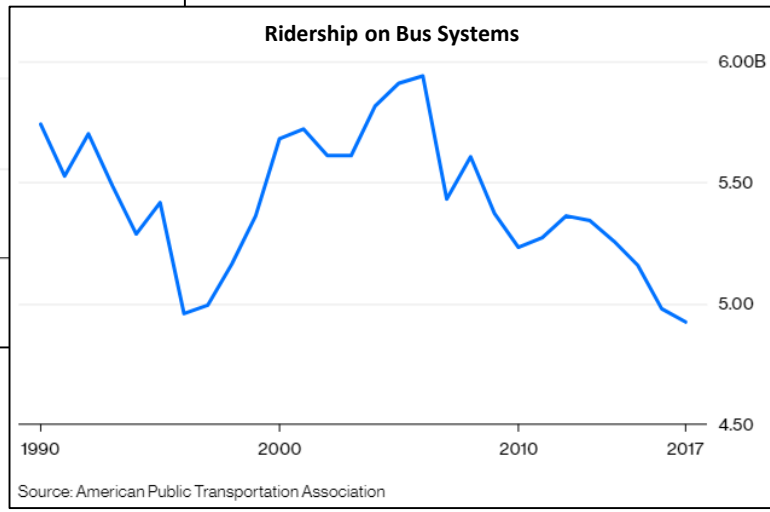
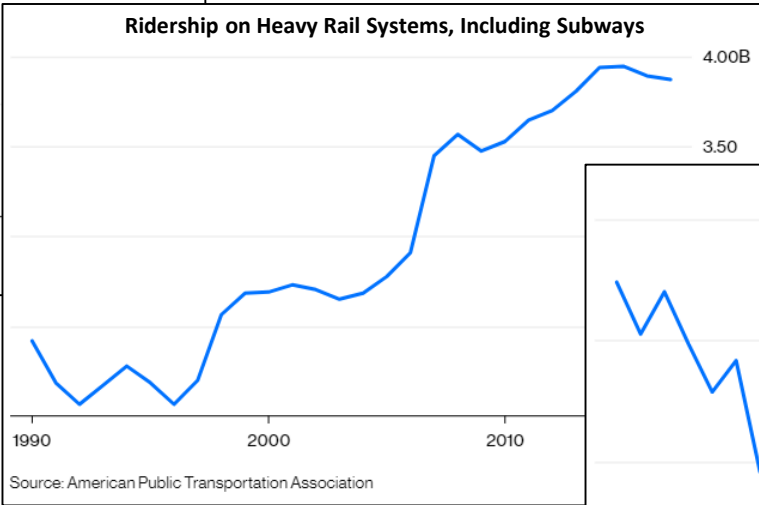
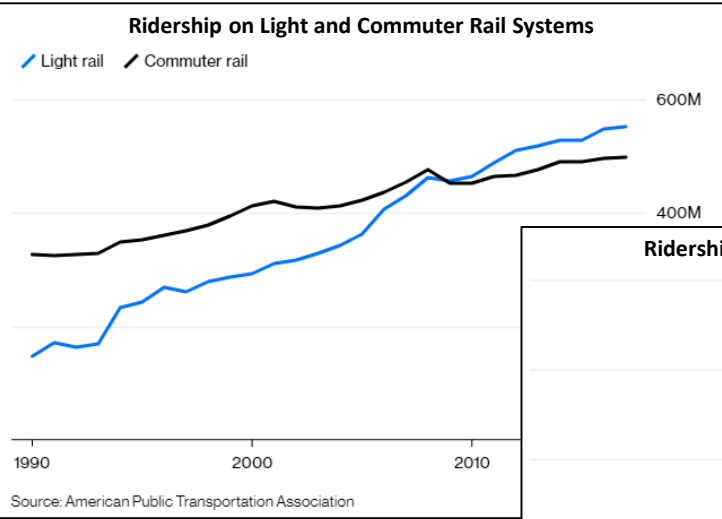
7. Density impacts, but does not define, transit options.

- [Seven dwelling units per acre is the average density required to support basic 30-minute bus service, yet increasing density without planning or funding will not improve the quality of public transit.](#)
- [The private sector has consistently increased its funding for Transportation Management Associations \(TMAs\) in Massachusetts municipalities to increase transportation options.](#)
- [In U.S. suburban and rural areas, people improvise to fill transit system gaps, such as carpools that pick up from bus stations or other fixed points \(aka “slugging”\) and vanpools.](#)
- [In Massachusetts, rural areas have limited usage of TNCs, as usage is concentrated in Greater Boston.](#)
- RTAs provide some coverage, but the majority of rural communities do not have access to public transit.
- [While some predict that rural riders will be late adopters of MaaS...](#)
- [...the start-up Liberty Mobility Now is looking to fill transit gaps in rural areas in the U.S.](#)
- [Transit ridership is increasing proportionally faster in rural areas than urban areas despite decreasing population.](#)

1. Transit usage is changing.

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National Transit Ridership Trends¹

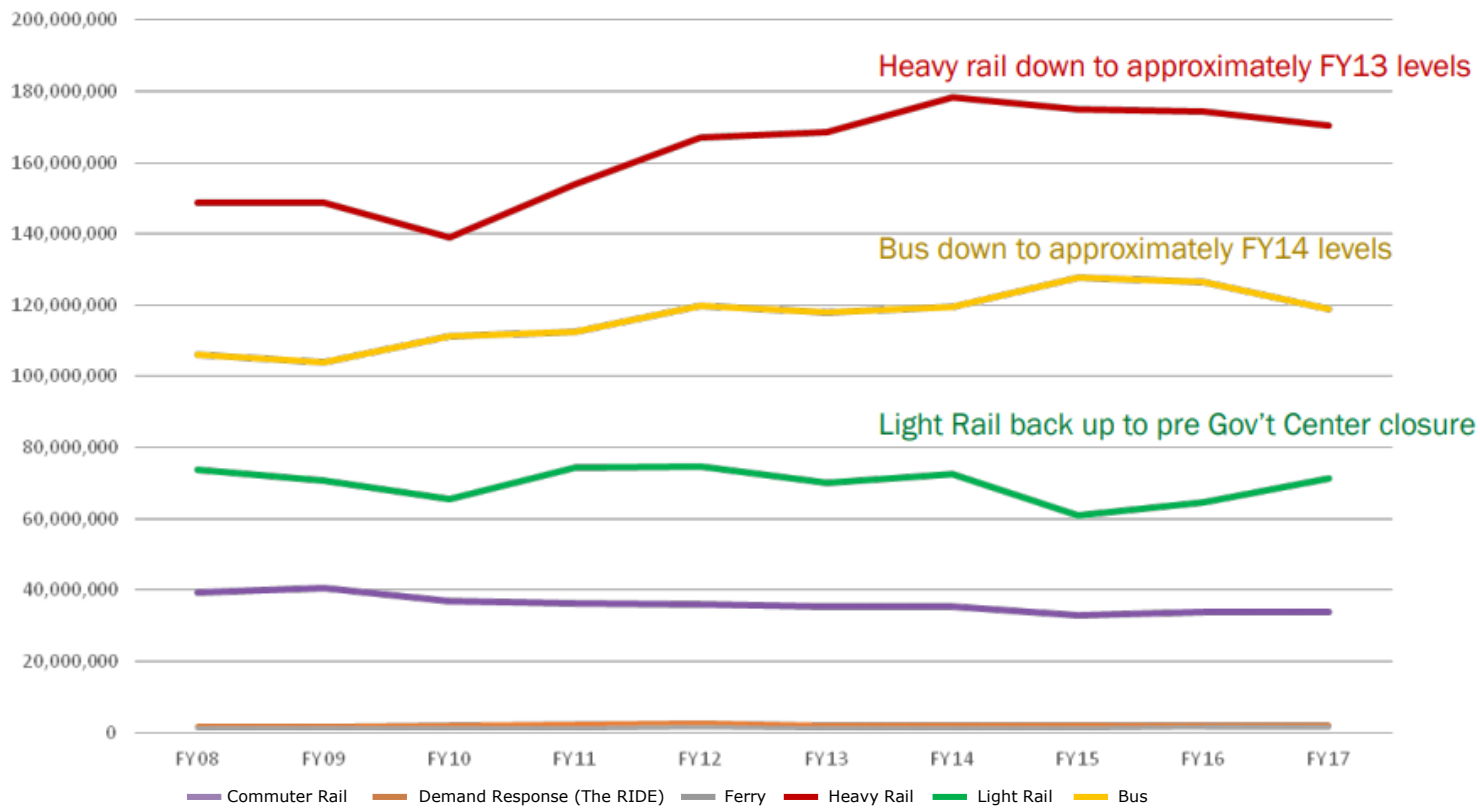


1. Bloomberg. (2018). *The Outlook for Public Transit Isn't All That Bad*. <https://www.bloomberg.com/view/articles/2018-04-09/the-outlook-for-public-transit-isn-t-all-that-bad>

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- Summing the benefits associated with travel time savings, travel cost, crashes avoided, and reduced vehicular emissions, MBTA transit services provide an approximately \$11.4 billion benefit to the greater Boston region annually – the annual MBTA budget is approximately \$2 billion, demonstrating a significant return on investment.¹
- However, MBTA ridership, along with most other transit agencies in the U.S., is trending down.²

Ridership Reported to National Transit Database by Mode since CharlieCard Implementation¹



National Transit Database

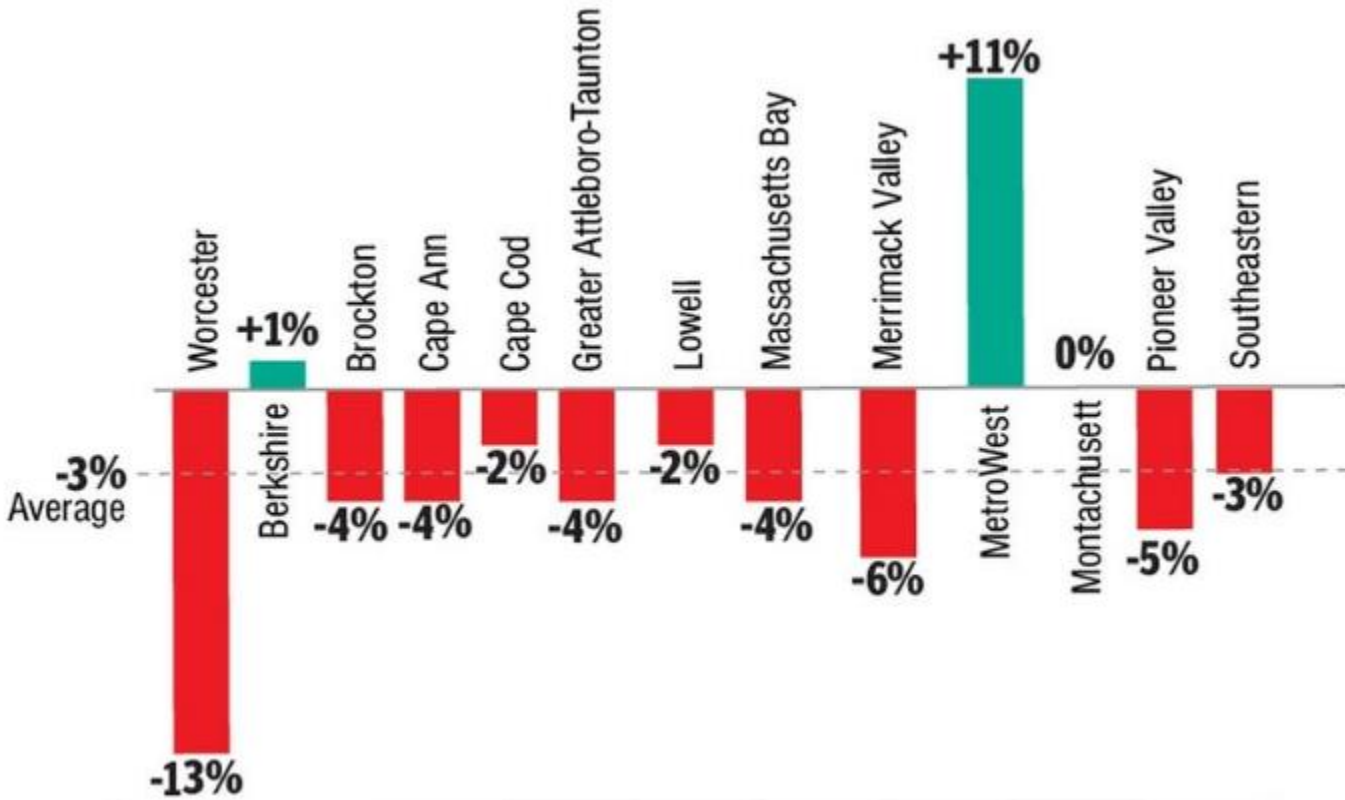
1. A Better City. (2018). *The Transportation Dividend: Transit Investments and the Massachusetts Economy*. <http://www.abettercity.org/assets/images/Transportation%20Dividend%20-%20FINAL%20-%202012918.pdf>

2. MBTA. (2017). *MBTA Ridership Update FY15-FY17*. <https://cdn.mbta.com/sites/default/files/fmcb-meeting-docs/2017/october/2017-10-23-fmcb-ridership-update-fy15-fy17-corrected.pdf>

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- [Almost all of Massachusetts' Regional Transit Authorities \(RTAs\) are experiencing ridership declines, in line with nationwide trends.](#)¹

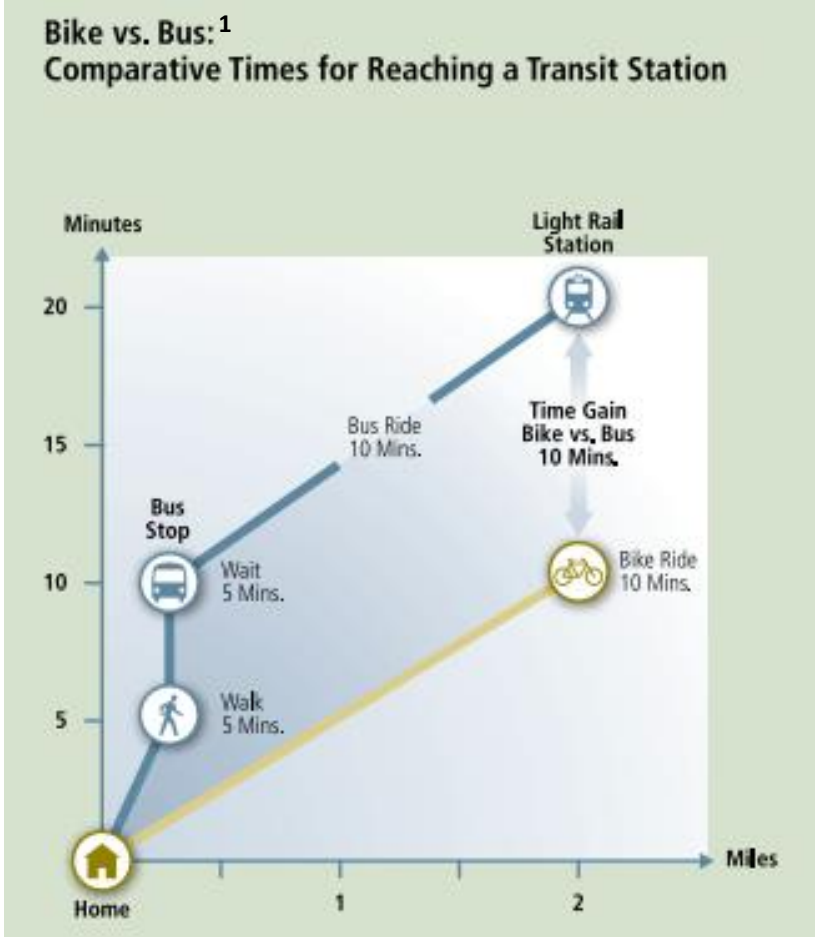
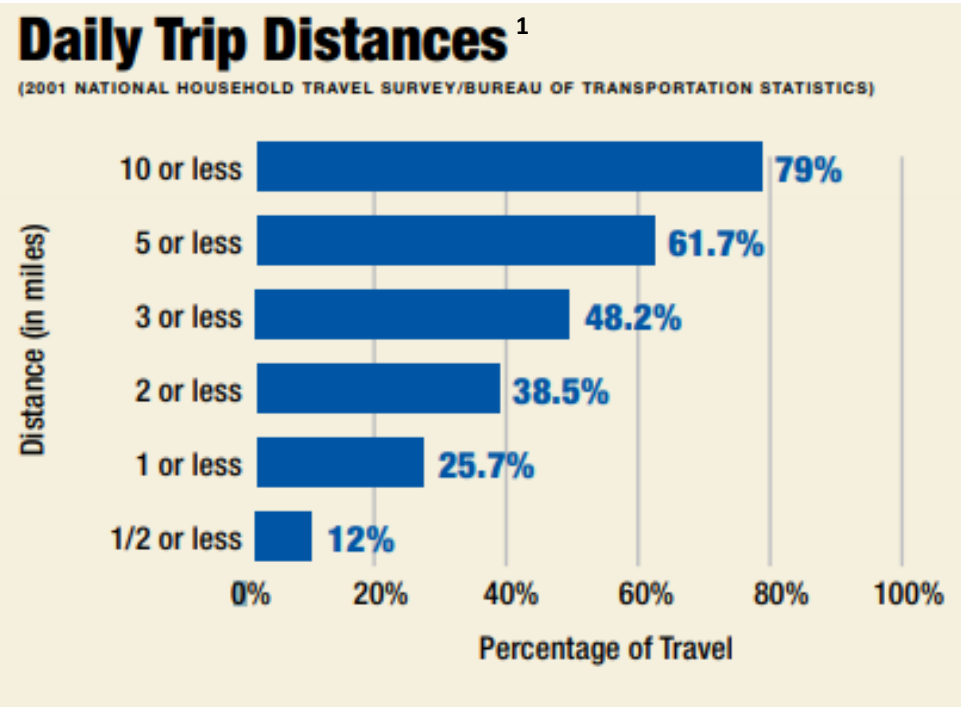
Percentage Change of Fixed-Route Ridership for the First Three Quarters of FY17 Compared to FY18 for Massachusetts RTAs¹



1. Telegram (Worcester, MA). (2018). *WRTA ridership decline is worst in the US.* <http://www.telegram.com/news/20180626/wrta-ridership-decline-is-worst-in-us>

2. Active transportation and micro-mobility are becoming more prevalent.

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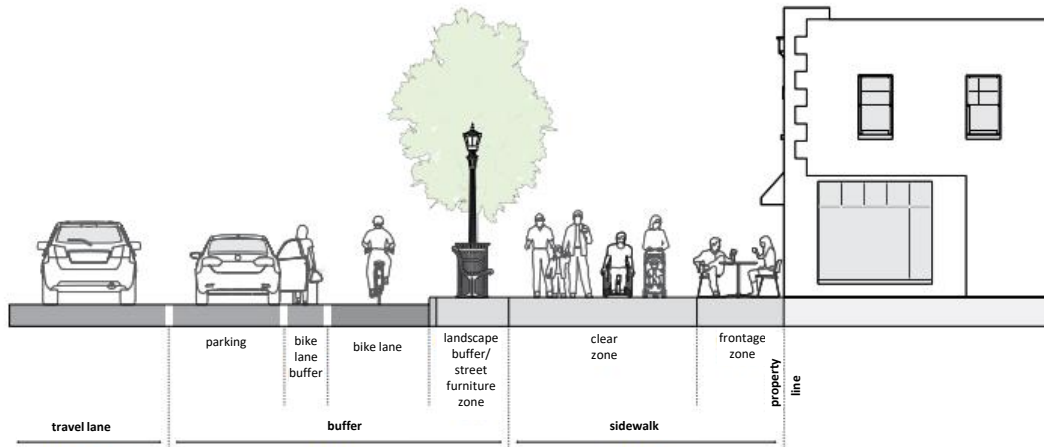


1. AARP. (2013). *Active Transportation for America*. <https://www.aarp.org/livable-communities/learn/transportation-mobility/info-2013/active-transportation-for-america.html>

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- [MassDOT is planning to improve walkability](#)² and [bike networks for communities statewide.](#)³

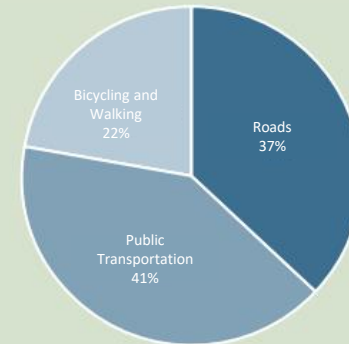
Functional Zones in a Town or Village Center Mixed-Use Environment⁴



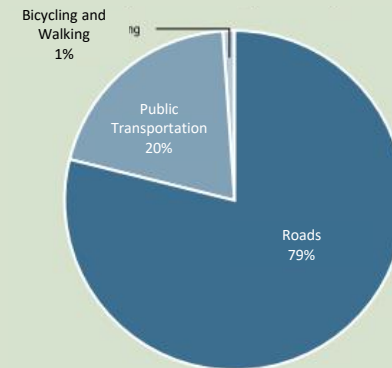
How Americans Would Allocate Transportation Funding¹

81% support "allocation of the dollars toward the expansion and improvement of public transportation, sidewalks, and bike paths in your community." (Margin of error = 3%)

How Respondents Would Allocate Transportation Funding



How Transportation Funding is Currently Allocated

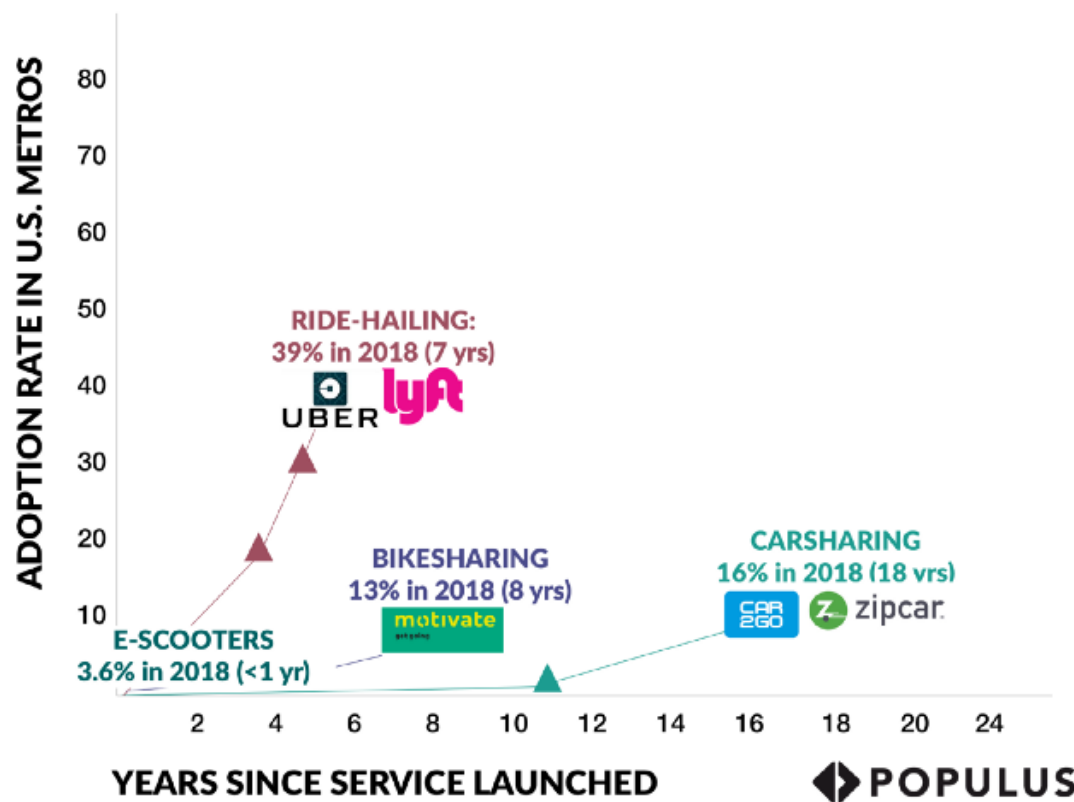


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2. Commonwealth of Massachusetts. (2018). *Pedestrian Plan*. <https://www.mass.gov/service-details/pedestrian-plan>
3. Commonwealth of Massachusetts. (2018). *Bicycle Plan*. <https://www.mass.gov/service-details/bicycle-plan>
4. MassDOT. (2018). *Municipal Resource Guide for Walkability* https://www.mass.gov/files/documents/2018/09/17/MunicipalResourcesGuideForWalkability_2018-08-24.pdf

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MOBILITY SERVICE ADOPTION IS SPREADING FASTER²



Sources: Populus Groundtruth; Clewlow & Mishra, 2017; Clewlow, 2016

1. Blue Bikes. (2018). *Media Kit*. <https://www.bluebikes.com/about/media-kit>

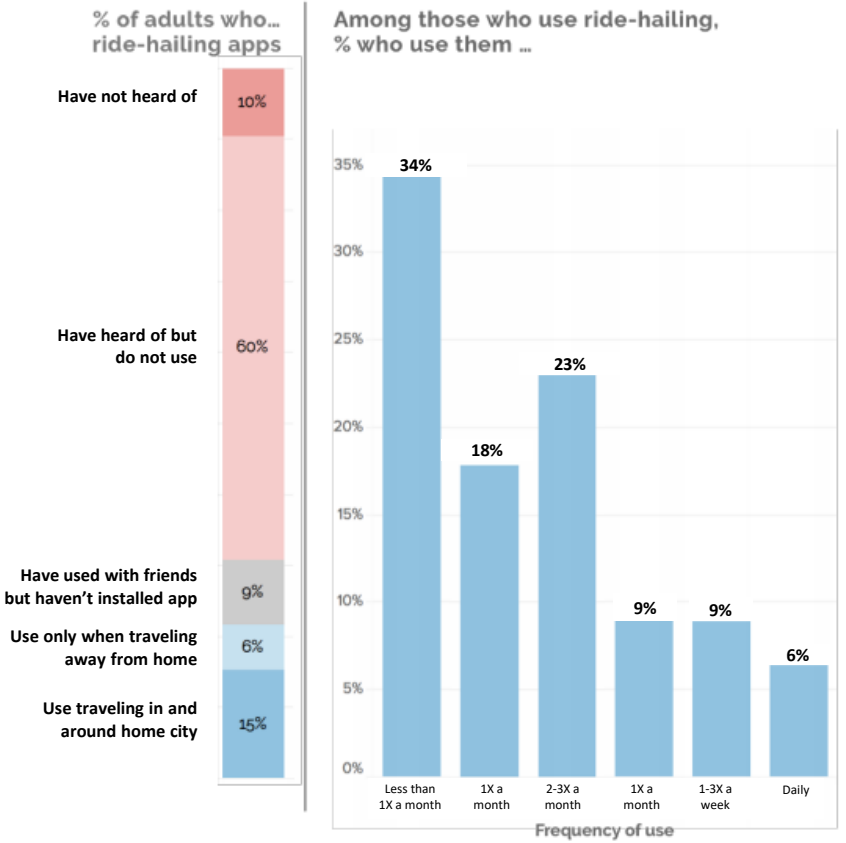
2. Populus. (2018). *The Micro-Mobility Revolution*. <https://medium.com/populus-ai/the-micro-mobility-revolution-95e396db3754>

3. Axios. (2018). *GM and Ford push into 2-wheeled transportation*. <https://www.axios.com/gm-ford-going-beyond-cars-with-scooters-and-bikes-6c625bd5-35b1-4b4e-a4f5-fea3d1988a28.html>

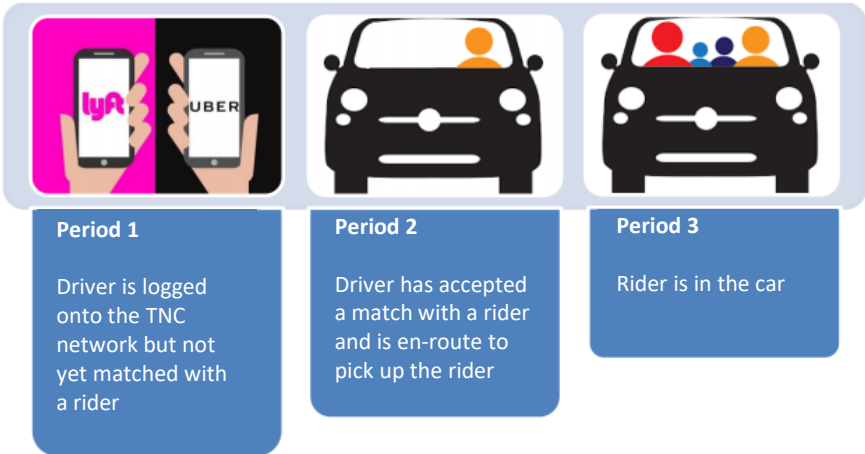
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- [In major cities, 21 percent of adults have used ride-hailing services, but only one-quarter use them on a weekly basis.](#)²

Adoption and Utilization of Ride-Hailing²



Three Periods of a TNC Transaction³



1. American Association of Motor Vehicle Administrators (AAMVA). (2018). *Transportation Network Companies*. <https://www.aamva.org/about-aamva/>

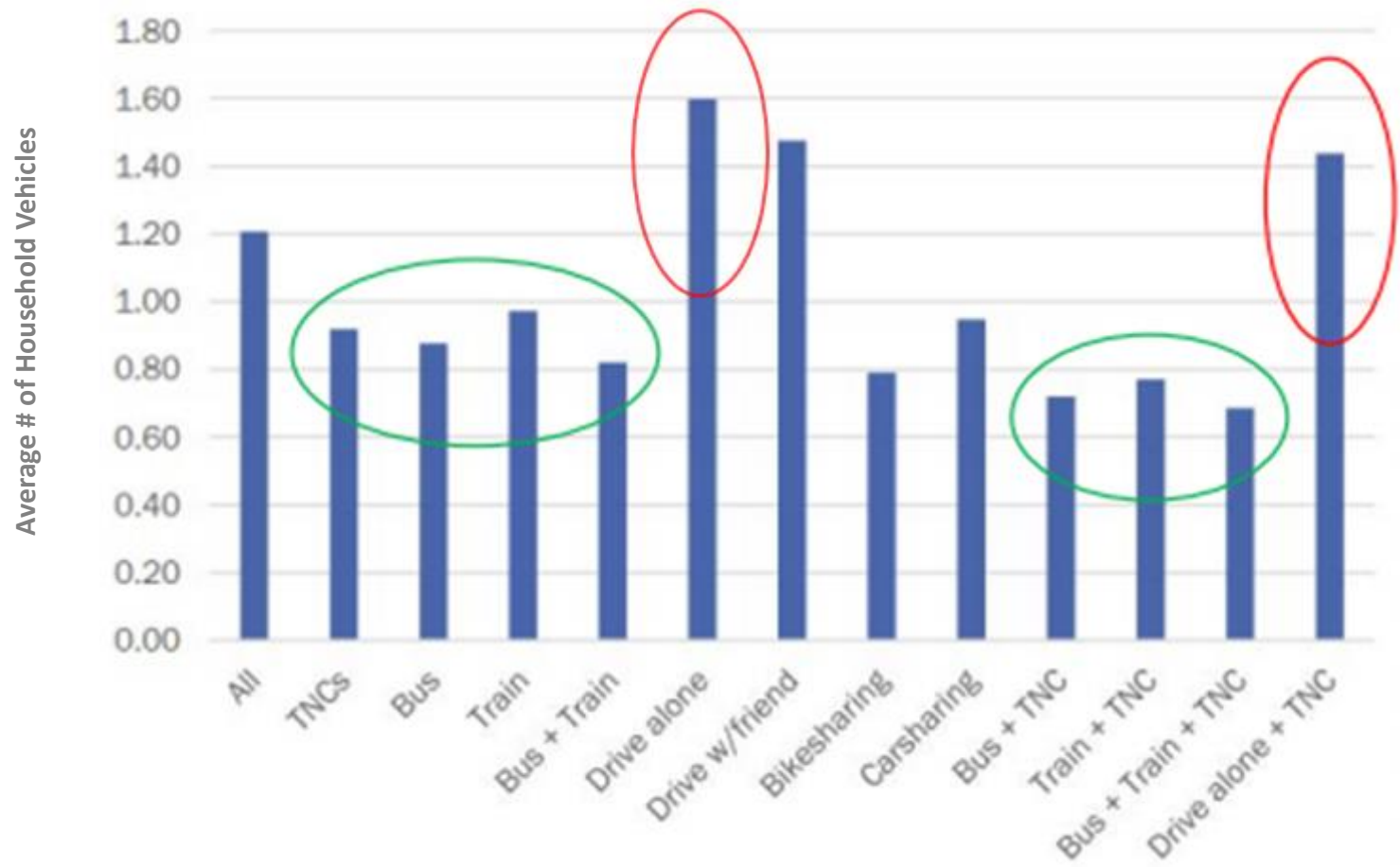
2. Institute of Transportation Studies, University of California, Davis. (2017). *Disruptive Transportation: The Adoption, Utilization, and Impacts of Ride-Hailing in the United States*. https://itspubs.ucdavis.edu/wp-content/themes/ucdavis/pubs/download_pdf.php?id=2752

3. Commonwealth of Massachusetts. (2018). *Ride for Hire Task Force*. <https://www.mass.gov/orgs/ride-for-hire-task-force>

3. The use of transportation network companies (TNCs) is growing.

- [Frequent TNC users in the U.S. have lower household vehicle ownership.](#)¹

Average Household Vehicles by Frequently Used Mode (weekly)¹



1. TRB. (2018). *Who's Riding TNCs and What Does It Mean for Public Agencies?* <http://onlinepubs.trb.org/onlinepubs/webinars/180515.pdf>

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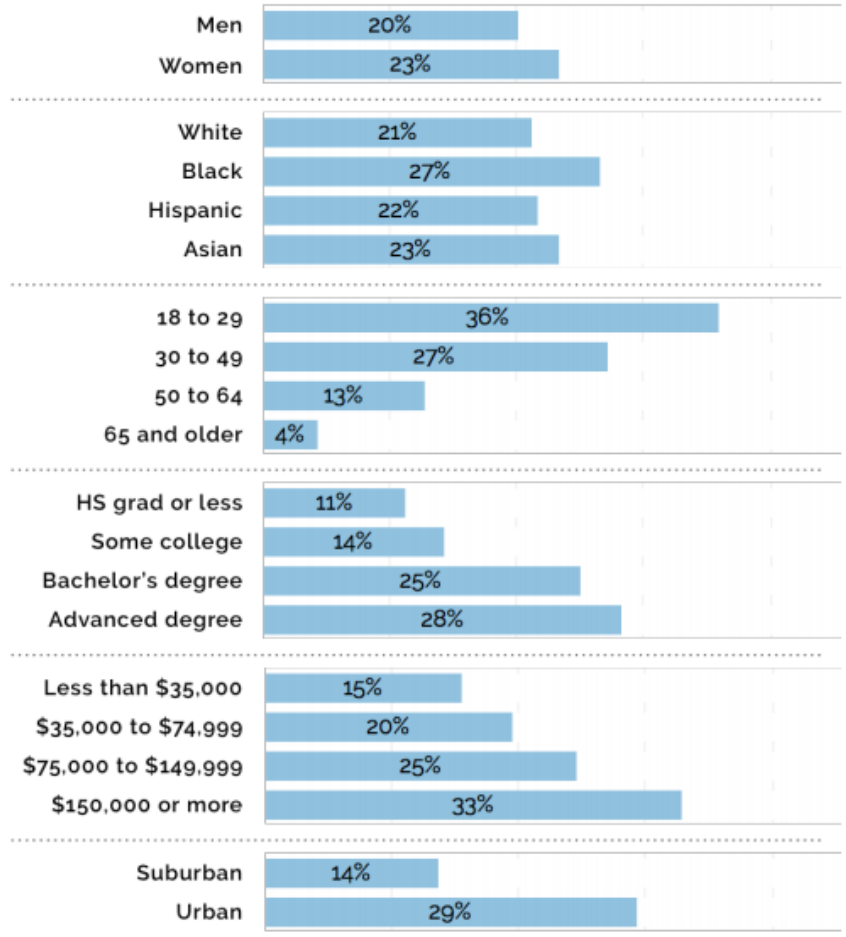
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- [TNC riders in the U.S. are on average younger and have higher education levels and higher average incomes.](#)²

Demographics for TNC Users¹

	MARTA		NJT		WMATA	BART ¹⁷	
	Users	Non-users	Users	Non-users	Overall	Users	Non-users
Male (%)	54	53	51	46	50	49	54
Mean age (yrs.)	31	38	36	43	41	--	--
Mean income (\$)	35,900	30,200	104,000	77,000	125,900	--	--
Ethnicity: Hispanic (%)	10	6	16	18	6	16	14
Race: White (%)	24	13	57	52	73	58	54
Race: Black (%)	71	87	12	21	15	9	14
Race: Asian/Pac. Isl. (%)	4	0	15	9	8	27	26
Race: Mixed (%)	--	--	6	6	4	8	7
Race: Other (%)	4	0	10	12	2	5	6
Has disability (%)	--	--	--	--	3	4	8
Has smartphone (%)	94	85	--	--	--	98	85

MARTA = Metropolitan Atlanta Rapid Transit Authority
NJT = New Jersey Transit
WMATA = Washington Metropolitan Area Transit Authority
BART = Bay Area Rapid Transit

Ride-Hailing Adoption Rates by Demographic and Geography²

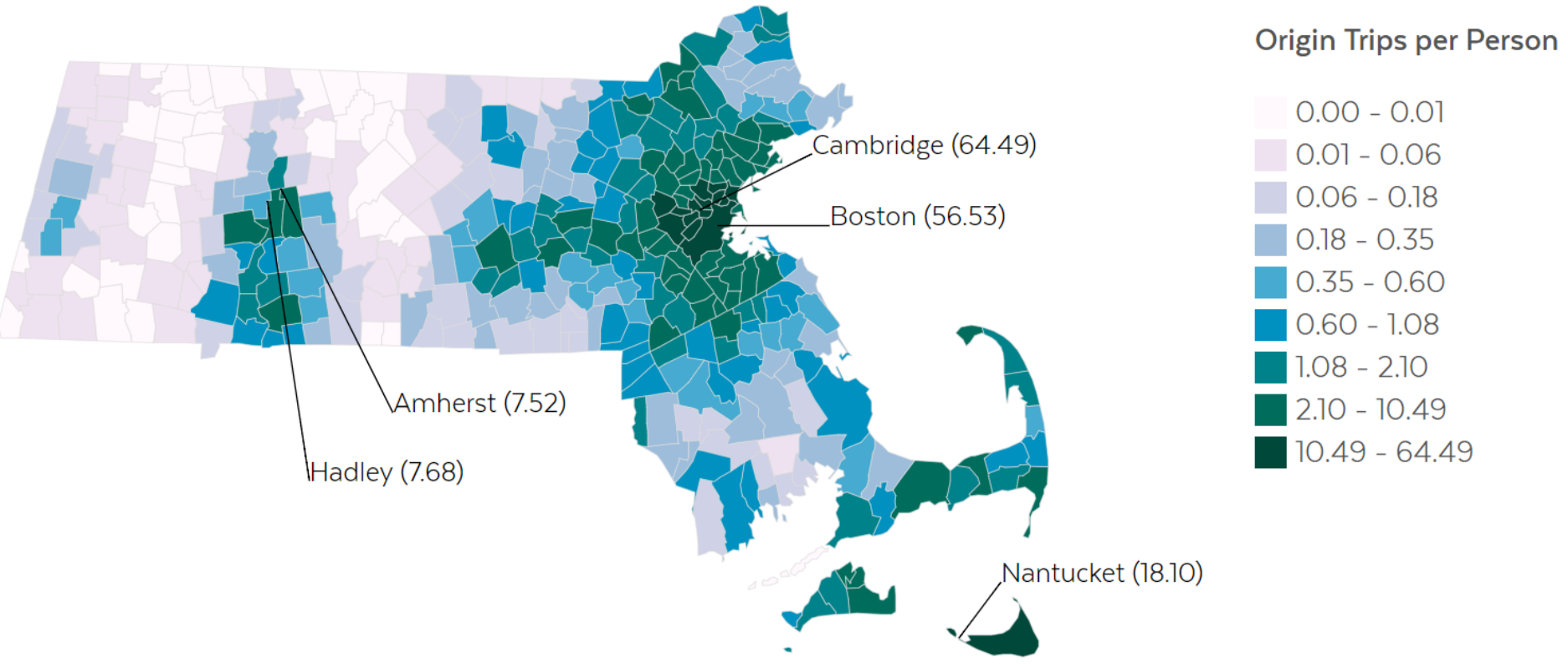


1. TRB. (2018). *Who's Riding TNCs and What Does It Mean for Public Agencies?* <http://onlinepubs.trb.org/onlinepubs/webinars/180515.pdf>
 2. Institute of Transportation Studies, University of California, Davis. (2017). *Disruptive Transportation: The Adoption, Utilization, and Impacts of Ride-Hailing in the United States.* https://itspubs.ucdavis.edu/wp-content/themes/ucdavis/pubs/download_pdf.php?id=2752

3. The use of transportation network companies (TNCs) is growing.

- [In 2017, Massachusetts saw 64.8 million ride-hailing trips...](#)¹
- [...compared to 408 million trips on public transit and 5.9 million by taxi...](#)¹
- [...however these trips are not evenly distributed; ride-hailing trips accounted for nearly one out of every 25 trips made in Boston, but barely more than one out of every 100 trips over the entire MAPC region.](#)²

Overall Travel Mode Share of Ride-Hailing Trips Concluding in Greater Boston Region Municipalities³

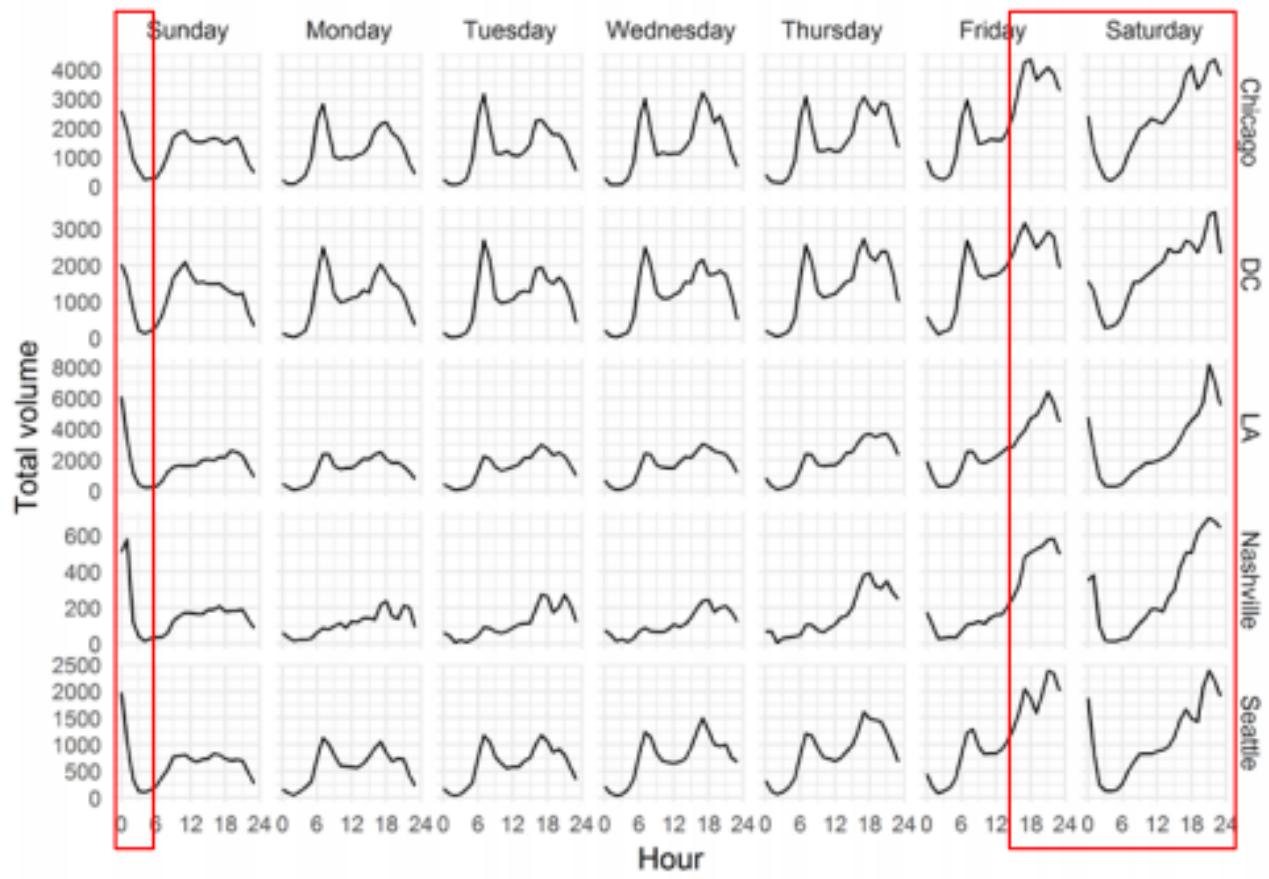


1. Commonwealth of Massachusetts. (2018). *Ride for Hire Task Force*. <https://www.mass.gov/orgs/ride-for-hire-task-force>
2. MAPC. (2018). *Share of Choices: Further Evidence of the ride-hailing effect in Metro Boston and Massachusetts*. <https://www.mapc.org/farechoices/>
3. Department of Public Utilities Transportation Network Company Division. (2018). *Rideshare in Massachusetts*. <http://massgis.maps.arcgis.com/apps/MapSeries/index.html?appid=f7efe80f5d3b49b6b7fc8d2d65469efa>

3. The use of transportation network companies (TNCs) is growing.

- [In Massachusetts, almost half of ride-hailing trips would have been completed on transit if TNCs were not available, and 30 percent of those trips occurred during rush hour.](#)¹
- [Weekend nights dominate usage, although rush hour usage varies across locations in the U.S.](#)²

TNC Ridership by Time of Week in Select Cities²

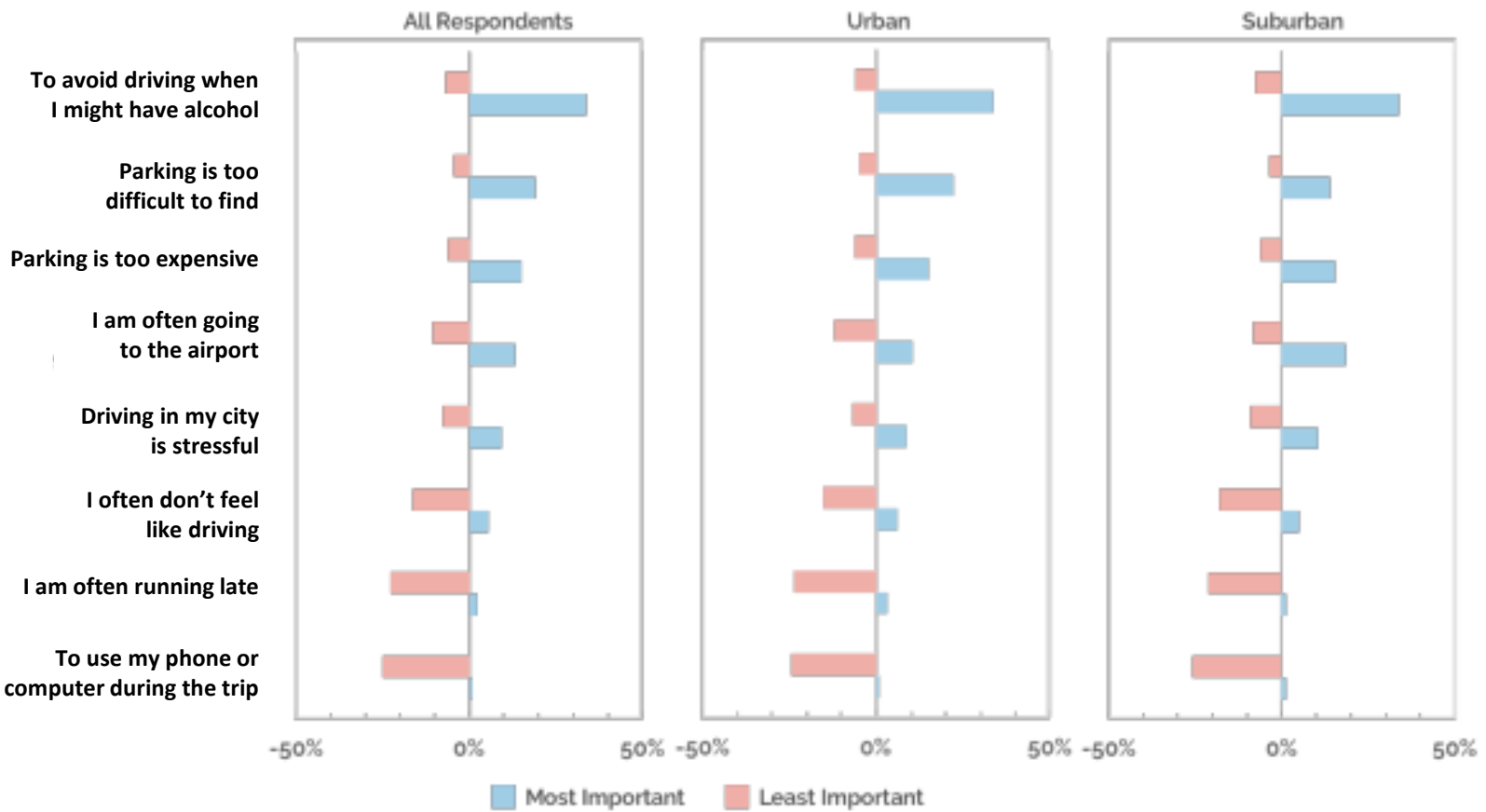


1. MAPC. (2018). *Fare Choices: A Survey of Ride-Hailing Passengers in Metro Boston*. <https://www.mapc.org/farechoices/>
2. TRB. (2018). *Who's Riding TNCs and What Does It Mean for Public Agencies?* <http://onlinepubs.trb.org/onlinepubs/webinars/180515.pdf>

3. The use of transportation network companies (TNCs) is growing.

- [This trend in usage is likely because parking concerns and alcohol consumption are two of the top reasons for using TNCs in the U.S.](#)¹

Reasons for Using Ride-Hailing Services Instead of Driving Oneself¹



1. Institute of Transportation Studies, University of California, Davis. (2017). *Disruptive Transportation: The Adoption, Utilization, and Impacts of Ride-Hailing in the United States.* https://itspubs.ucdavis.edu/wp-content/themes/ucdavis/pubs/download_pdf.php?id=2752

3. The use of transportation network companies (TNCs) is growing.

- [Massachusetts signed legislation in 2016 regulating and taxing TNCs.](#)¹
- [Massachusetts assesses TNCs a \\$0.20 per-ride fee on every trip started in the state.](#)²
- [After factoring in the impact on transit ridership and the per-ride TNC fee, there was about \\$10 million net revenue loss to the state’s transportation system in 2017 due to TNCs.](#)³

Revenue of Ride-Hailing Trip Fees for Massachusetts Communities²

Community	Trips Started	Fees
Lawrence	350,752	\$35,075
Salem	296,482	\$29,648
Methuen	104,578	\$10,457
Haverhill	104,076	\$10,407
Peabody	177,346	\$17,734
Danvers	87,187	\$8,718
Beverly	121,950	\$12,195
Andover	85,159	\$8,515
North Andover	55,409	\$5,540
Swampscott	51,522	\$5,152
Marblehead	43,184	\$4,318
Newburyport	26,196	\$2,619
Middleton	11,809	\$1,180

1. Commonwealth of Massachusetts. (2018). *Ride for Hire Task Force*. <https://www.mass.gov/orgs/ride-for-hire-task-force>

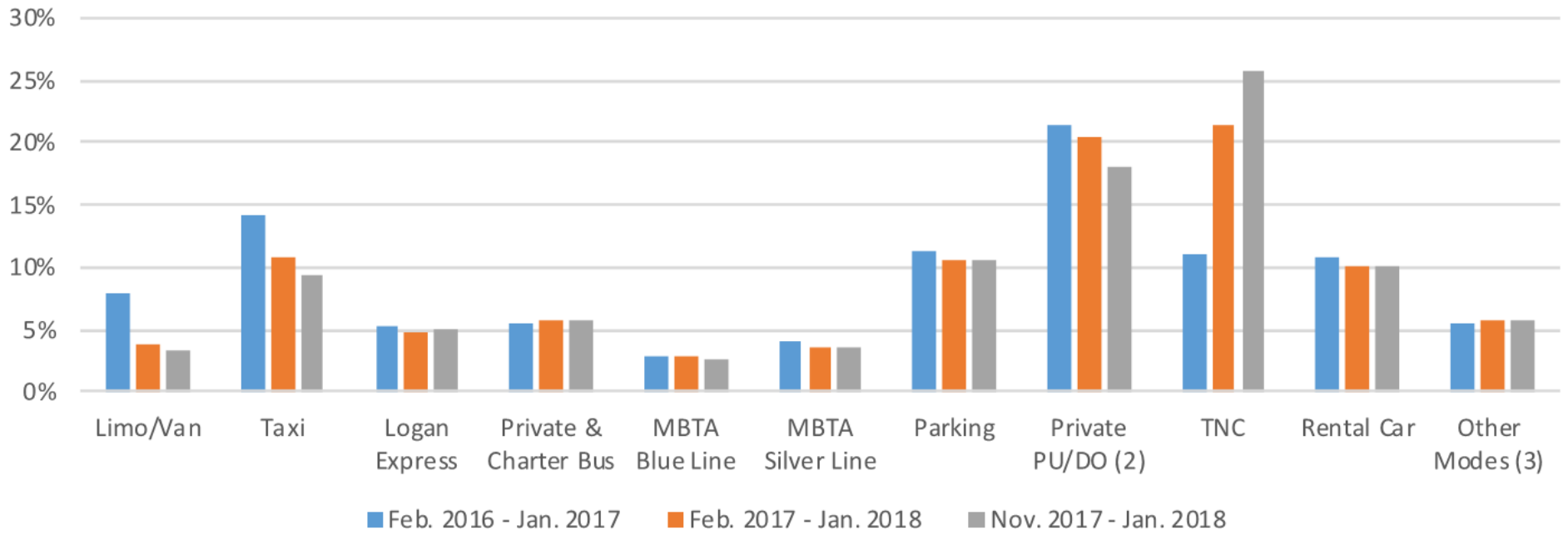
2. Eagle Tribune (North Andover, MA). (2018). *Massachusetts cities, towns make thousands from ride-hailing fees*. http://www.eagletribune.com/news/merrimack_valley/massachusetts-cities-towns-make-thousands-from-ride-hailing-fees/article_c73f7e5e-8057-11e8-b64b-dfe1e0c5140c.html

3. MAPC. (2018). *Fare Choices: A Survey of Ride-Hailing Passengers in Metro Boston*. <https://www.mapc.org/farechoices/>

3. The use of transportation network companies (TNCs) is growing.

- TNCs are rapidly gaining mode share at Logan Airport.¹
- [TNCs generally do not share their data freely; however, legislatures and public agencies may mandate that they provide some of the data.](#)²

Logan Air Passenger Ground Access Mode Share Estimates, Combined Pick-Ups and Drop-Offs¹

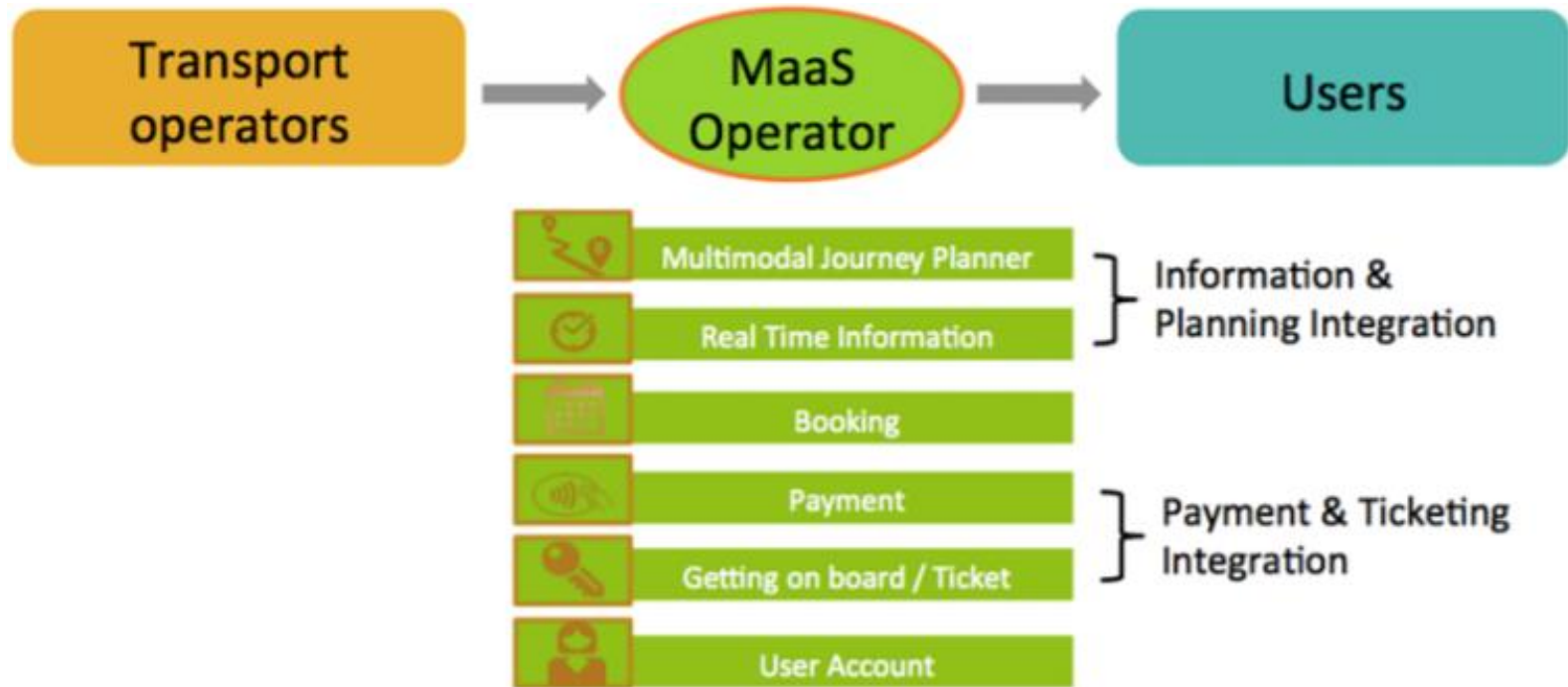


1. Massachusetts Port Authority. (2018). *Transportation Network Company (TNC) Operations at Logan International Airport*.
 2. ITProPortal. (2018). *Does Mobility as a Service hold the answer to the future of transport?* <https://www.itproportal.com/features/does-mobility-as-a-service-hold-the-answer-to-the-future-of-transport/>

4. Mobility as a Service (MaaS) looks to change how people plan, pay for, and take trips.

- MaaS provides mobility options without requiring the user to own the means of transportation (ride-hailing, bike-sharing etc.), though some definitions go further specifying it as the integration of various forms of transport services into a single mobility service that is accessible on demand (i.e. use one app to plan and pay for a door-to-door trip using multiple modes – both public and private).¹

Functions of MaaS Operator¹



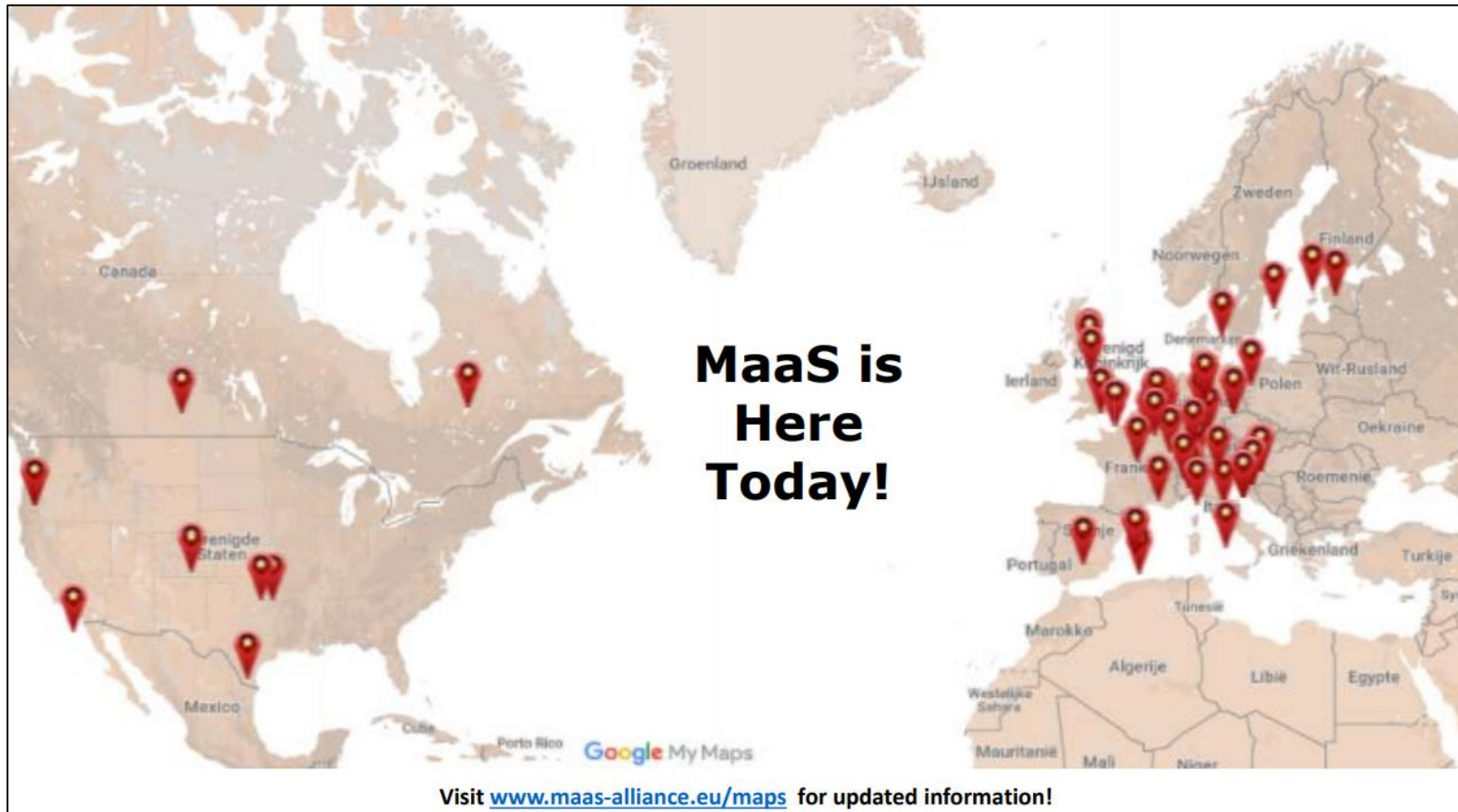
Source: UCL MaaS Lab, 2015

1. MaaS Alliance. (2017). *Guidelines & Recommendations to create the foundations for a thriving MaaS Ecosystem*. https://maas-alliance.eu/wp-content/uploads/sites/7/2017/09/MaaS-WhitePaper_final_040917-2.pdf

4. Mobility as a Service (MaaS) looks to change how people plan, pay for, and take trips.

- [Integrated MaaS is available in some forms today. Europe leads the U.S. in adoption.](#)¹

Locations of Existing MaaS Providers¹

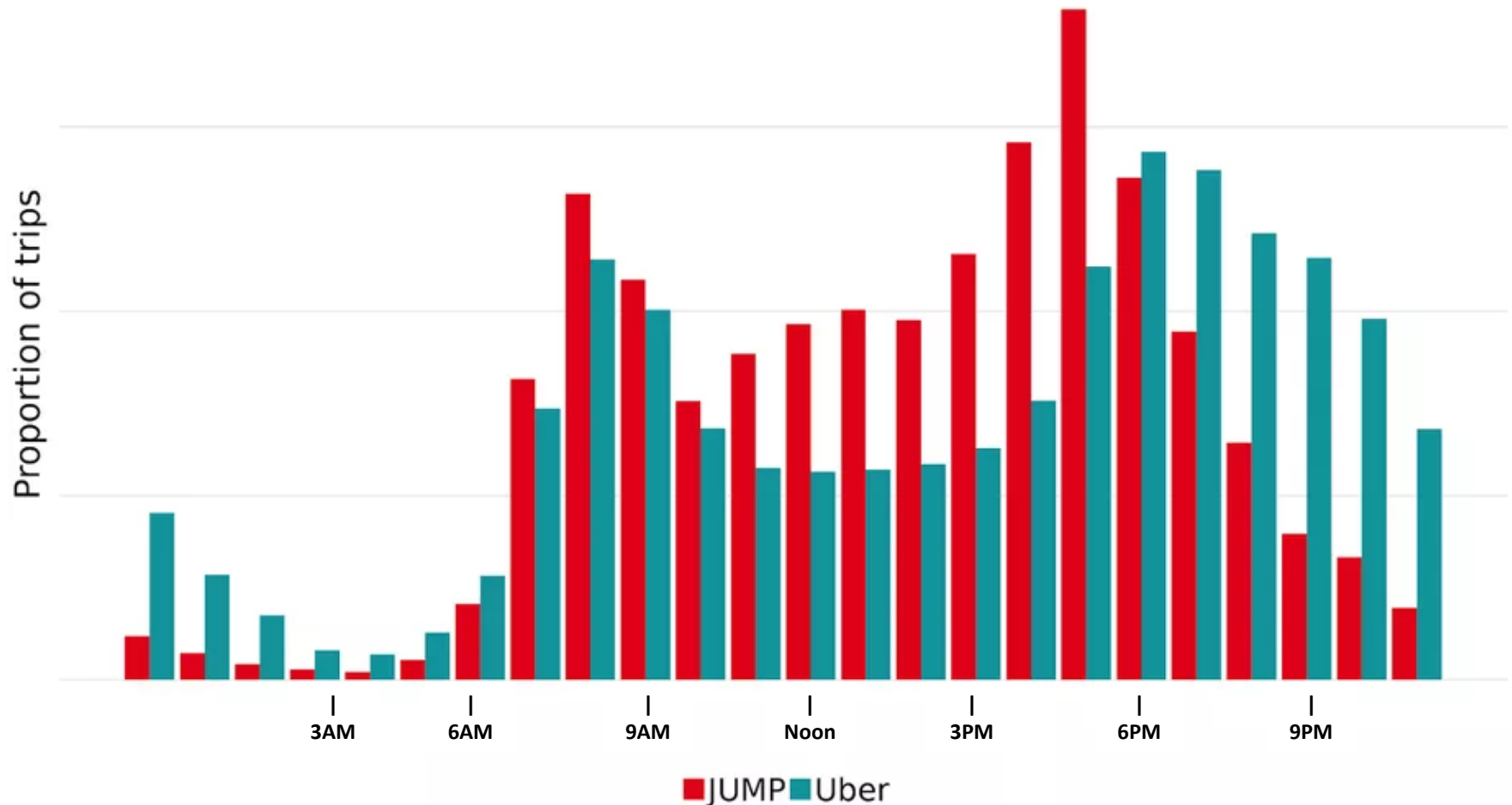


1. TRB. (2018). *Nail it or Fail it: Building a Successful Mobility as a Service Story*. <http://onlinepubs.trb.org/onlinepubs/webinars/180618.pdf>

4. Mobility as a Service (MaaS) looks to change how people plan, pay for, and take trips.

- [Even as ride-hailing grows, TNCs are beginning to invest in micro-mobility options, which are becoming more popular, especially as travelers are trying to avoid rush-hour congestion.](#)¹

Distribution of Trips by Time of Day for Jump (Electric Bike-share) and Uber¹



1. Curbed. (2018). Scooters and e-bikes begin to replace car trips. <https://www.curbed.com/2018/7/24/17604772/uber-lime-jump-bikes-scooters>

4. Mobility as a Service (MaaS) looks to change how people plan, pay for, and take trips.

- [Transit agencies see MaaS as a way to increase the mobility options they can offer to travelers \(e.g., bike-share, micro-transit\).](#)¹
- [Founder of MaaS-provider Whim \(the “Netflix of transportation” based in Finland\) wants to “prove that we can beat the service level of a car. Or at least be comparable to it.”](#)²

Potential for MaaS in Different Geographical Scope³

Cities	<ul style="list-style-type: none">• Objectives: reduce the use of private cars (causing problems related to congestion, parking and emissions and air quality)• Based on: existing public transport, extended with rental and shared cars and bikes etc
Suburban areas	<ul style="list-style-type: none">• Objectives: No need for a second car, first mile & last mile accessibility• Based on: park & ride services, on-demand transport and other services connecting suburban to city transport services
Rural areas	<ul style="list-style-type: none">• Objectives: increase efficiency, maintain sufficient service level, improve accessibility• Based on: demand-responsive transport, taxis, buses and connections to long-haul transport, car-pooling: parcel deliveries, library services, grocery & medicine distribution as add-on services
Long-haul transport	<ul style="list-style-type: none">• Objectives: offer easy all-in-one packages• Based on: long-haul transport services (incl. aviation), ride-sharing: accommodation, event tickets as add-ons

1. Mass Transit. (2018). *Transit Trends for 2018 and Beyond*. <https://www.masstransitmag.com/blog/12389128/transit-trends-for-2018-and-beyond>

2. Deloitte Review. (2017). *The rise of mobility as a service*. <https://www2.deloitte.com/content/dam/Deloitte/nl/Documents/consumer-business/deloitte-nl-cb-ths-rise-of-mobility-as-a-service.pdf>

3. MaaS Alliance. (2017). *Guidelines & Recommendations to create the foundations for a thriving MaaS Ecosystem*. https://maas-alliance.eu/wp-content/uploads/sites/7/2017/09/MaaS-WhitePaper_final_040917-2.pdf

4. Mobility as a Service (MaaS) looks to change how people plan, pay for, and take trips.

- [Uber is adding bike-sharing, car-sharing, transit start-ups, and, more recently, scooters in an effort to expand mobility options.](#)²
- [While micro-transit start-ups have not always panned out, they may have a place as part of a bigger system like MaaS.](#)³



<https://www.bloomberg.com/news/articles/2018-07-09/uber-will-rent-scooters-through-its-app-in-partnership-with-lime>

1. CityLab. (2018). *Uber Pivots to On-Demand Everything*. <https://www.citylab.com/transportation/2018/04/uber-pivots-to-on-demand-everything/557528/>
2. Bloomberg. (2018). *Uber Is Building Its Own Scooter to Compete in Frenzy*. <https://www.bloomberg.com/news/articles/2018-08-30/uber-embraces-bikes-scooters-as-the-future-of-urban-transport>
3. CityLab. (2017). *Bridj Is Dead, But Microtransit Isn't*. <https://www.citylab.com/transportation/2017/05/bridj-is-dead-but-microtransit-isnt/525156/>

5. New trends and technology will impact congestion, as will attitudes towards ride and vehicle sharing.

- [Many studies find TNCs are already contributing to congestion.](#)¹
- [TNCs look to reduce car ownership, but their use may reduce congestion only if rides are shared, and “deadhead” miles may increase congestion.](#)²
- [Consumers interested in vehicle subscription services still see personal vehicles as their primary mode of transportation.](#)³

Passenger Hailing a Ride from a TNC⁴



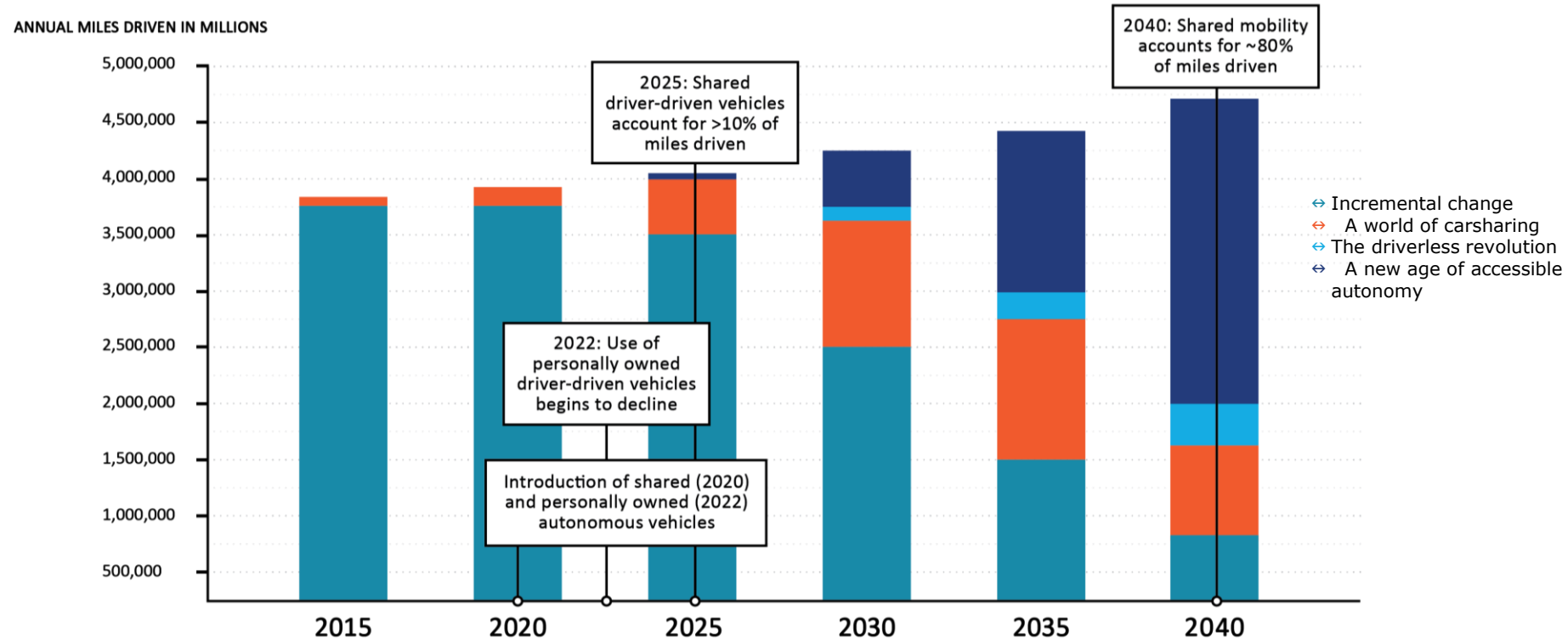
1. Chicago Tribune. (2018). *Studies are increasingly clear: Uber and Lyft congest cities.* <http://www.chicagotribune.com/bluesky/technology/ct-uber-lyft-congestion-20180225-story.html>
2. Government Technology. (2018). *Uber, Lyft and Other Mobility Options are Shaking Up Parking.* <http://www.govtech.com/fs/Uber-Lyft-and-Other-Mobility-Options-Shaking-Up-Parking.html>
3. IBM Institute for Business Value. (2016). *A new relationship—people and cars: How consumers around the world want cars to fit their lives.* <https://www-01.ibm.com/common/ssi/cgi-bin/ssialias?subtype=XB&infotype=PM&htmlfid=GBE03718USEN&attachment=GBE03718USEN.PDF>
4. Culture Map Austin. (2017). *New ride-hailing service arrives in Austin — but it's not like Uber.* <http://austin.culturemap.com/news/innovation/06-01-17-new-ride-hailing-service-pickup-test-capital-metro/>

5. New trends and technology will impact congestion, as will attitudes towards ride and vehicle sharing.

- [The potential of MaaS to reduce congestion is predicated on it minimizing the reliance on private vehicles for transportation. It needs to incorporate public transit and shared rides.](#)¹
- [Automated Vehicles \(AVs\) will play a large role in the adoption of TNCs and MaaS, with predictions of up to 80 percent of miles in Urban areas being completed by shared AVs.](#)²

People Miles Driven, by Future State²

As the population grows and new population segments gain access to mobility, miles driven will likely increase by up to 35%, with shared mobility accounting for the vast majority of them



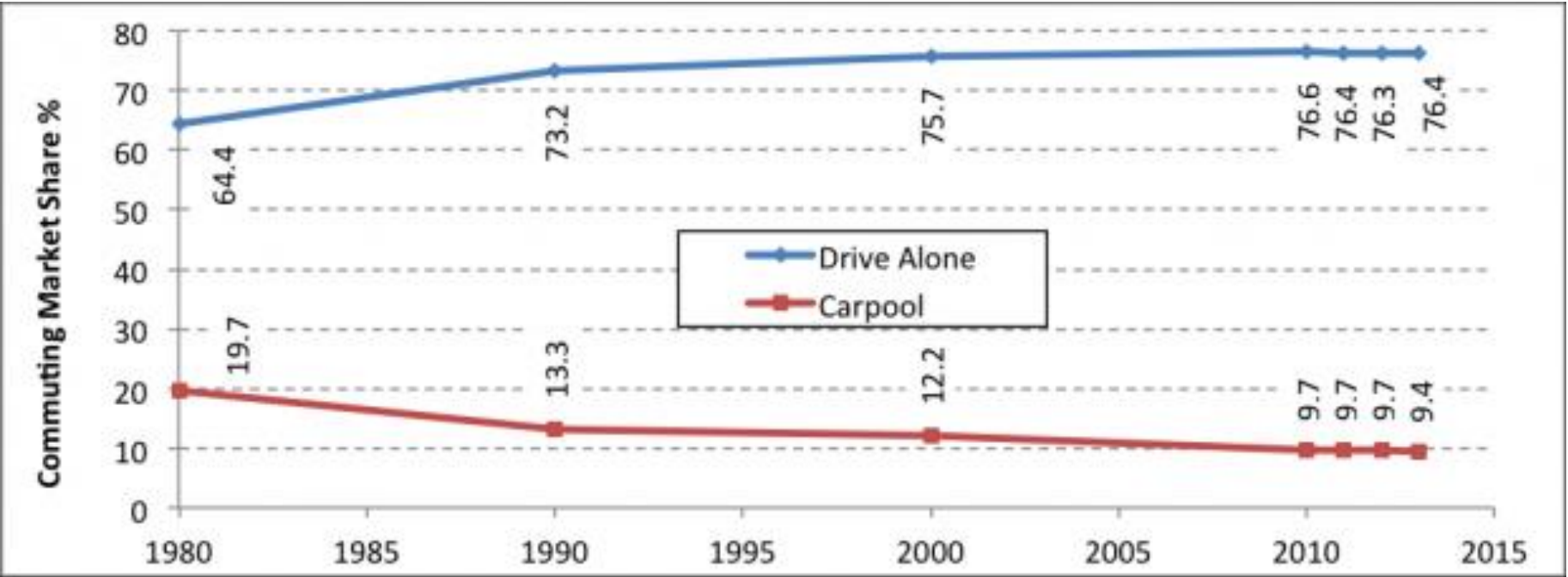
1. ITProPortal. (2018). *Does Mobility as a Service hold the answer to the future of transport?* <https://www.itproportal.com/features/does-mobility-as-a-service-hold-the-answer-to-the-future-of-transport/>

2. Deloitte Review. (2018). *Gearing for change: Preparing for transformation in the automotive ecosystem.* <https://www2.deloitte.com/insights/us/en/focus/future-of-mobility/future-of-mobility-transformation-in-automotive-ecosystem.html>

5. New trends and technology will impact congestion, as will attitudes towards ride and vehicle sharing.

- [Despite the fact that ridesharing is common feature in many predictions for the future, carpooling in the U.S. has been declining in recent years.](#)¹
- [Uber contends that the complexity of carpooling is a major reason it is not more prevalent; services like Uberpool and Lyftline will reduce complexity and have seen significant ridership increases since their launch...](#)²
- [...however, other analysis in the U.S. indicates that most ridepool users are actually drawn away from transit and active transportation modes rather than single occupant trips.](#)³

U.S. Trend for Carpooling and Driving Alone¹



1. Planetizen. (2018). *The Decline of Carpooling—Can App-Based Carpooling Reverse the Trend?* <https://www.planetizen.com/node/74522/decline-carpooling%E2%80%94can-app-based-carpooling-reverse-trend>

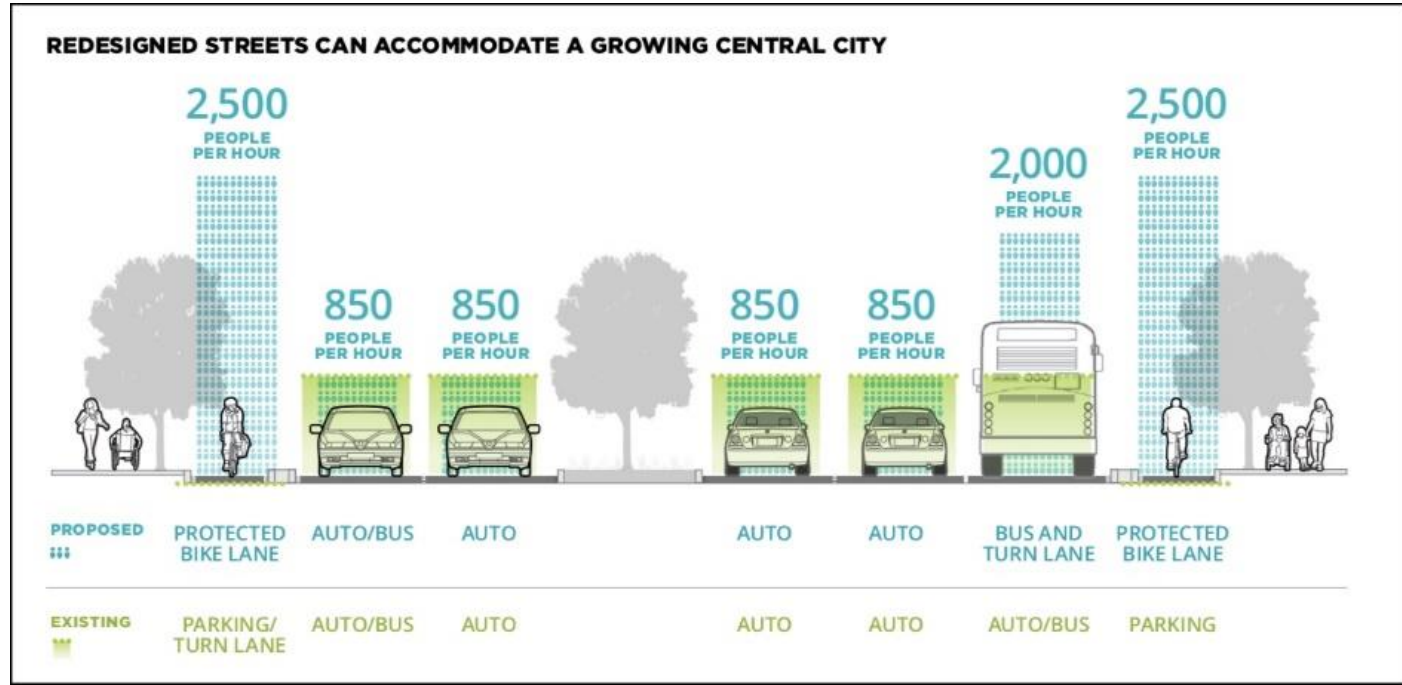
2. Uber Newsroom. (2016). *Slugs on Earth Day.* <https://www.uber.com/newsroom/earth-day-16>

3. Washington Post (2018). *Services like UberPool are making traffic worse, study says.* https://www.washingtonpost.com/news/dr-gridlock/wp/2018/07/25/a-new-study-says-services-like-uberpool-are-making-traffic-worse/?utm_term=.98d7ac55b380

5. New trends and technology will impact congestion, as will attitudes towards ride and vehicle sharing.

- Some cities, such as Portland, are rolling out new approaches to allocating street spaces to reduce congestion – Portland’s effort calls for removing parking spaces in the congested downtown to increase the land area set aside for bus and bike lands from 4 to 6 percent and increase total people-carrying capacity of downtown street by an average of 60 percent.¹

Increasing Street Capacity without Adding Cars¹

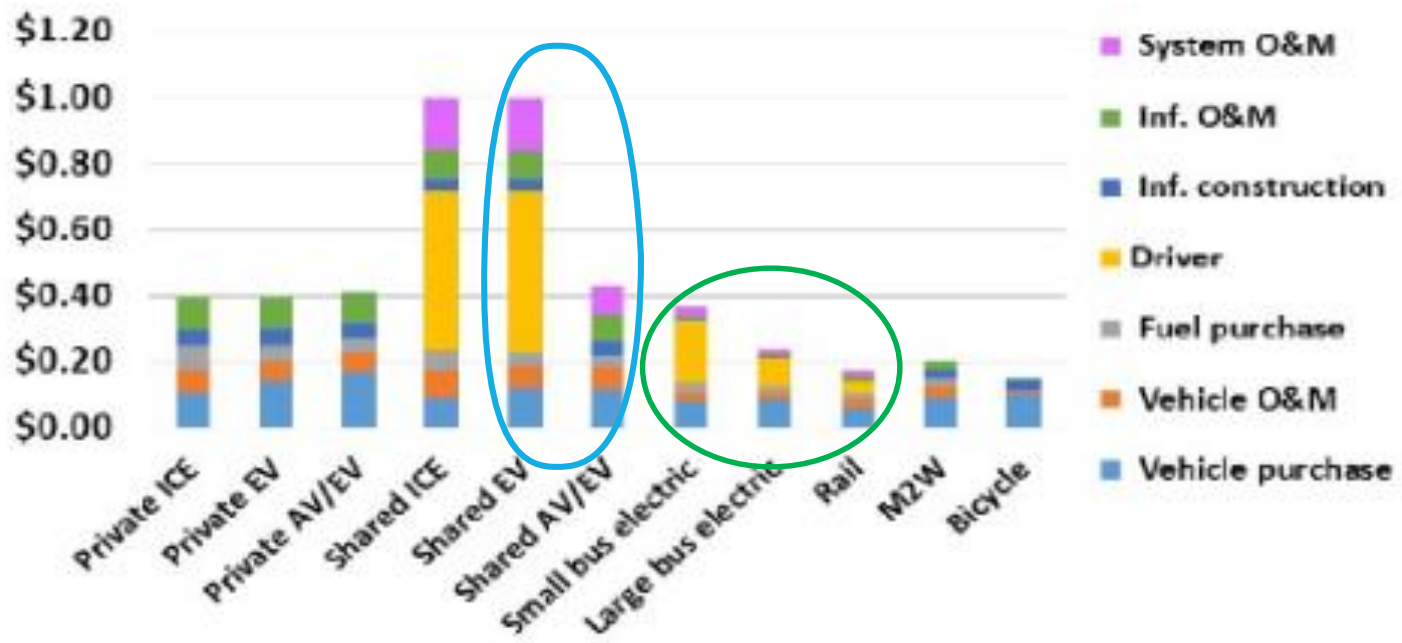


1. Streets Blog. (2018). *Portland Will Grow — But Without Adding Cars*. <https://usa.streetsblog.org/2018/11/16/how-portland-plans-to-grow-its-downtown-without-adding-cars/>

6. These new transportation options potentially play a big role in improving mobility.

- Automation will make TNCs and MaaS more cost-efficient and improve adoption, though public transit will still be the least expensive option for users.¹
- New mobility options are prompting parking professionals to view themselves as “transportation mobility professionals” who figure out how best to use current parking facilities given new trends and technology.²

Automation Decreases Cost of Shared Rides, However Transit Still Costs Less¹ 2030 – United States



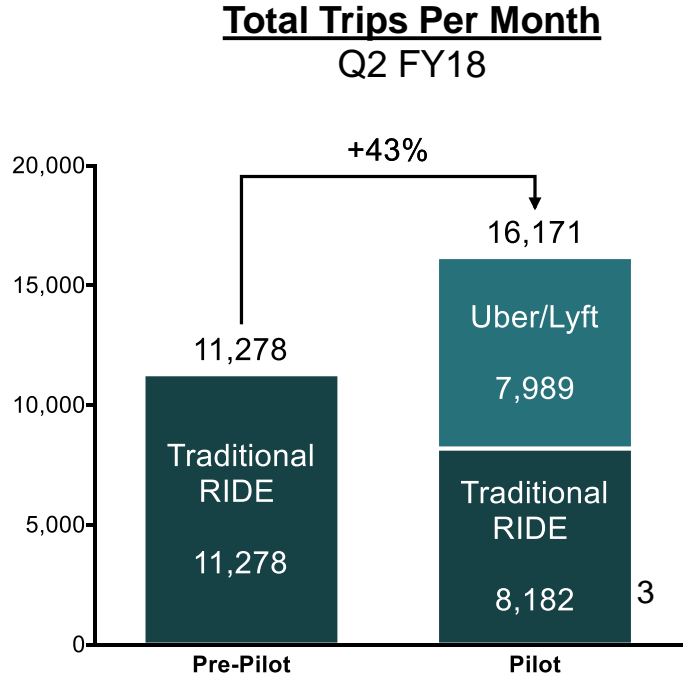
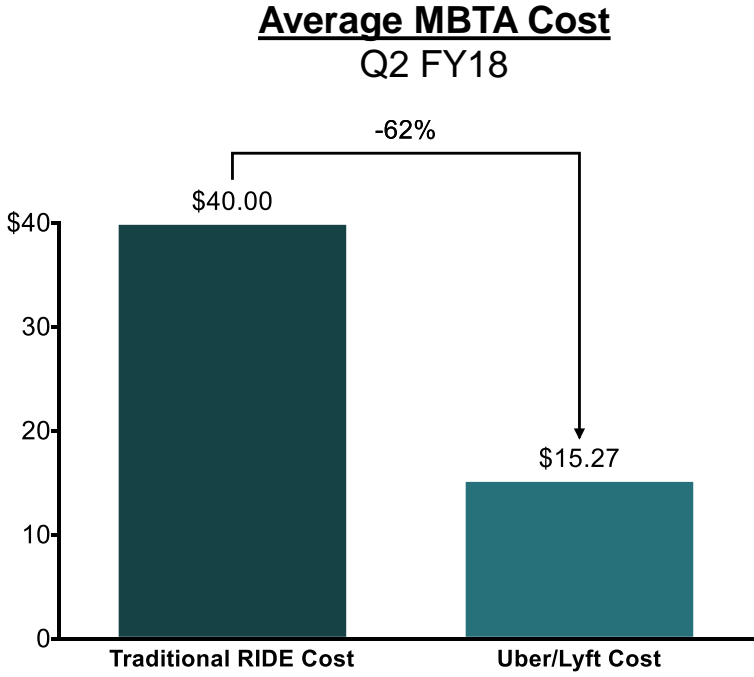
1. Institute of Transportation Studies, University of California, Davis. (2017). *Three Revolutions in Urban Transportation*. https://steps.ucdavis.edu/wp-content/uploads/2017/05/STEPS_ITDP-3R-Report-5-10-2017-2.pdf

2. Government Technology. (2018). *Uber, Lyft and Other Mobility Options are Shaking Up Parking*. <http://www.govtech.com/fs/Uber-Lyft-and-Other-Mobility-Options-Shaking-Up-Parking.html>

6. These new transportation options potentially play a big role in improving mobility.

- [These technologies and innovations are not solely for private transportation, but can improve and reshape public transit as well.](#)¹
- [A rural Ontario town of 36,000 provided 26,700 transit trips in eight months and saved hundreds of thousands of dollars by partnering with Uber, instead of adding fixed bus routes.](#)²
- [The MBTA is running a pilot program with Uber and Lyft to offer on-demand transit service to RIDE customers at a subsidized rate](#)³ which helps provide more rides and lower costs.⁴

Benefits of MBTA's On-demand Pilot⁴



1. The Verge. (2018). *We can't forget about mass transit when we talk about the 'future of transportation.'* <https://www.theverge.com/2018/5/12/17346014/future-of-transportation-public-buses-pedestrians-jetpack>

2. Toronto Star. (2018). *Small Ontario town's Uber partnership could signal shift for Canadian public transit.* <https://www.thestar.com/news/gta/2018/04/12/small-ontario-towns-uber-partnership-could-signal-shift-for-canadian-public-transit.html>

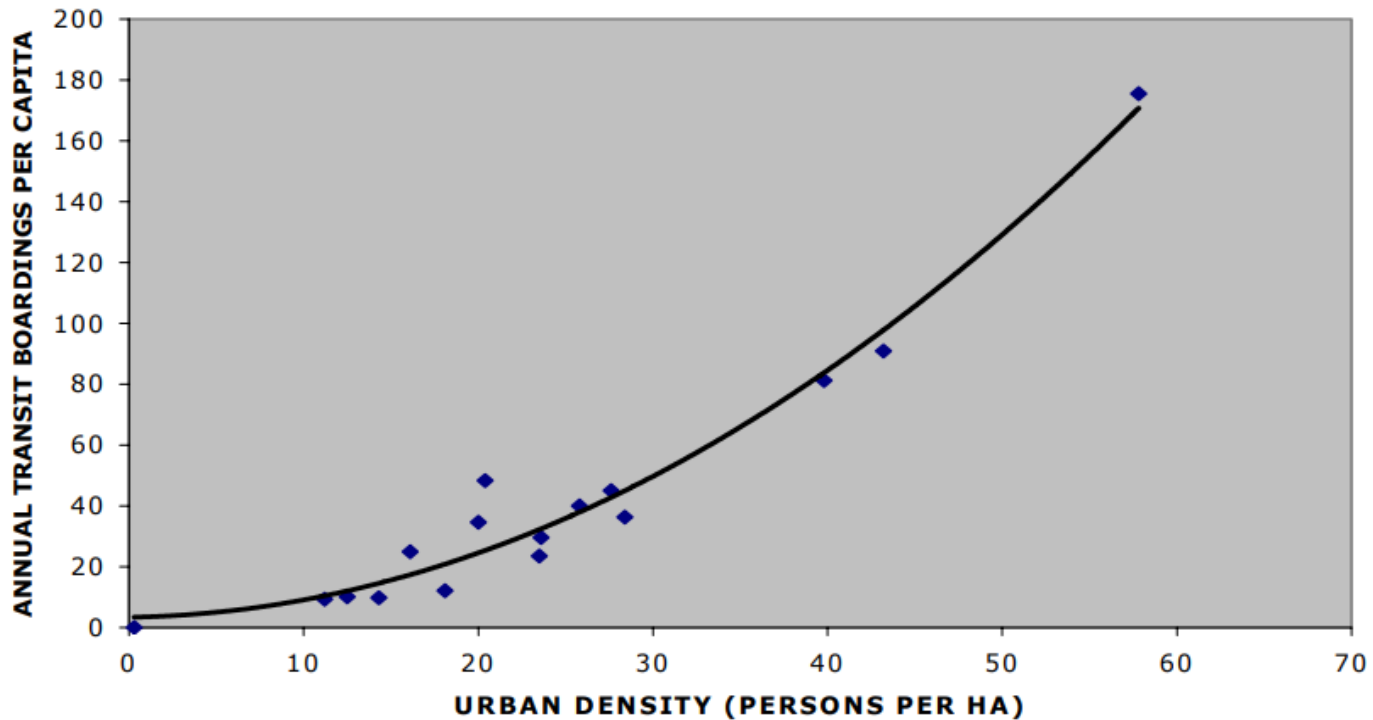
3. MBTA. (2018). *On-Demand Paratransit Pilot Program.* <https://www.mbta.com/accessibility/the-ride/on-demand-pilot>

4. MBTA. (2018). *The RIDE On-Demand Paratransit Pilot Review of Results and Discussion of Future Plan.* <https://cdn.mbta.com/sites/default/files/fmcb-meeting-docs/2018/february/2018-02-26-fmcb-ride-pilot-revised.pdf>

7. Density impacts, but does not need to define, transit options.

- [Seven dwelling units per acre is the average density required to support basic 30-minute bus service,¹ yet increasing density without planning or funding will not improve the quality of public transit.²](#)

Urban Density versus Transit Use in the Los Angeles Region, 1990¹



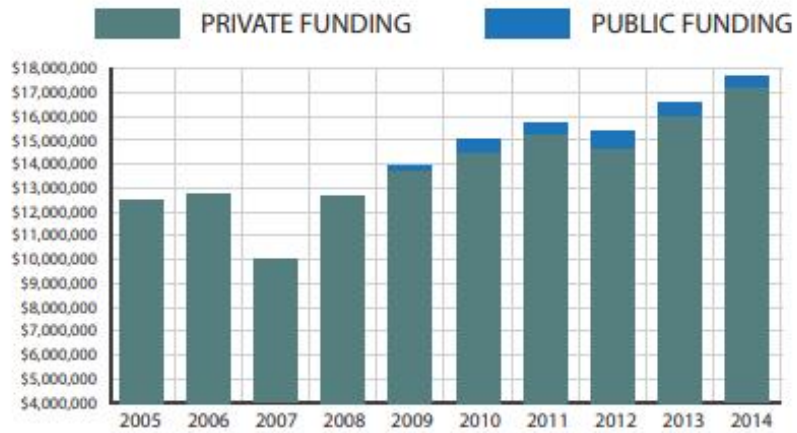
1

1. Reconnecting America. (2018). *Featured Topic: Transit Supportive Density*. <http://www.reconnectingamerica.org/resource-center/transit-supportive-density/>

2. Public Transport Users Association (PTUA). (2018). *Myth: Viable public transport requires high population densities*. <https://www.ptua.org.au/myths/density/>

7. Density impacts, but does not need to define, transit options.

- The private sector has consistently increased its funding for Transportation Management Associations (TMAs) in Massachusetts municipalities to increase transportation options.¹



Since 2009, MassCommute TMAs have received a combination of public (MassDOT) and private (membership dues) funds.

Government support has triggered even more private sector investment in transportation, yielding continually growing public benefits.

\$2,900,000 in public funding has been leveraged into \$75,850,826 in private sector investment since 2009.

↑ Private Dollars RESULTS IN ↑ Public Benefits

2006

17,637 tons
CO2 Emissions Reduced
37,794,911
Vehicle Miles Reduced
429
Education/Outreach Events



2014

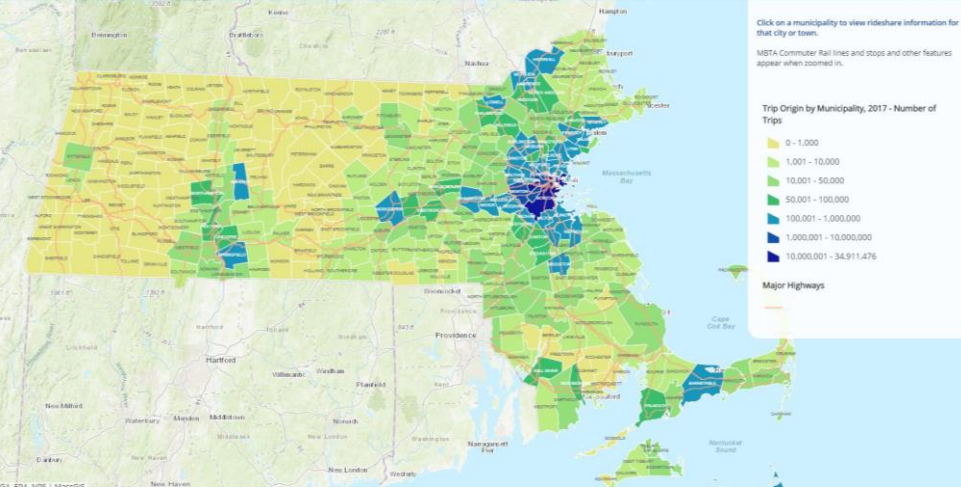
42,000 tons
CO2 Emissions Reduced
109,923,335
Vehicle Miles Reduced
1007
Education/Outreach Events

1. "MassCommute. (2015). *MassCommute TMAs: Successful Public-Private Partnerships for a Better Massachusetts, Decade at a Glance 2005-2015*. <http://static1.1.sqspcdn.com/static/f/1287395/26336065/1435090885643/MassCommute+TMA+Trends+Brochure.2015.pdf>"

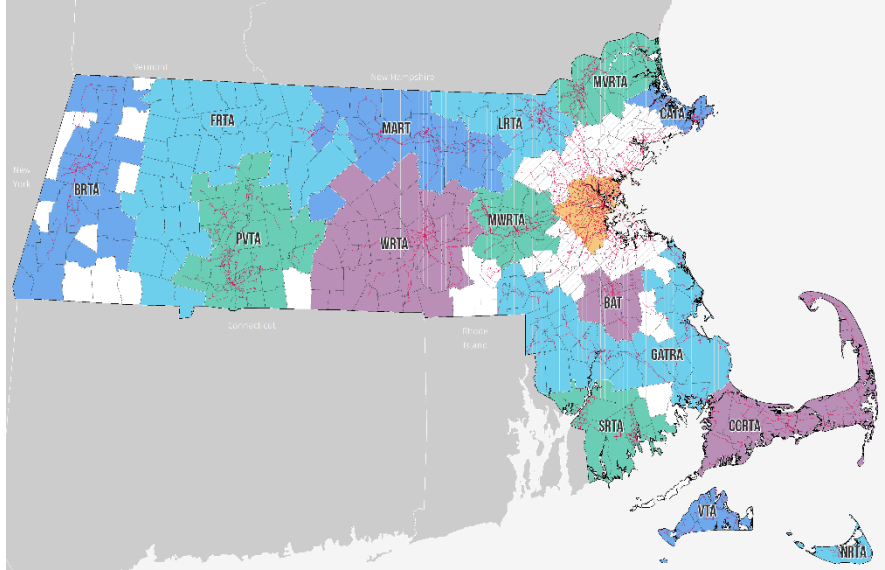
7. Density impacts, but does not need to define, transit options.

- [In U.S. suburban and rural areas, people improvise to fill transit system gaps, such as carpools that pick up from bus stations or other fixed points \(aka “slugging”\) and vanpools.](#)¹
- [In Massachusetts, rural areas have limited usage of TNCs, as usage is concentrated in Greater Boston.](#)²
- RTAs provide some coverage, but the majority of rural communities do not have access to public transit.³

TNC Ridership Is Low in Rural Areas²



RTA Service Areas and Bus Routes (shown in red)³



1. Mobility Lab. (2018). *Non-car modes already play a huge role in suburban and rural life.* <https://mobilitylab.org/2018/05/18/non-car-modes-already-play-a-huge-role-in-suburban-and-rural-life/>

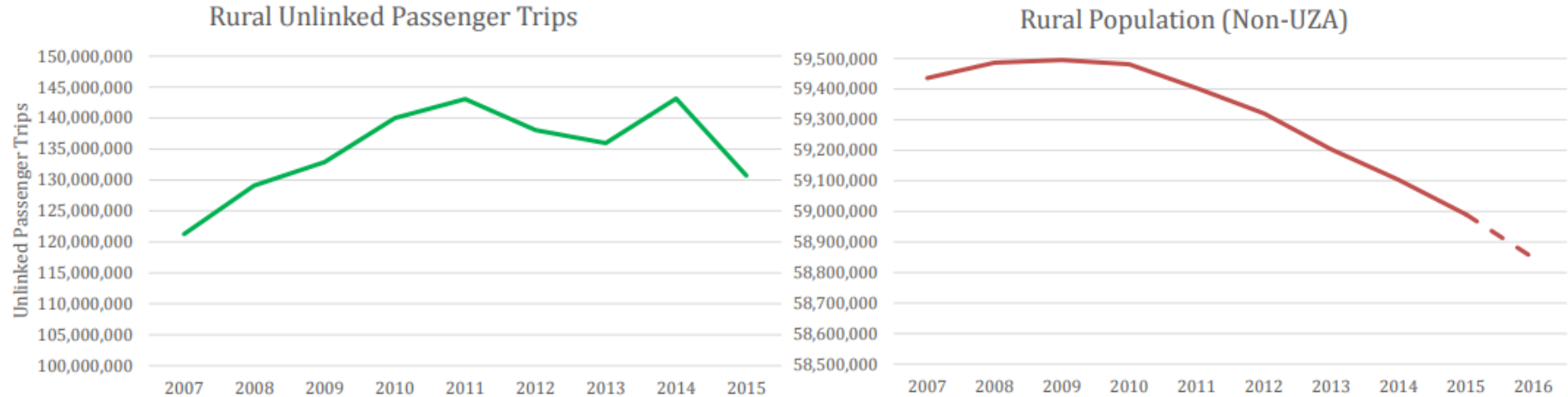
2. MassGIS. (2017). *TNC Trip Origins.* <http://massgis.maps.arcgis.com/apps/MapSeries/index.html?appid=f7efe80f5d3b49b6b7fc8d2d65469efa>

3. MassDOT Office of Transportation Planning. (2018). *Map of RTA Service Areas and Bus Routes.*

7. Density impacts, but does not need to define, transit options.

- [While some predict that rural riders will be late adopters of MaaS...](#)¹
- [...the start-up Liberty Mobility Now is looking to fill transit gaps in rural areas in the U.S.](#)²
- [Nationwide, transit ridership is increasing proportionally faster in rural areas than urban areas, despite decreasing population.](#)³

National Ridership and Population Trends³



1. RethinkX (Seba). (2017). Rethinking Transportation 2020-2030. <https://www.rethinkx.com/transportation/>

2. NPR. (2017). Ride Hailing In Rural America: Like Uber With A Neighborly Feel. <https://www.npr.org/sections/alltechconsidered/2017/04/17/524339669/ride-hailing-in-rural-america-like-uber-with-a-neighborly-feel>

3. American Public Transportation Association (APTA). (2017). Public Transportation's Impact on Rural and Small Towns: A Vital Mobility Link. <https://www.apta.com/resources/reportsandpublications/Documents/APTA-Rural-Transit-2017.pdf>

CONNECTED AND AUTONOMOUS VEHICLES

Why do Connected and Autonomous Vehicles (C/AVs) matter?

1. Connected and Autonomous Vehicles (C/AVs) are beginning to impact the transportation market.
2. C/AVs have the potential to increase the safety of travelers...
3. ...affect roadway capacity...
4. ...and change how, where, and when people will travel.
5. Automation and connectivity will impact modes of transportation beyond the passenger vehicle...
6. ...and can dramatically impact urban form.
7. C/AVs will be a source of massive amounts of data; how that data is handled and shared is an important question.

Summary

1. Connected and autonomous vehicles (C/AVs) are beginning to impact the transportation market.

- [Connected vehicle technology will enable vehicles, roads and other infrastructure, and our smartphones to all communicate and share vital transportation information through advanced wireless communication technology.](#)
- [The 'autonomy' of vehicles describes the level of self-driving automation enabled by the vehicle's technology.](#)
- [Forty two states have passed or are considering AV legislation.](#)
- [At the same time, many automakers are making substantial investments in developing C/AVs.](#)
- [Even after fully autonomous vehicles are the norm in showrooms, there will be a long lag until most vehicles on the road are autonomous because fleet turnover is decreasing; as evidenced by the increasing average age of vehicles on the road.](#)
- [By 2040, we could see anywhere from 20 to 75 percent of vehicles at level 4 automation.](#)
- [In the future, AVs could make up 87 percent of ride-hailed trips, which is a mode that is rapidly increasing its share in the Boston area.](#)
- [However, all vehicles do not contribute equally to total miles driven; it is possible the percentage of trips completed by AVs will be much higher than the percentage of vehicles that are autonomous.](#)

2. C/AVs have the potential to increase the safety of travelers...

- [Over 90 percent of all crashes are caused by human error.](#)
- [While driver-assist features, such as automatic emergency braking, has been shown to reduce crashes....](#)
- [...fully autonomous test vehicles were not demonstrably safer than manually driven vehicles, though there was significant difference in accident type \(primarily being rear-ended by other drivers\).¹](#)
 - [Determining safety can be very difficult due lack of data, statistical uncertainties, types of accidents considered, and unreported accidents.²](#)
- [Broadcasting Signal Phasing and Timing \(SPaT\) to vehicles, even without automation, can save thousands of lives.³](#)

3. ...affect roadway capacity...

- [Broadcasting SPaT to vehicles could reduce arterial delays by 20 percent.](#)
- [Highway capacity could increase by more than 100 percent per lane when utilized solely by connected and autonomous vehicles.](#)
- [Highway capacity could be further increased due to the added precision of autonomous vehicles, which would allow for narrower lanes. However, narrow residential lanes that require coordination for two-way traffic could pose an issue.](#)
- [A mixed fleet of autonomous and human drivers will have an uncertain impact on road capacity.](#)
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- [People will travel longer distances in an AV because they can do other things in the vehicle besides drive.](#)
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- [AVs that are driving without passengers or driving farther away to park will add more miles traveled to the transportation system...](#)
- [...but that added travel will not necessarily increase congestion. Yet, it could replace short transit trips in downtown Boston, increasing congestion and travel times by 5.5 percent.](#)
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5. Automation and connectivity will impact modes of transportation beyond the personal passenger vehicle...

- [AVs are likely to arrive in fleet applications before private ownership due to the profit potential and stricter control on when, where, and how they are used.](#)
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- Current road systems are built for human drivers.
- [Narrower lanes and increased lane capacities could provide road space to alternate transportation modes, new green space, or new development.](#)
- [Parking priorities could also shift, freeing up a great deal of high value land. In Boston, AVs could obviate the need for roughly half as many parking spots on streets and in garages.](#)
- [Instead of parking lots, drop off zones may become a priority.](#)

7. C/AVs will be a source of massive amounts of data; how that data is handled and shared is an important question.

- [C/AVs will generate a tremendous amount of data, ranging from road conditions to video images of surrounding landscape and travelers. Some of that data will need to be shared in real time.](#)
- [Some of the data will be useful for analytics and improving the system, if agencies are equipped to process it.](#)
- [The data may provide a new revenue source for vehicle manufacturers, roadway operators, and third party companies.](#)
- [However, the infrastructure required for these services may not be economically attractive for rural areas.](#)
- [All of the data will come with many privacy and security concerns.](#)
 - [Some companies are already beginning to address customer concerns about their data.](#)
- [Connectivity is not a single issue, as different types of connectivity have different needs and benefits.](#)
 - [Vehicle-to-vehicle \(V2V\) can improve flow and reduce crashes.](#)
 - [Vehicle-to-infrastructure \(V2I\) can share road hazard and traffic control information.](#)
 - [Vehicle-to-everything \(V2X\) or vehicle-to-network \(V2N\) can provide other services and conveniences.](#)

1. Connected and autonomous vehicles (C/AVs) are beginning to impact the transportation market.

- [Connected vehicle technology will enable vehicles, roads and other infrastructure, and our smartphones to all communicate and share vital transportation information through advanced wireless communication technology.](#)¹
- [The 'autonomy' of vehicles describes the level of self-driving automation enabled by the vehicle's technology.](#)²

Visualization of connected vehicle communication¹



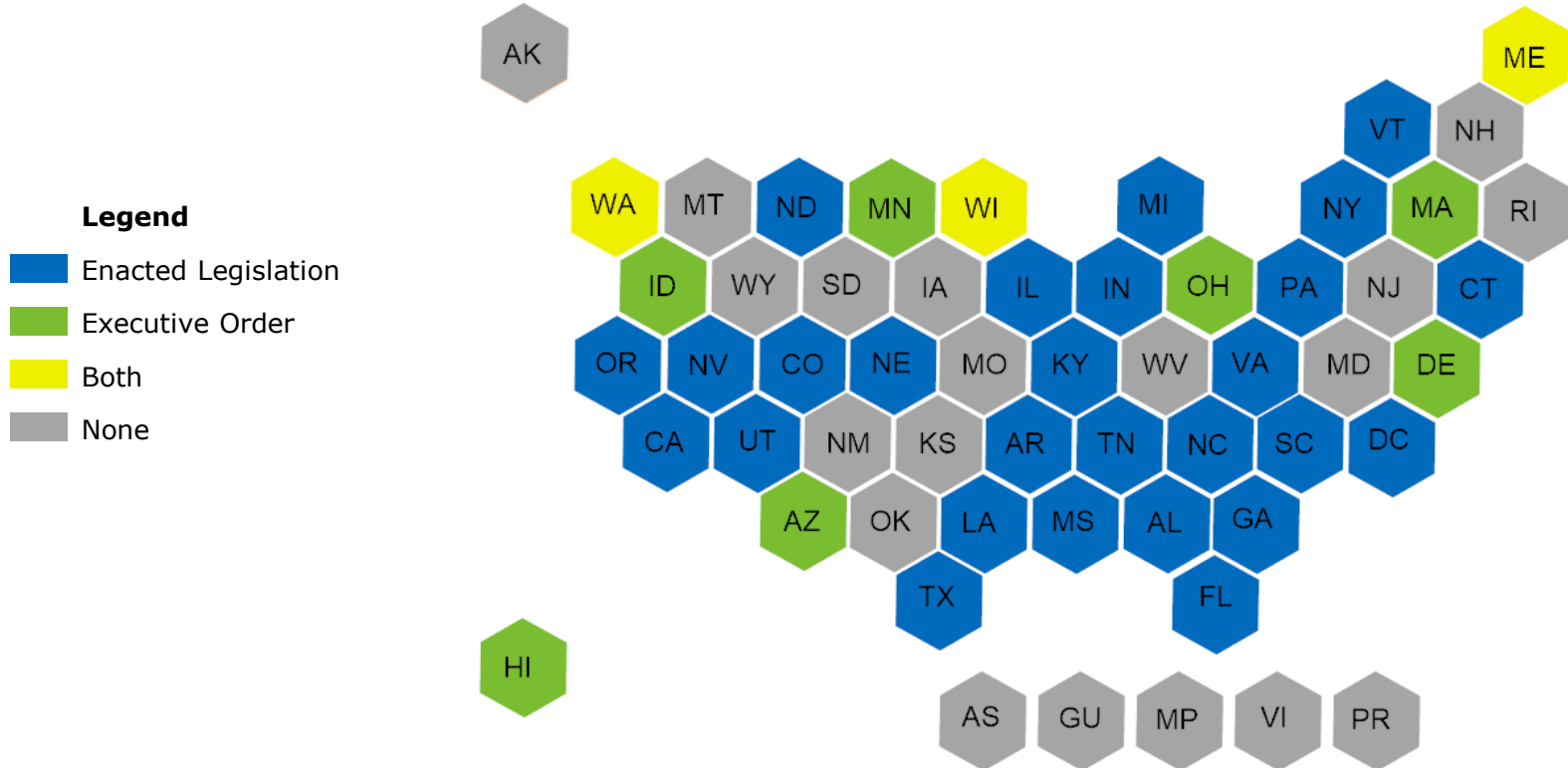
1. USDOT: ITS Joint Program Office. (2018). What Are Connected Vehicles and Why Do We Need Them? https://www.its.dot.gov/cv_basics/cv_basics_what.htm

2. NHTSA. (2018). Automated Vehicles for Safety. <https://www.nhtsa.gov/technology-innovation/automated-vehicles-safety>

1. Connected and autonomous vehicles (C/AVs) are beginning to impact the transportation market.

- Forty two states have passed or are considering AV legislation.^{1,2}

States with AVs Enacted Legislation and Executive Orders²



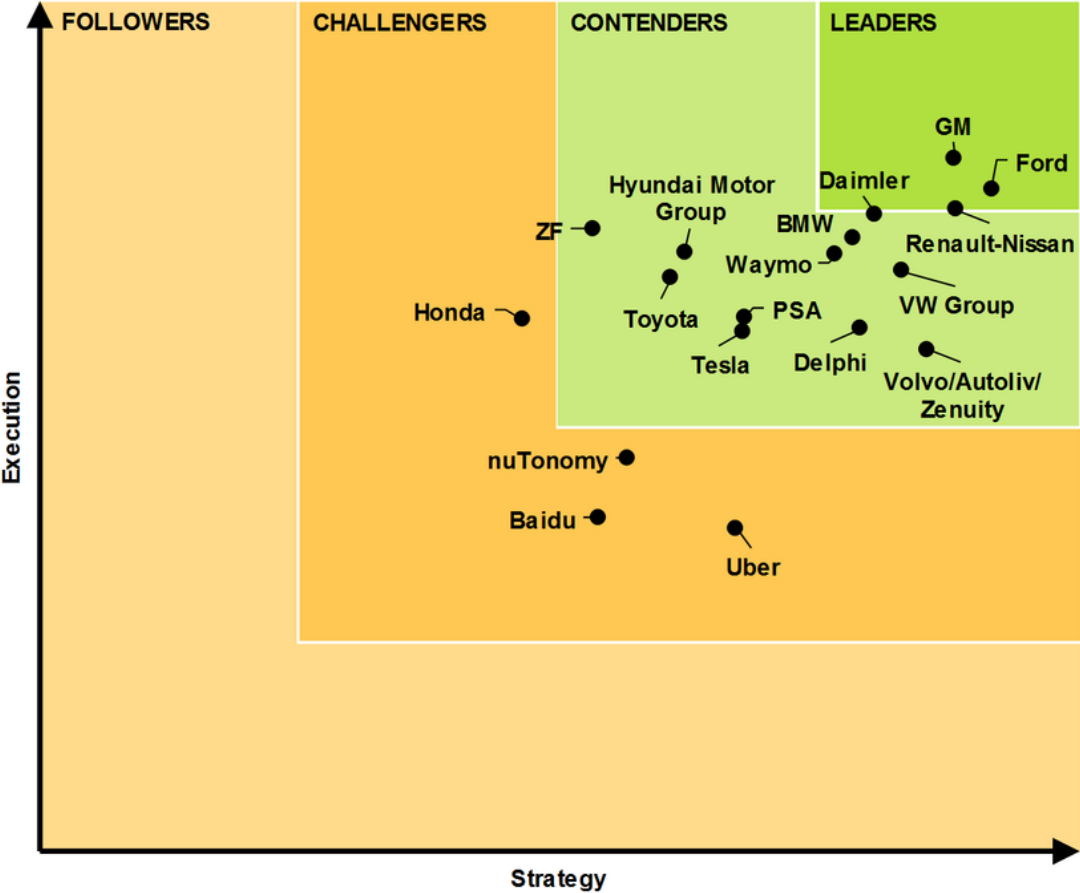
1. Brookings Institute. (2018). *Charts of the week: Autonomous vehicles, mobile money, and biases in online courses*. <https://www.brookings.edu/blog/brookings-now/2018/05/04/charts-of-the-week-autonomous-vehicles-mobile-money-and-biases-in-online-courses/>

2. National Conference of State Legislators (2018). *Autonomous Vehicles*. <http://www.ncsl.org/research/transportation/autonomous-vehicles-self-driving-vehicles-enacted-legislation.aspx>

1. Connected and autonomous vehicles (C/AVs) are beginning to impact the transportation market.

- [At the same time, many automakers are making substantial investments in developing C/AVs.](#)¹

Navigant Research Automated Driving Systems Leaderboard, 2017¹

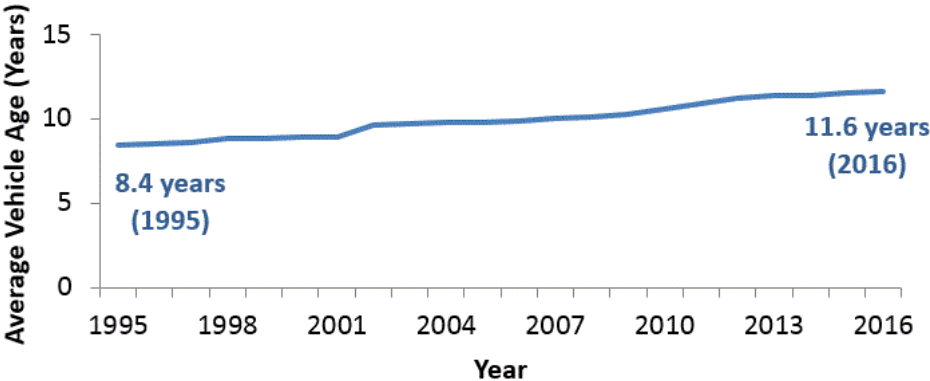


¹.Business Insider. (2017). RANKED: The 18 companies most likely to get self-driving cars on the road first. <https://www.businessinsider.com/the-companies-most-likely-to-get-driverless-cars-on-the-road-first-2017-4>

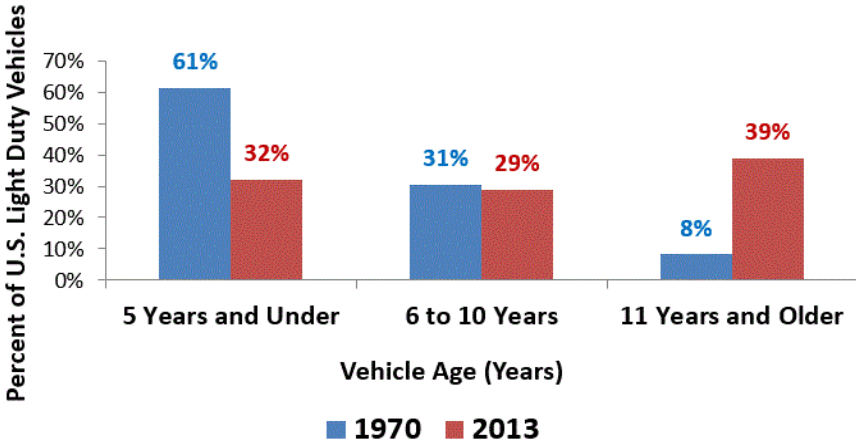
1. Connected and autonomous vehicles (C/AVs) are beginning to impact the transportation market.

- [Even after fully autonomous vehicles are the norm in showrooms,¹ there will be a long lag until most vehicles on the road are autonomous because fleet turnover is decreasing; as evidenced by the increasing average age of vehicles on the road.²](#)

Increasing Average Age of U.S. Light-Duty Vehicles (1995-2016)²



Age Distribution, U.S. Light-Duty Vehicles (1970 vs. 2013)²



For predictions of when AVs will be in show rooms, see “The Self-Driving Car Timeline – Predictions from the Top 11 Global Automakers”¹

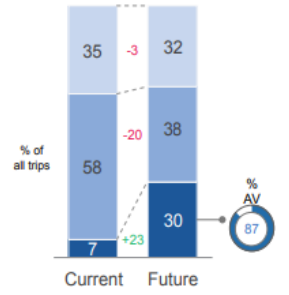
1. TechEmergence. (2018). *The Self-Driving Car Timeline – Predictions from the Top 11 Global Automakers*. <https://www.techemergence.com/self-driving-car-timeline-themselves-top-11-automakers/>

2. The Fuse. (2018). *America’s Aging Vehicles Delay Rate of Fleet Turnover*. <http://energyfuse.org/americas-aging-vehicles-delay-rate-fleet-turnover/>

1. Connected and autonomous vehicles (C/AVs) are beginning to impact the transportation market.

- [By 2040, we could see anywhere from 20 percent¹ to 75 percent of vehicles at level 4 automation.²](#)
- [In the future, AVs could make up 87 percent of ride-hailed trips, which is a mode that is rapidly increasing its share in the Boston area.³](#)

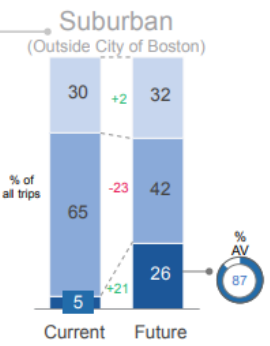
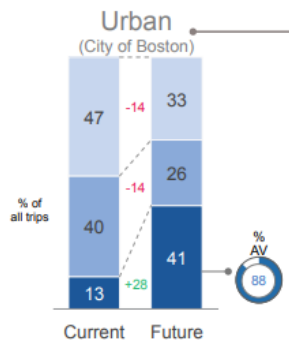
Figure 7: The shift in Boston's modal mix



Source: World Economic Forum, BCG analysis

Forecasted Mode Shift and Associated Adoption of AVs³

Boston's modal mix – urban vs suburban



■ Mass transit ■ Bus/subway + commuter rail
■ Personal car ■ Personal car + autonomous personal car
■ Mobility-on-demand ■ Taxi/ride hailing + autonomous taxi + autonomous shared taxi + autonomous minibus

AV Levels of Automation⁴

AV Technology

"a fully-featured Google self-driving car might be 30 years away." Chris Urmson SXSW 2016

Level 4 AV technology could be **19-75%** of vehicles by 2040.

Banal and Kitchman, "Forecasting America's Long-term adoption of connected and autonomous vehicles technologies", Transportation Research part A, 2017

Level	Description	Timeline
0	No automation	Now
1	Drive assistance	Now
2	Partial automation	TODAY
3	Conditional automation	5-10 YEARS
4	High automation	5-10 YEARS
5	Full automation	10+ YEARS

Facts/Trends/Developments:

- Cost and willingness to pay are the major economic forces behind technology adoption
- Full level 5 automation is more than 10 years away

Impacts

- Level 4 automation is an important consideration, where when and how might these vehicles be bounded

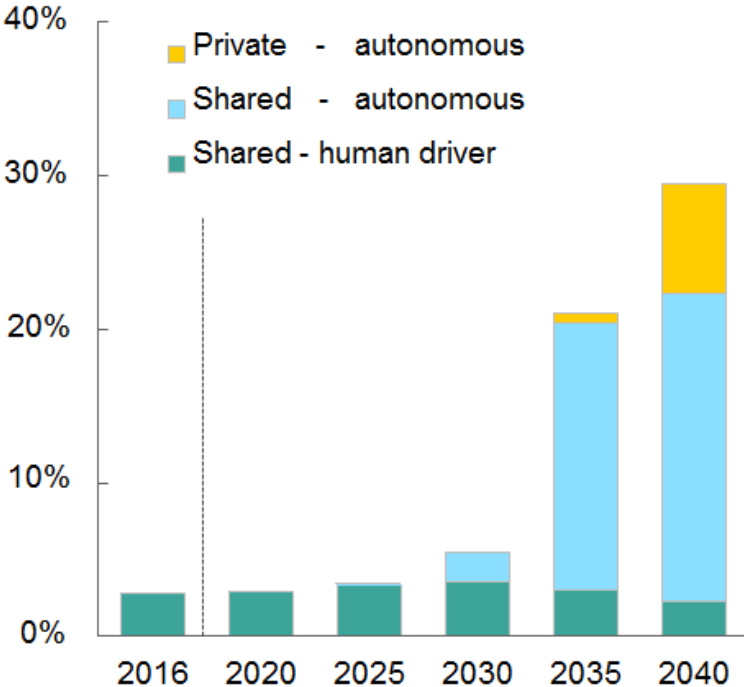
Image Source: MarketWatch research, SAE International

1. Victoria Transport Policy Institute. (2018). *Autonomous Vehicle Implementation Predictions: Implications for Transport Planning*. <https://www.vtpi.org/avip.pdf>
2. Intelligent Transportation Systems Society. (2014). *You won't need a driver's license by 2040*. <http://sites.ieee.org/its/2014/09/15/you-wont-need-a-drivers-license-by-2040/>
3. World Economic Forum. (2018). *Reshaping Urban Mobility with Autonomous Vehicles: Lessons from the City of Boston*. http://www3.weforum.org/docs/WEF_Reshaping_Urban_Mobility_with_Autonomous_Vehicles_2018.pdf
4. Commission on the Future of Transportation in the Commonwealth. (2018). *Looking at 2040 Update & Input*. <https://www.mass.gov/doc/massdot-looking-at-2040-update-and-input-9122018>

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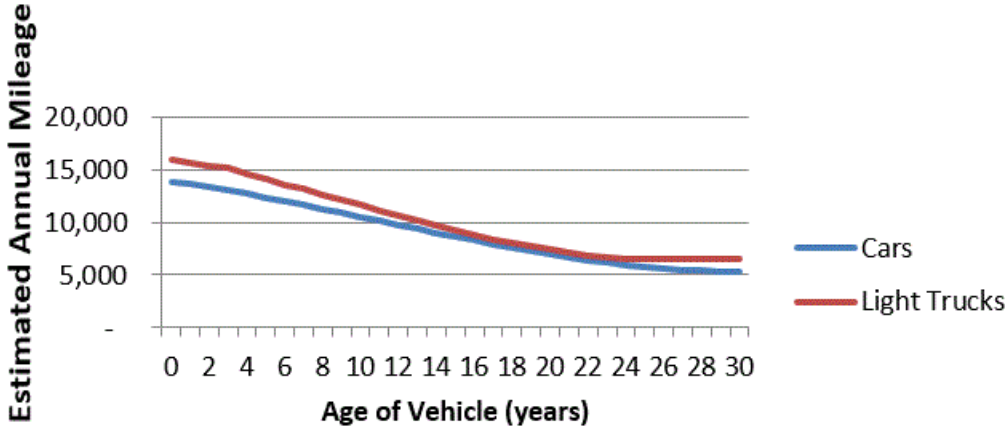
- [However, all vehicles do not contribute equally to total miles driven; so it is possible the percentage of trips completed by AVs will be much higher than the percentage of vehicles that are autonomous.](#)¹

Projected Share of VMT by New Mobility Options¹



2018 BP Energy Outlook

Annual Mileage over Vehicle Life-Span (2006)²



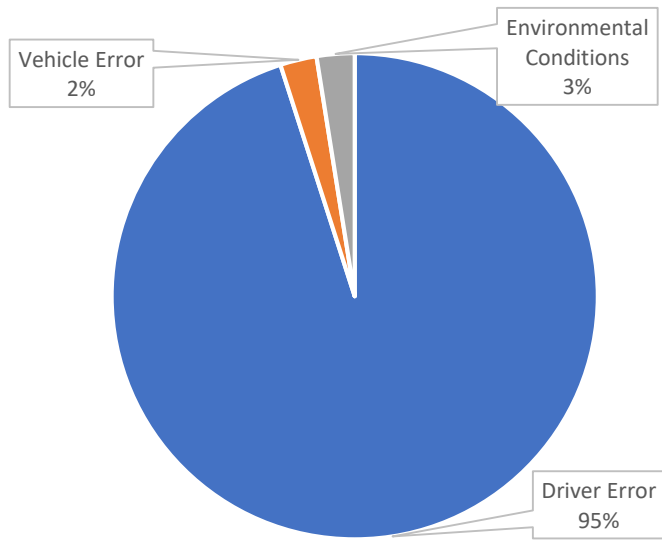
1. Market Watch. (2018). *Self-driving cars could slash Uber, Lyft prices by 50%, BP chief economist says.* <https://www.marketwatch.com/story/self-driving-cars-could-slash-uber-lyft-prices-by-50-bp-chief-economist-says-2018-02-21>
 2. The Fuse. (2018). *America's Aging Vehicles Delay Rate of Fleet Turnover.* <http://energyfuse.org/americas-aging-vehicles-delay-rate-fleet-turnover/>

2. C/AVs have the potential to increase the safety of travelers...

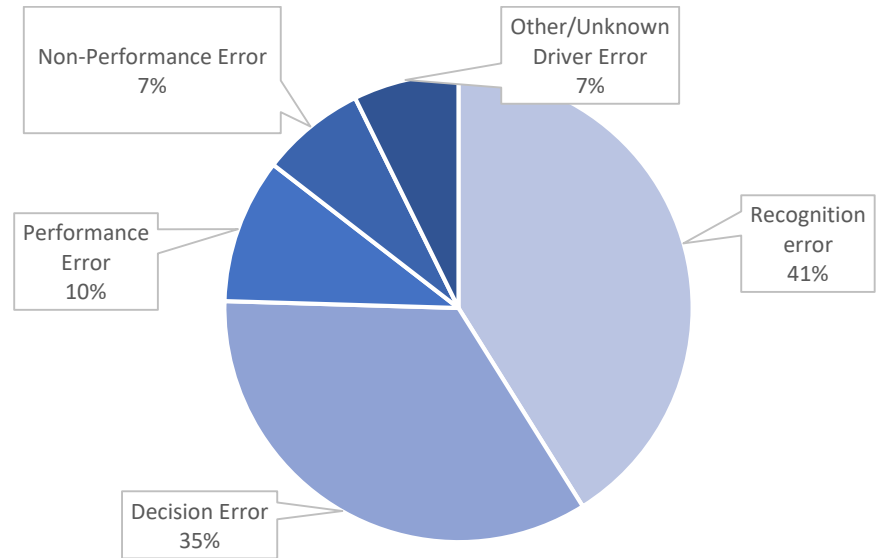
- [Over 90 percent of all crashes are caused by human error.](#)¹
- [While driver-assist features such as automatic emergency braking has been shown to reduce crashes...](#)²

Reason for the Critical Pre-Crash Event³

(This is not always the primary or sole cause of the event, but rather the final event that occurred before the accident)



Breakdown of Reasons for Driver Error in the Critical Pre-Crash Event³



1. National Motor Vehicle Crash Causation Survey NHTSA. (2008). *Human error as a cause of vehicle crashes*. <https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/811059>

2. IIHS. (2016). *U.S. DOT and IIHS announce historic commitment of 20 automakers to make automatic emergency braking standard on new vehicles*.

<https://www.iihs.org/iihs/news/desktopnews/u-s-dot-and-iihs-announce-historic-commitment-of-20-automakers-to-make-automatic-emergency-braking-standard-on-new-vehicles>

3. Data from: National Motor Vehicle Crash Causation Survey NHTSA. (2008). *Human error as a cause of vehicle crashes*.

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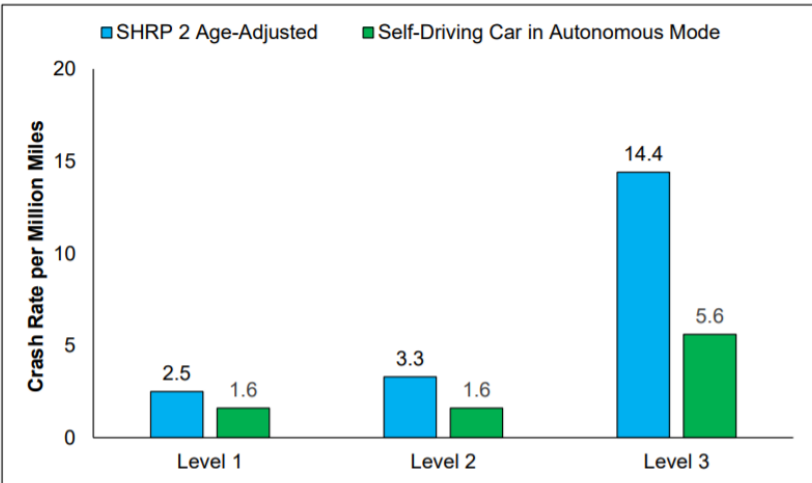
- ...fully autonomous test vehicles were not demonstrably safer than manually driven vehicles, though there was significant difference in accident type (primarily being rear-ended by other drivers).¹
 - Determining safety can be very difficult due lack of data, statistical uncertainties, types of accidents considered, and unreported accidents.²
- Broadcasting Signal Phasing and Timing (SPaT) to vehicles, even without automation, can save thousands of lives.³

Comparison of AV Accident Rates Across All Companies in California for September 2014 to March 2017 (Shows AVs nearly 10 times as likely to be in accident)¹

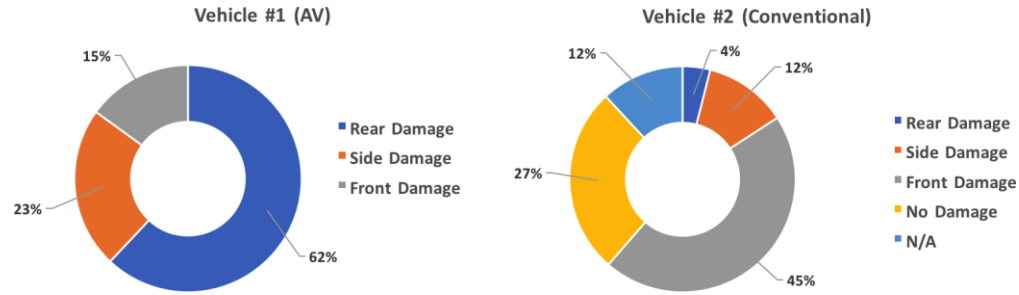
Type of Vehicle	Total number of Accidents	Total Miles Travelled	Accident Frequency	Miles per Accident
AV	26	1,088,453	2.38e-5	42,017
Conventional	6,296,000	3.148 trillions	2.0e-6	500,000

<https://doi.org/10.1371/journal.pone.0184952.t004>

Comparison of Accident Rates from SHRP 2 Data Set, Accounting for Unreported Accidents to Google’s AV Accident Rate through October 2015 (Shows AVs Less Than Half as Likely to be in an Accident)²



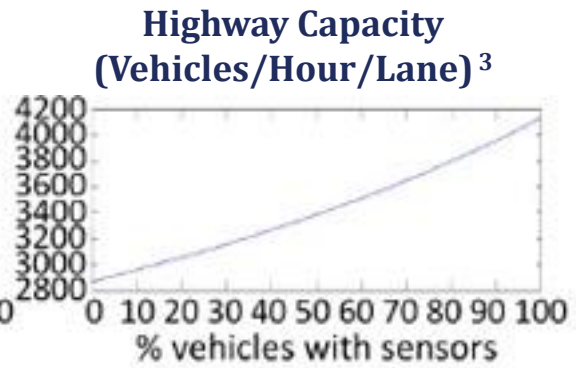
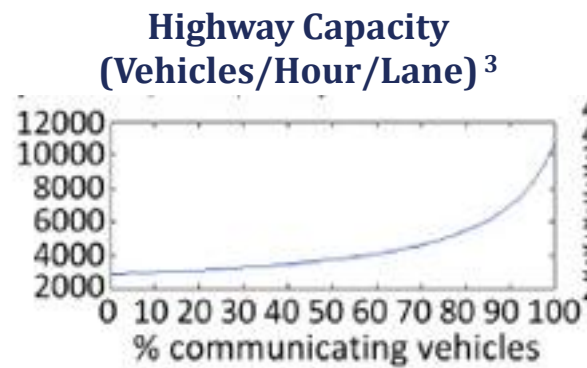
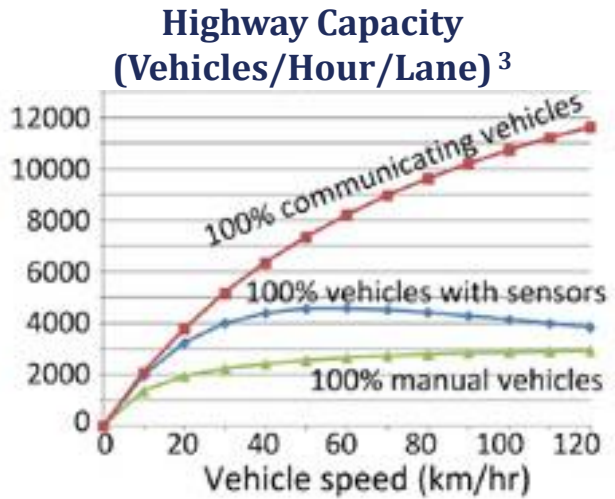
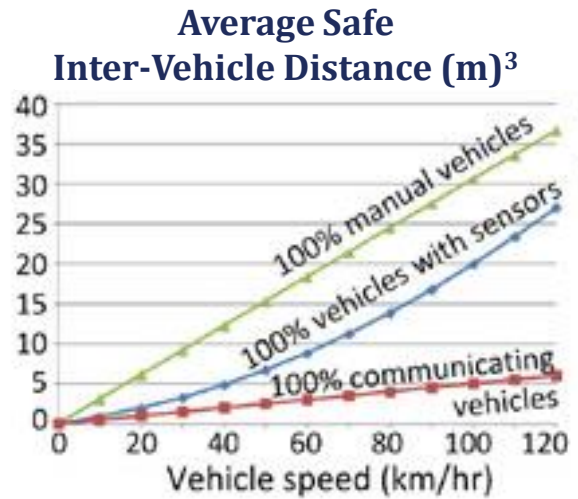
Comparison of Type of Damage Sustained by the Vehicle (Rear-End Damage Higher for AV)¹



1. PLOS One. (2017). Examining accident reports involving autonomous vehicles in California. <https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0184952#pone-0184952-g004>
 2. Virginia Tech Transportation Institute. (2016). Automated Vehicle Crash Rate Comparison Using Naturalistic Data. https://www.apps.vtti.vt.edu/PDFs/Automated%20Vehicle%20Crash%20Rate%20Comparison%20Using%20Naturalistic%20Data_Final%20Report_20160107.pdf
 3. California PATH Program, Institute of Transportation Studies, UC Berkeley. (2011). Investigating the Potential Benefits of Broadcasted Signal Phase and Timing (SPaT) Data under IntelliDriveSM. http://www.cts.virginia.edu/wp-content/uploads/2014/04/PFS_SPAT99_Final.pdf

3. ...affect roadway capacity...

- [Broadcasting SPaT to vehicles could reduce arterial delays by 20 percent.](#)¹
- [Highway capacity could increase](#)² [by more than 100 percent per lane when utilized solely by](#)³ [connected and autonomous vehicles.](#)⁴



1. California PATH Program, Institute of Transportation Studies, UC Berkeley. (2011). *Investigating the Potential Benefits of Broadcasted Signal Phase and Timing (SPaT) Data under IntelliDriveSM*. http://www.cts.virginia.edu/wp-content/uploads/2014/04/PFS_SPAT99_Final.pdf

2. Center for Urban Transportation Research. (2013). *Highway Capacity Impacts of Autonomous Vehicles: An Assessment*. <https://pdfs.semanticscholar.org/713c/da5859535ca41986413e8c77c105f4898f2a.pdf>

3. IEEE Spectrum. (2012). *Study: Intelligent Cars Could Boost Highway Capacity by 273%*. <https://spectrum.ieee.org/automaton/robotics/artificial-intelligence/intelligent-cars-could-boost-highway-capacity-by-273>

4. ITE Journal. (2016). *Autonomous Vehicles: The Implication on Urban Transportation and Traffic Flow Theory*. <http://www.worldcat.org/title/ite-journal/oclc/614107147>

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Image Source: Wired. (2018). *IT TAKES A SINGLE AUTONOMOUS CAR TO PREVENT PHANTOM TRAFFIC JAMS.* https://www.wired.com/story/one-autonomous-car-prevent-traffic-jams/?mbid=synd_digg

1. Urban Science. (2018). *Developing Policy for Urban Autonomous Vehicles: Impact on Congestion.* <http://www.mdpi.com/2413-8851/2/2/33/pdf>

2. Transportation Research Record. (2018). *Transportation Planning for Connected Autonomous Vehicles: How It All Fits Together.* <http://journals.sagepub.com/doi/full/10.1177/0361198118756632>

3. Wired. (2018). *IT TAKES A SINGLE AUTONOMOUS CAR TO PREVENT PHANTOM TRAFFIC JAMS.* https://www.wired.com/story/one-autonomous-car-prevent-traffic-jams/?mbid=synd_digg

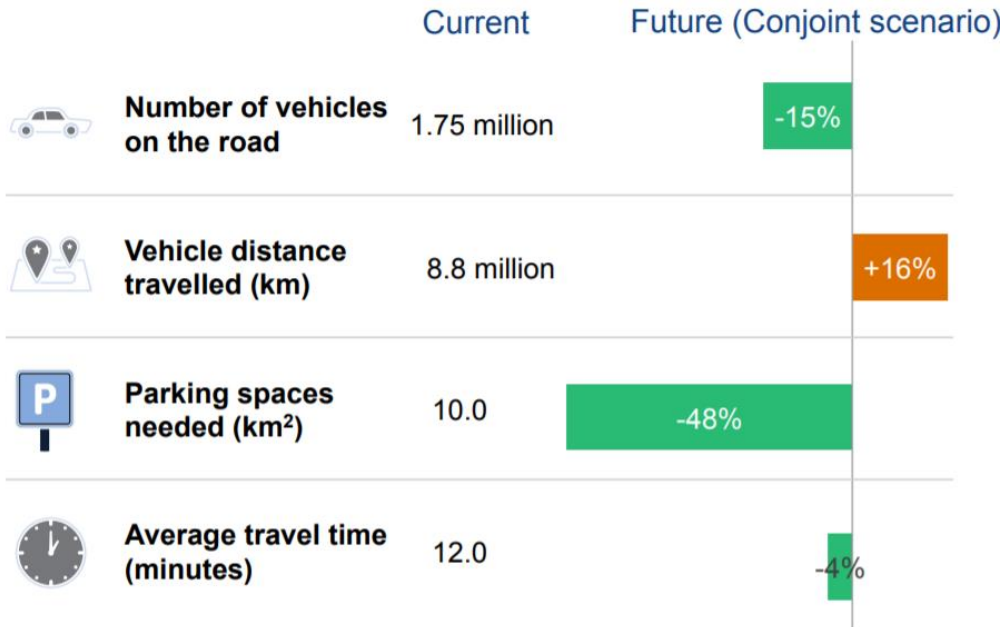
4. Atkins. (2016). *Research on the Impacts of Connected and Autonomous Vehicles (CAVs) on Traffic Flow.*

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/530091/impacts-of-connected-and-autonomous-vehicles-on-traffic-flow-summary-report.pdf

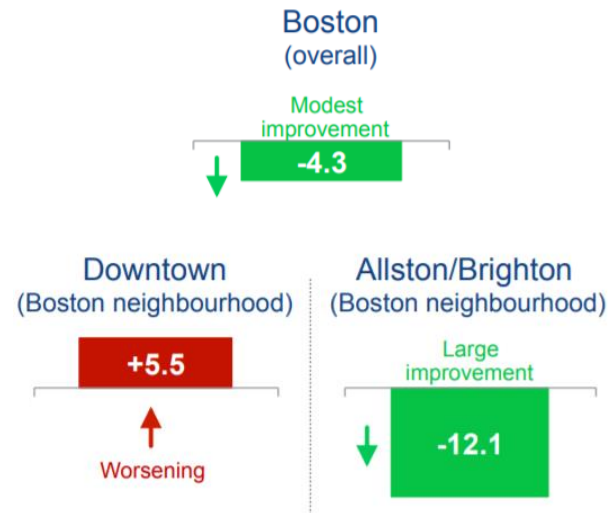
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Impact of AVs in a Future Scenario in Boston³



Impact of Autonomous Vehicles on Travel Times broken Down by Neighborhood in a Future Scenario in Boston³



1. German Aerospace Center, Institute of Transport Research. (2017). *Estimation of value of time for autonomous driving using revealed and stated preference method.* https://www.researchgate.net/publication/320373854_Estimation_of_value_of_time_for_autonomous_driving_using_revealed_and_stated_preference_method

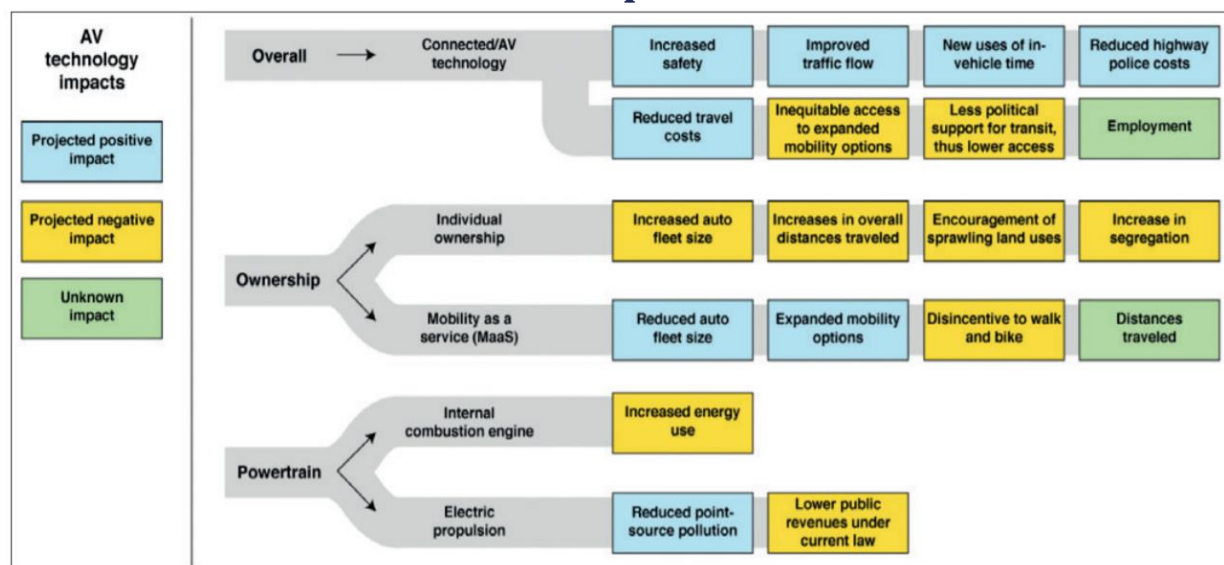
2. Fehr and Peers. (2018). *Effects of Next-Generation Vehicles on Travel Demand and Highway Capacity.* <http://www.fehrandpeers.com/autonomous-vehicles/>

3. World Economic Forum. (2018). *Reshaping Urban Mobility with Autonomous Vehicles Lessons from the City of Boston.* http://www3.weforum.org/docs/WEF_Reshaping_Urban_Mobility_with_Autonomous_Vehicles_2018.pdf

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Potential Impacts of AVs⁶

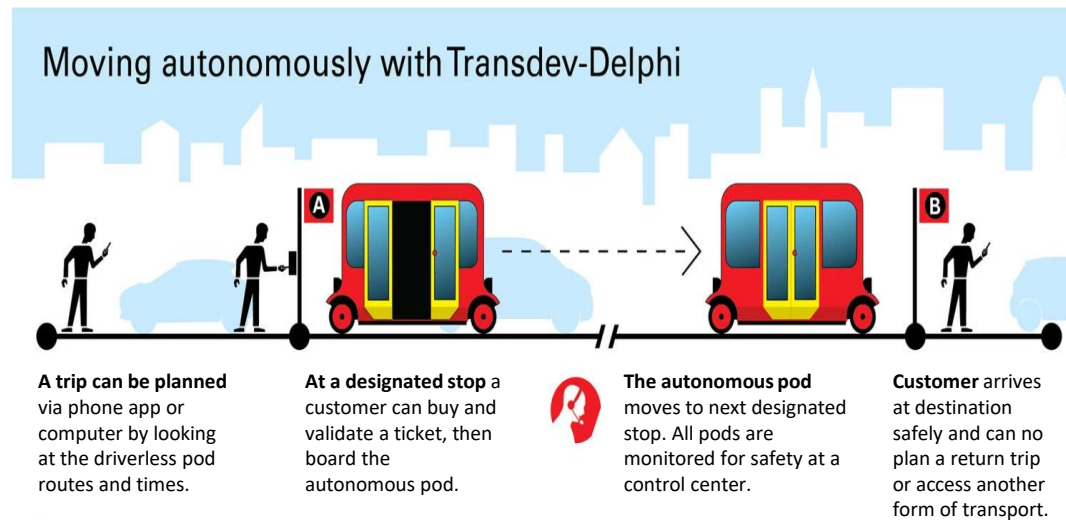


1. Huffington Post. (2017). *Self-Driving Cars: Transforming Mobility For The Elderly And People With Disabilities*. https://www.huffingtonpost.com/jules-polonetsky/selfdriving-cars-transfor_b_12545726.html
2. MIT CSAIL. (2018). *Autonomous Vehicle Navigation In Rural Environments Without Detailed Prior Maps (MIT)*. https://toyota.csail.mit.edu/sites/default/files/documents/papers/ICRA2018_AutonomousVehicleNavigationRuralEnvironment.pdf
3. Mobility Lab. (2017). *Cities will need to fight zero-occupant miles with "TDM for autonomous vehicles."* <https://mobilitylab.org/2017/05/30/tdm-for-autonomous-vehicles/>
4. TRR. (2018). *Transportation Planning for Connected Autonomous Vehicles: How It All Fits Together*. <http://journals.sagepub.com/doi/full/10.1177/0361198118756632>
5. World Economic Forum. (2018). *Reshaping Urban Mobility with Autonomous Vehicles: Lessons from the City of Boston*. http://www3.weforum.org/docs/WEF_Reshaping_Urban_Mobility_with_Autonomous_Vehicles_2018.pdf
6. John Burns Real Estate Consulting. (2017). *8 Big Housing Changes Thanks to Driverless Cars*. https://www.realestateconsulting.com/8-big-housing-changes-thanks-driverless-cars/?utm_content=61726555&utm_medium=social&utm_source=linkedin
7. Atelier parisien d'urbanisme. (2018). *Impacts and potential benefits of autonomous vehicles: From an international context to Grand Paris*. https://www.apur.org/sites/default/files/documents/publication/etudes/impacts_potential_benefits_autonomous_vehicles.pdf

5. Automation and connectivity will impact modes of transportation beyond the personal passenger vehicle...

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Example of On-Demand Transit in France³



1. The Economist. (2018). *Autonomous vehicles are just around the corner.* <https://www.economist.com/special-report/2018/03/01/autonomous-vehicles-are-just-around-the-corner>
2. Market Watch. (2018). *Self-driving cars could slash Uber, Lyft prices by 50%, BP chief economist says.* <https://www.marketwatch.com/story/self-driving-cars-could-slash-uber-lyft-prices-by-50-bp-chief-economist-says-2018-02-21>
3. TechCrunch. (2017). *Delphi and Transdev to develop global on-demand driverless transportation.* <https://techcrunch.com/2017/06/07/delphi-and-transdev-to-develop-global-on-demand-driverless-transportation/>
4. CDL Career Now. (2017). *Autonomous Trucking And The Trucking Industry.* <https://www.cdcareernow.com/articles/the-truth-about-autonomous-trucking>
5. NPR. (2018). *Trucking Industry Struggles With Growing Driver Shortage.* <https://www.npr.org/2018/01/09/576752327/trucking-industry-struggles-with-growing-driver-shortage>
6. PEW Charitable Trusts. (2016). *Delivery Robots Are Showing Up on City Sidewalks.* <https://www.pewtrusts.org/en/research-and-analysis/blogs/stateline/2016/12/07/delivery-robots-are-showing-up-on-city-sidewalks>

6. ...and can dramatically impact urban form.

- Current road systems are built for human drivers.
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What a Street Looks like Today Compared to What it Might Look Like When Less Space is Needed for Vehicles¹



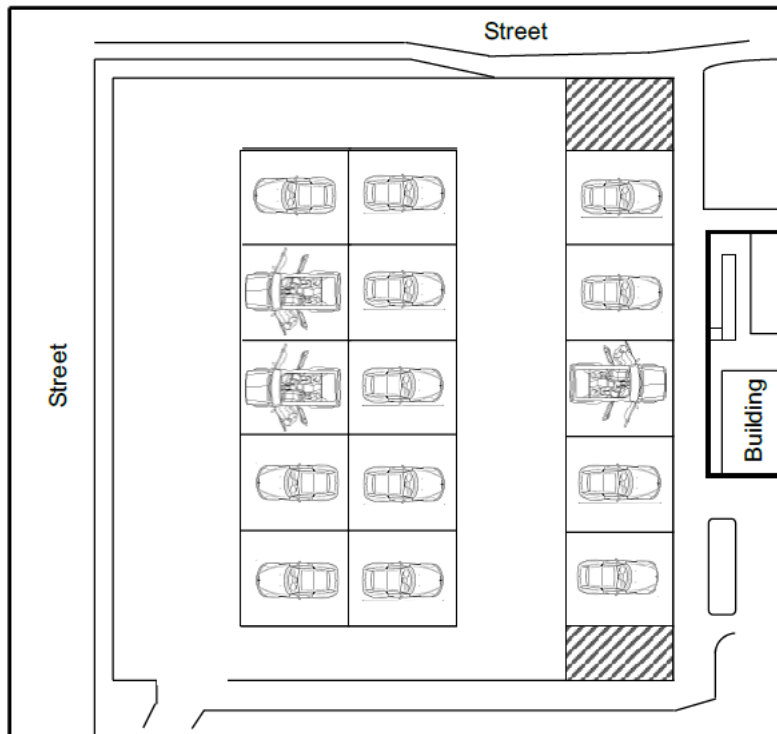
1. Public Square. (2018). *Street design implications of autonomous vehicles*. <https://www.cnu.org/publicsquare/2018/03/12/street-design-implications-autonomous-vehicles>

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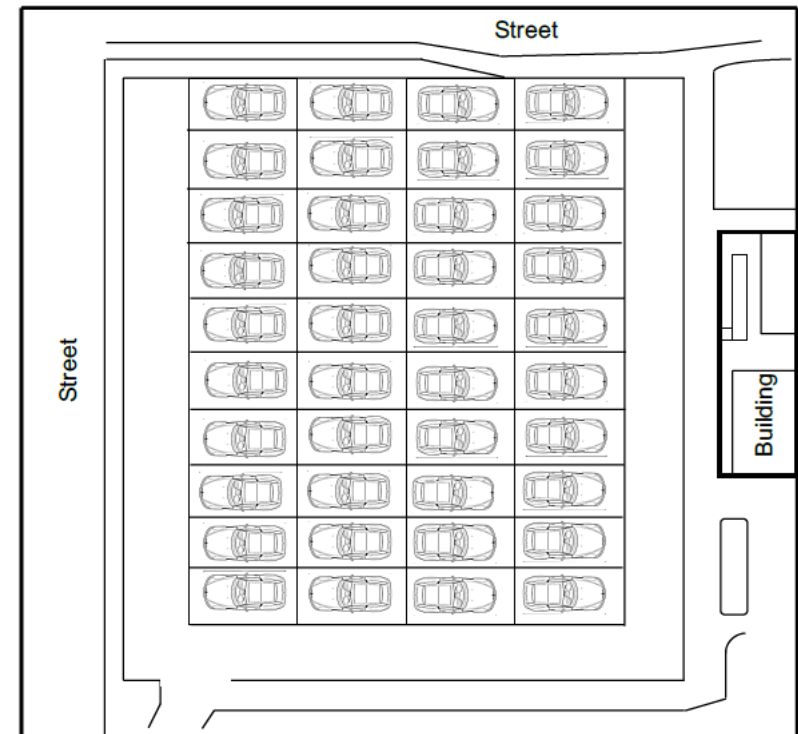
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- [Instead of parking lots, drop off zones may become a priority.](#)³

Comparison of Parking Spaces Available in Conventional Lots and AV Only lots¹

Conventional car-parks



Autonomous vehicle car-parks



1. Transportation Research Part B: Methodological. (2017). *Designing Parking Facilities for Autonomous Vehicles*.
https://www.researchgate.net/publication/318350739_Designing_Parking_Facilities_for_Autonomous_Vehicles

2. World Economic Forum. (2018). *Reshaping Urban Mobility with Autonomous Vehicles: Lessons from the City of Boston*.
http://www3.weforum.org/docs/WEF_Reshaping_Urban_Mobility_with_Autonomous_Vehicles_2018.pdf

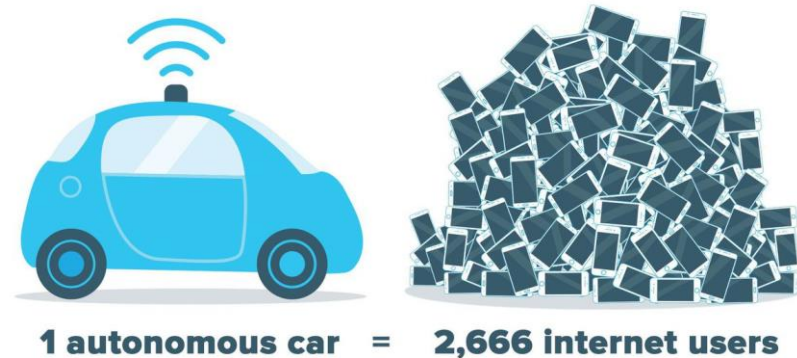
3. Forbes. (2018). *The End Of Parking Lots As We Know Them: Designing For A Driverless Future*. <https://www.forbes.com/sites/alanohnsman/2018/05/18/end-of-parking-lot-autonomous-cars/#23b5069a7244>

7. C/AVs will be a source of massive amounts of data. How that data is handled and shared is an important question.

- [C/AVs will generate a tremendous amount of data, ranging from road conditions to video images of surrounding landscape and travelers. Some of that data will need to be shared in real time.](#)¹

Autonomous Car Data vs. Human Data³

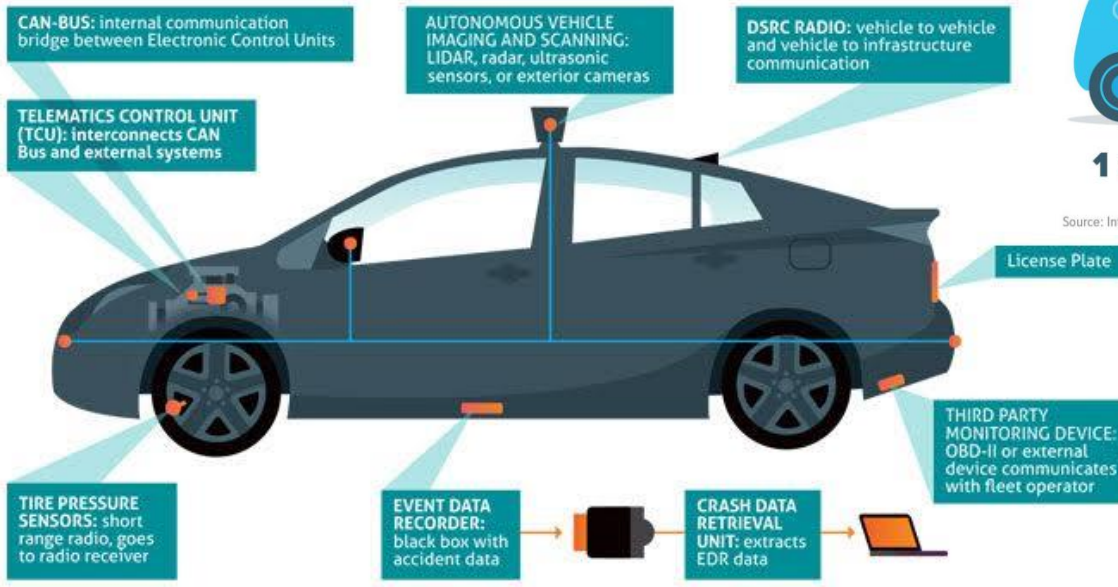
In 2020, the average autonomous car may process 4,000 gigabytes of data per day, while the average internet user will process 1.5 gigabytes. That means...



Source: Intel

Mashable

Data and the Connected Car²



1. Network World. (2016). *Just one autonomous car will use 4,000 GB of data/day.* <https://www.networkworld.com/article/3147892/internet/one-autonomous-car-will-use-4000-gb-of-dataday.html>

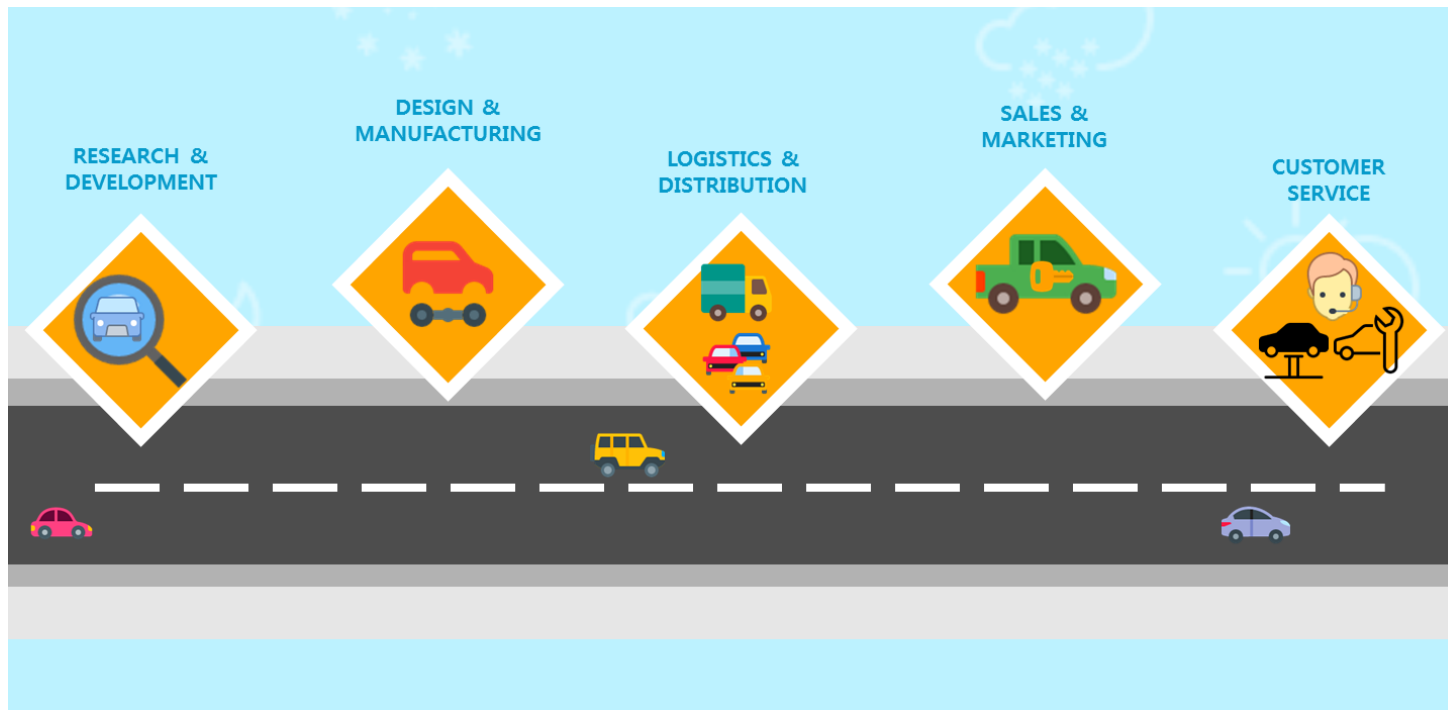
2. Future of Privacy Forum. (2017). *Infographic: Data and the Connected Car – Version 1.0.* <https://fpf.org/2017/06/29/infographic-data-connected-car-version-1-0/>

3. Mashable. (2016). *Autonomous cars will make your data plan look tiny.* <https://mashable.com/2016/08/17/intel-autonomous-car-data/#n8qQcGFULqqM>

7. C/AVs will be a source of massive amounts of data. How that data is handled and shared is an important question.

- [Some of that data will need to be shared in real time.](#)¹
- [Some of the data will be useful for analytics and improving the system, if agencies are equipped to process it.](#)²
- [The data may provide a new revenue source for vehicle manufacturers, roadway operators, and third party companies.](#)³
- [However, the infrastructure required for these services may not be economically attractive for rural areas](#)⁴

Big Data for the Automobile Ecosystem⁵



1. VIODI. (2017). *DSRC or 5G?* <http://viodi.com/2017/07/07/dsrc-or-5g/>

2. Xerox. (2018). *City analytics: Ten ways data can improve your city planning, traffic flow, public transportation and parking efficiency.* https://www.xerox.com/downloads/services/ebook/city_analytics.pdf

3. Boston Consulting Group. (2017). *Connected Vehicles and the Road to Revenue.* <https://www.bcg.com/en-us/publications/2017/connected-vehicles-road-revenue.aspx>

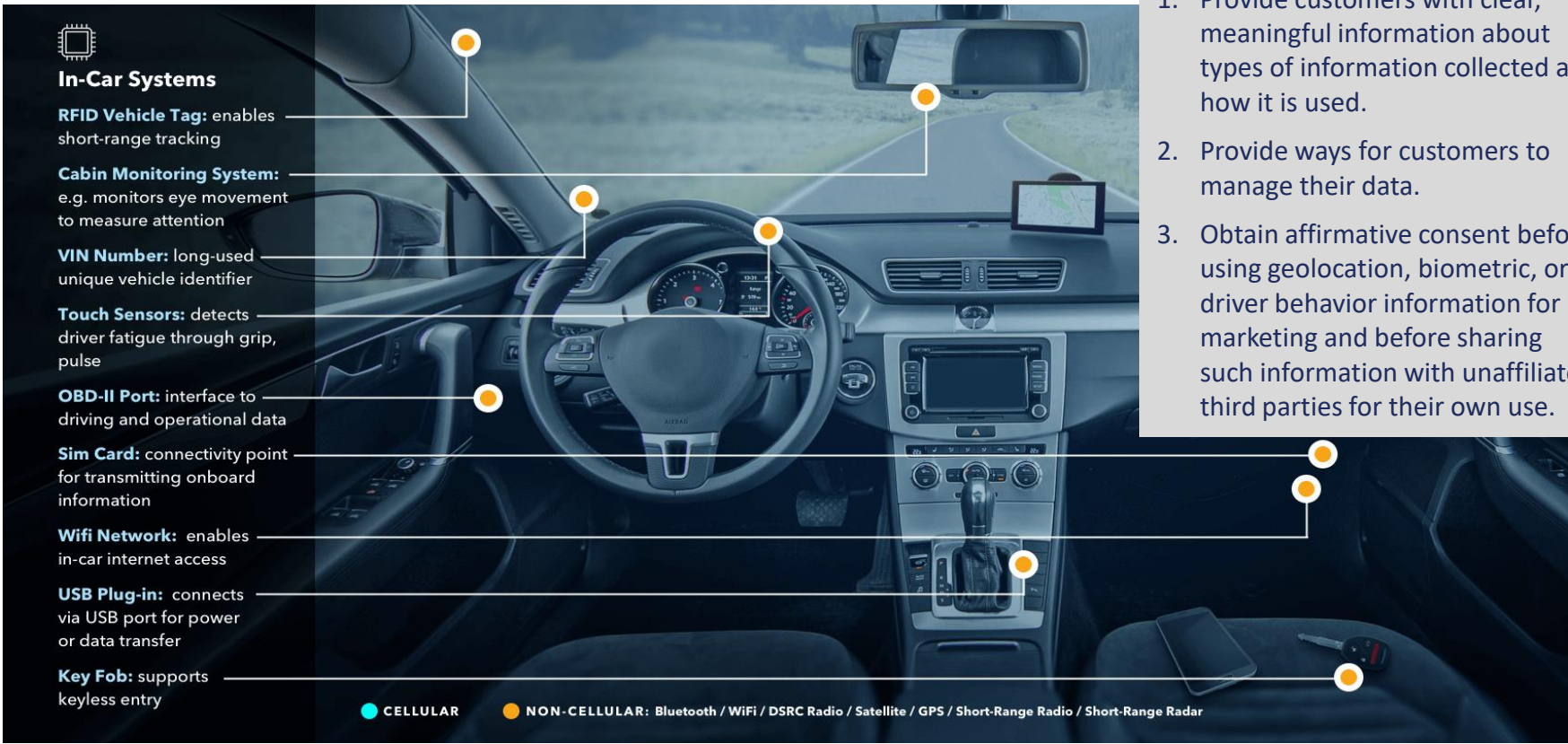
4. IEEE CTN (2015). *Is anyone out there? 5G, rural coverage and the next 1 billion.* <https://www.comsoc.org/ctn/anyone-out-there-5g-rural-coverage-and-next-1-billion>

5. Business Mobility as a Service (2017). *One for the road — big data & the automobile industry.* <https://www.businessmaas.com/connected-car/self-driving/one-road%E2%80%8A-%E2%80%8A-big-data-automobile-industry/>

7. C/AVs will be a source of massive amounts of data. How that data is handled and shared is an important question.

- [All of the data will come with many privacy and security concerns.](#) ¹
- [Some companies are already beginning to address customer concerns about their data.](#) ²

In-Car Communication Technologies²



The automakers of the Auto Alliance commit to:

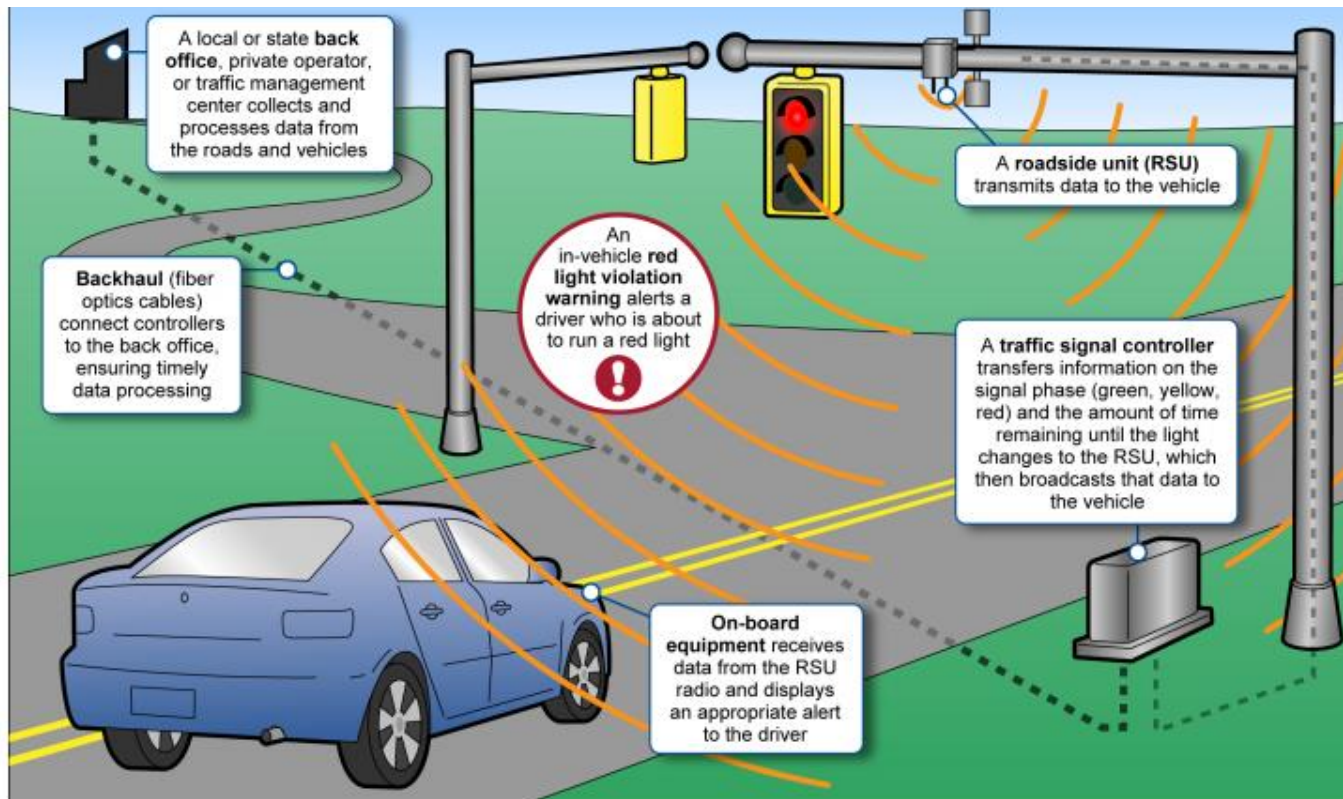
1. Provide customers with clear, meaningful information about types of information collected and how it is used.
2. Provide ways for customers to manage their data.
3. Obtain affirmative consent before using geolocation, biometric, or driver behavior information for marketing and before sharing such information with unaffiliated third parties for their own use.

1. Taylor Wessing. (2017). *Cybersecurity in CAVs*. <https://www.taylorwessing.com/download/article-cybersecurity-in-CAVs.html>
2. Auto Alliance. (2018). *About Automotive Privacy*. <https://autoalliance.org/connected-cars/automotive-privacy/>

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- [Connectivity is not a single issue, as different types of connectivity have different needs and benefits.](#)¹
 - [Vehicle-to-vehicle \(V2V\) can improve flow and reduce crashes](#)²
 - [Vehicle-to-infrastructure \(V2I\) can share road hazard and traffic control information.](#)³

Examples of Vehicle-to-Infrastructure Communication Provided through Roadside Equipment³



Source: GAO analysis of Department of Transportation documents. | GAO-15-775

1. USDOT – Intelligent Transportation Systems Joint Program Office. (2018). *Connected Vehicle Basics*. https://www.its.dot.gov/cv_basics/cv_basics_20qs.htm
2. FleetAnswers. (2014). *Vehicle to vehicle technology - More than just safety applications*. <http://www.fleetanswers.com/content/vehicle-vehicle-technology-more-just-safety-applications>
3. United States Government Accountability Office. (2015). *INTELLIGENT TRANSPORTATION SYSTEMS: Vehicle-to-Infrastructure Technologies Expected to Offer Benefits, but Deployment Challenges Exist*. <https://www.gao.gov/assets/680/672548.pdf>

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- [Connectivity is not a single issue, as different types of connectivity have different needs and benefits.](#)¹
- [Vehicle-to-everything \(V2X\) or vehicle-to-network \(V2N\) can provide other services and conveniences.](#)²



1. USDOT – Intelligent Transportation Systems Joint Program Office. (2018). *Connected Vehicle Basics*. https://www.its.dot.gov/cv_basics/cv_basics_20qs.htm
2. Intellias. (2018). *V2X: The Basics of Connected Vehicle Technology*. <https://www.intellias.com/v2x-basics-connected-vehicle-technology/>

CLIMATE CHANGE AND RESILIENCE

Why does climate change matter?

1. [Climate change leads to higher temperatures, sea level rise, flooding, and more extreme weather events...](#)
2. [...affecting the performance of transportation systems and damaging infrastructure.](#)
3. [Transportation is a leading producer of greenhouse gas emissions \(GHGs\).](#)
4. [Massachusetts has aggressive goals in place to mitigate the effects of and adapt to climate change.](#)
5. [Making infrastructure resilient to climate change will be a complex and ongoing effort.](#)

Summary

1. Climate change leads to higher temperatures, sea level rise, flooding, and more extreme weather events...

- [Globally, average temperatures in 2017 were 1.62°F warmer than the 1951 to 1980 mean.](#)
- [Increasing the global rate of CO₂ reductions may limit warming to 1.5°C by 2100, while no reduction could push warming to 2°C.](#)
- [Temperatures in the Northeastern U.S. are projected to rise higher, faster than the rest of the country and the globe. By 2035, projections for this region are 3.6°F \(2°C\) warmer on average than during the preindustrial era.](#)
- [While climate-related risks for global warming of 1.5°C are higher than at present, it is significantly better than a warming of 2°C.](#)
- [There are predicted to be as many as 29 days over 90 degrees by 2040 in Massachusetts \(there were only 11 in 1990\) and more in urban areas.](#)
- [Heat waves are associated with thousands of deaths in developed countries.](#)
- [Increasing GHG levels will exacerbate the risk of coastal flooding in the Commonwealth.](#)
- [Since 1991, Boston has experienced 21 events that triggered federal or state disaster declarations.](#)
- [Weather events causing over a billion dollars in damage are increasing nationally.](#)
- [Nuisance flooding will also become an increasing problem for coastal areas.](#)
 - [Massachusetts experienced 57 flood days from 2005 to 2014 of which 72 percent can be attributed to climate change.](#)

2. ...affecting the performance of transportation systems and damaging infrastructure.

- [Bad weather accounts for 15 percent of all roadway congestion nationally.](#)
- [Transit agencies cancel trips, and service gets delayed due to freezing rain or icy road conditions.](#)
- [New York City's subway hit an all-time low for on time service in January 2018, which was largely attributable to bad weather.](#)
- [Estimates suggest anywhere from 25 percent to 69 percent of delay in the National Airspace System is caused by weather.](#)
- [Sea level rise could have a mixed impact on shipping:](#)
 - [It could increase the availability of shipping lanes and allow heavier vehicles through some channels,](#)
 - [The world's biggest shipping firm is testing a route through the Russian Arctic, and](#)
 - [It could cause more debris and sediment to build up in shipping lanes and reduce the clearance under bridges.](#)
- [Heat can degrade all modes of transportation by:](#)
 - [Damaging pavement that cars and buses use to get around,](#)
 - [Warping rail lines on which trains operate,](#)
 - [Reducing the lift available to planes, sometimes even forcing airport closures, and](#)
 - [Discouraging active transportation modes.](#)

2. ...affecting the performance of transportation systems and damaging infrastructure (continued).

- [Warmer winters could lead to more winter precipitation falling as rain instead of snow, which can increase flooding and runoff, cause more damaging freeze thaw cycles, and result in icier conditions.](#)

3. Transportation is a leading producer of greenhouse gas emissions (GHGs).

- [Transportation is the largest producer of GHG emissions among all sectors in the U.S., accounting for 28.5 percent of total production.](#)
- [In 2015, transportation accounted for almost 40 percent of GHG emissions in Massachusetts.](#)
- [Almost half of transportation GHG emissions in Massachusetts are from passenger vehicles.](#)

4. Massachusetts has aggressive goals in place to mitigate the effects of and adapt to climate change.

- [In 2008, through the passage of the Global Warming Solutions Act, Massachusetts committed to reduce its GHG emissions by 80 percent below 1990 baseline levels by 2050.](#)
- [Massachusetts has several ongoing vulnerability assessments, including a focus on the transportation sector.](#)
- [Massachusetts is establishing an integrated climate change strategy for the Commonwealth through the implementation of Executive Order 569, which was issued in 2017 and had major elements codified in 2018.](#)
- [The Regional Greenhouse Gas Initiative \(RGGI\) is a cap-and-trade program covering CO₂ Emissions from larger power plants in some Mid-Atlantic and North-Eastern states. The RGGI program issues a limited number of tradable allowances that permit the emission of one ton of CO₂ from a power plant covered by the program.](#)
- [Massachusetts is incorporating climate considerations into other planning processes, including the freight plan.](#)

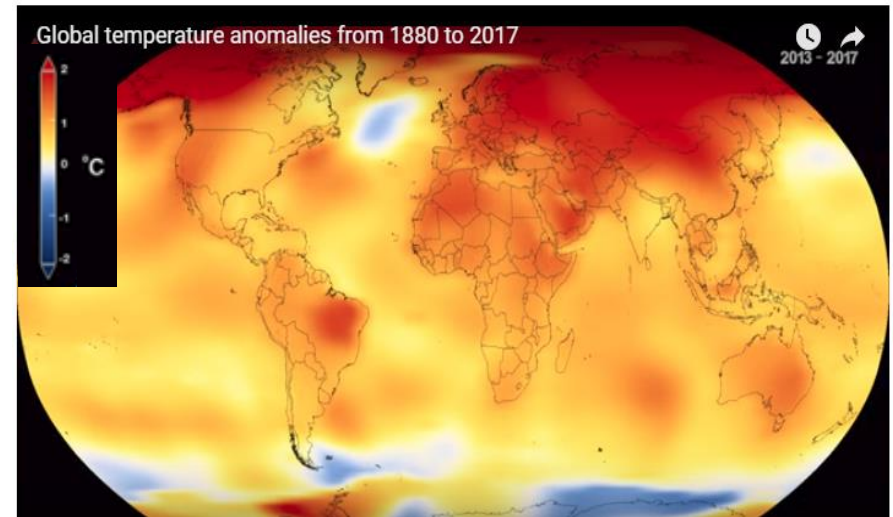
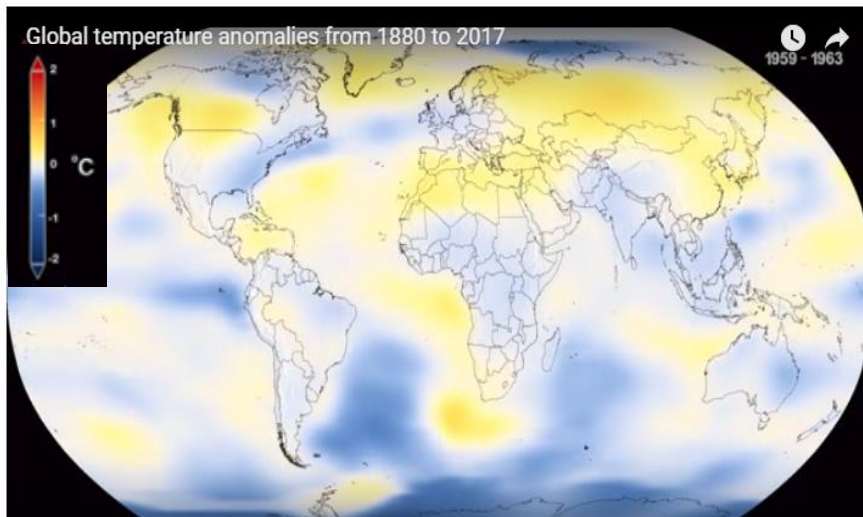
5. Making infrastructure resilient to climate change will be a complex and ongoing effort.

- [Sea level rise, coupled with storm surge, will continue to increase the risk of major coastal impacts on transportation infrastructure, including both temporary and permanent flooding of airports, ports and harbors, roads, rail lines, tunnels, and bridges.](#)
- [Interconnectedness can lead to cascading failures, even in systems that are not directly affected by a storm or extreme weather event, such as healthcare systems or hospitals impacted because of a lack of electricity or clean water.](#)
- [Telecommunications providers in Boston share critical infrastructure networks to provide service, meaning there is little redundancy; a single critical failure could eliminate all forms of communication except radio in a flood or disaster.](#)
- [Thirteen of the 47 largest U.S. airports have at least one runway within 12 feet of sea level \(though Boston is not among these\), and many are within the projected 50-year coastal storm surge.](#)

1. Climate change leads to higher temperatures, sea level rise, flooding, and more extreme weather events...

- [Globally, average temperatures in 2017 were 1.62°F warmer than the 1951 to 1980 mean.](#)¹

Global Temperature Change 1880 to 2017¹

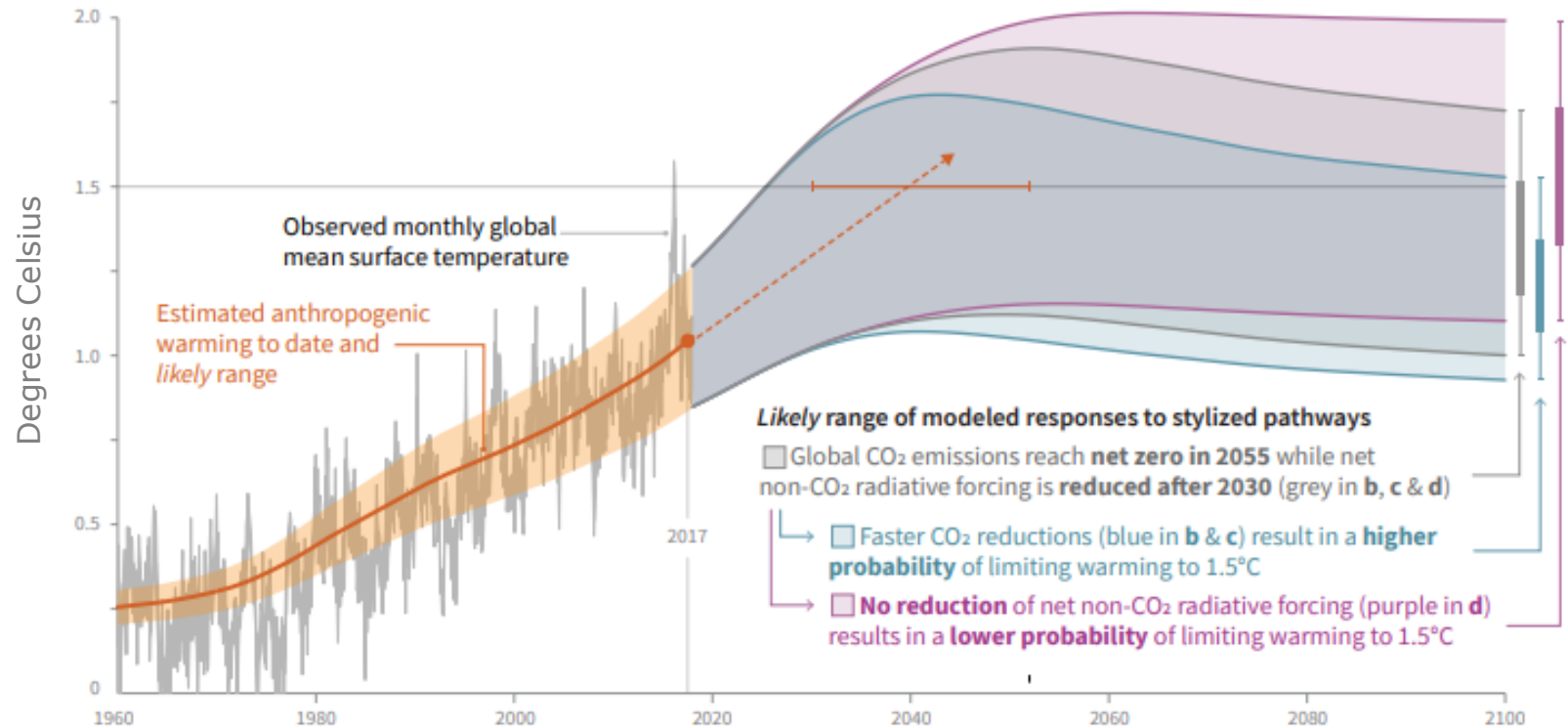


1. NASA. (2017). *Graphic: Global warming from 1880 to 2017*. https://climate.nasa.gov/climate_resources/139/graphic-global-warming-from-1880-to-2017/

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- [Temperatures in the Northeastern U.S. are projected to rise higher, faster than the rest of the country and the globe. By 2035, projections for this region are 3.6°F \(2°C\) warmer on average than during the preindustrial era.](#)²

Global Warming Forecasts Relative to 1850 - 1900¹



1. Intergovernmental Panel on Climate Change (2018). *Special Report on Global Warming of 1.5 °C (SR15)*. <http://www.ipcc.ch/report/sr15/>

2. Dupigny-Giroux, L.A., E.L. Mccray, M.D. Lemcke-Stampone, G.A. Hodgkins, E.E. Lentz, K.E. Mills, E.D. Lane, R. Miller, D.Y. Hollinger, W.D. Solecki, G.A. Wellenius, P.E. Sheffield, A.B. MacDonald, and C. Caldwell (2018). *Northeast. In Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II* [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA. doi: 10.7930/NCA4.2018.CH18. <https://nca2018.globalchange.gov/chapter/18/>

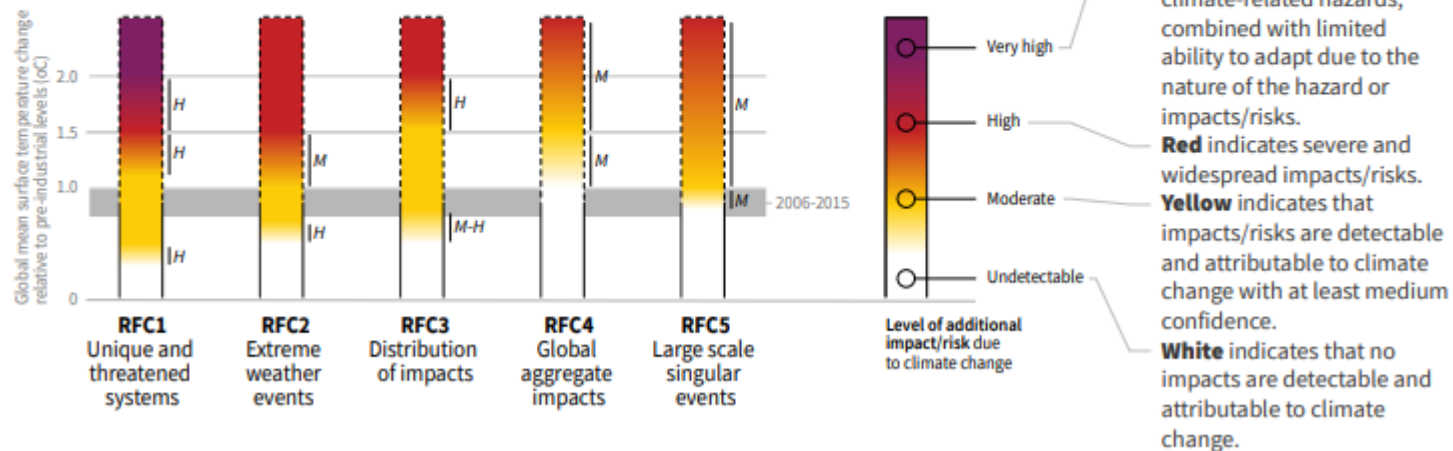
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- [While climate-related risks for global warming of 1.5°C are higher than at present, it is significantly better than a warming of 2°C.](#)¹

Five Primary Reasons for Concern About Global Warming and their Severity for Different Amounts of Warming

Five Reasons For Concern (RFCs) illustrate the impacts and risks of different levels of global warming for people, economies and ecosystems across sectors and regions.

Impacts and risks associated with the Reasons for Concern (RFCs)

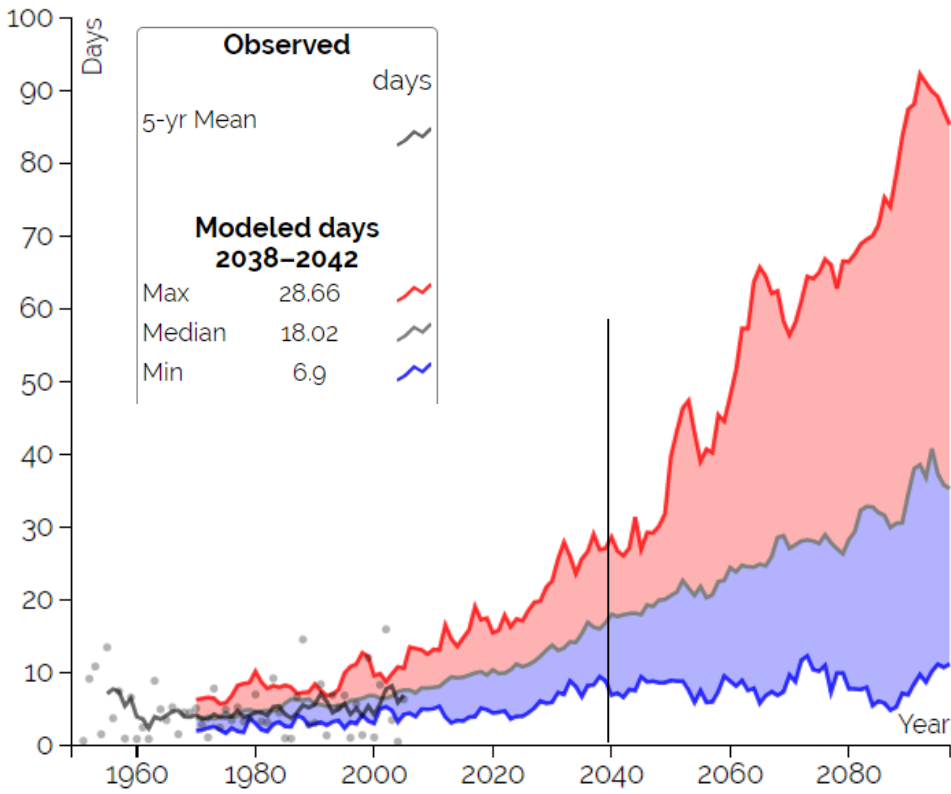


- Unique and threatened systems include coral reefs, the Arctic, mountain glaciers, and biodiversity hotspots.
- Extreme weather events include heat waves, heavy rain, drought and associated wildfires, and coastal flooding.
- Distribution of impacts means risks that disproportionately affect particular groups due to uneven distribution of physical climate change hazards, exposure or vulnerability.
- Global aggregate impacts include global monetary damage, global scale degradation and loss of ecosystems and biodiversity.
- Large-scale singular events include disintegration of the Greenland and Antarctic ice sheets.

1. Climate change leads to higher temperatures, sea level rise, flooding, and more extreme weather events...

- [There are predicted to be as many as 29 days over 90 degrees by 2040 in Massachusetts \(there were only 11 in 1990\) and more in urban areas.](#)¹
- [Heat waves are associated with thousands of deaths in developed countries.](#)²

Annual Days with Maximum Temperature Above 90°F in Massachusetts¹



*Baseline represents historical average from 1971-2000. Upper values from high emissions scenario. Lower values from low emissions scenario.

Massachusetts Observed Climate Changes

- Temperature: **↑ 2.9°F** Since 1895 (Statewide)
- Growing Season: **↑ 15 Days** Since 1950
- Sea Level Rise: **↑ 11 inches** Since 1922 (Boston)
- Heavy Precipitation: **↑ 55%** Since 1958

Source: Climate Special Report, 2017; NOAA NCEI nClimDiv; NOAA Ocean Service

Massachusetts Climate Changes Projected by the 2090s

- Temperature: **↑ 7.2°F** Average Annual; Range: 4 to 11 °F
- 90°F Days: **↑ 34** Annual; Range: 11 to 64 days
- Sea Level Rise: **↑ 4 to 10.2 feet** Relative to mean sea level in 2000
- 2" Precipitation Days: **↑ 47%** Annual

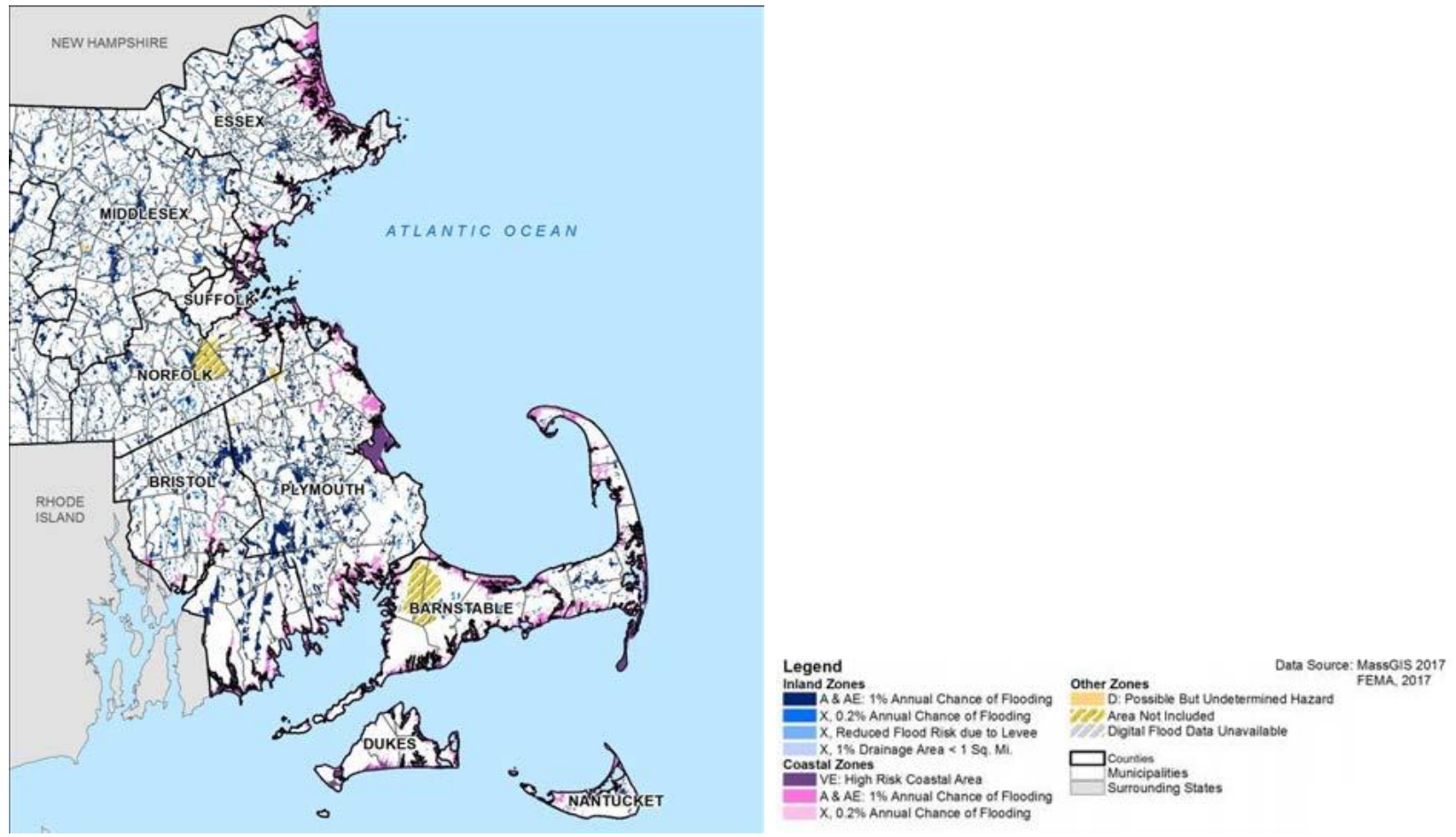
Source: Northeast Climate Adaptation Science Center

1. Resilient MA. (2018). *Climate Data Grapher*. <http://www.resilientma.org/datagrapher/?c=Temp/state/maxt/ANN/MA/>
 2. National Academies Press. (2016). *Attribution of Particular Types of Extreme Events*. <https://www.nap.edu/read/21852/chapter/6#113>

1. Climate change leads to higher temperatures, sea level rise, flooding, and more extreme weather events...

- Increasing GHG levels will exacerbate the risk of coastal flooding in the Commonwealth.^{1,2}

FEMA Flood Hazard Areas in Coastal Region² 2018 Massachusetts Hazard Mitigation and Climate Adaptation Plan



1. Massachusetts Department of Public Health, Bureau of Environmental Health. (2017). *Massachusetts Statewide Flood Zone Map*. <http://resilientma.org/resources/resource::1649/massachusetts-statewide-flood-zone-map>

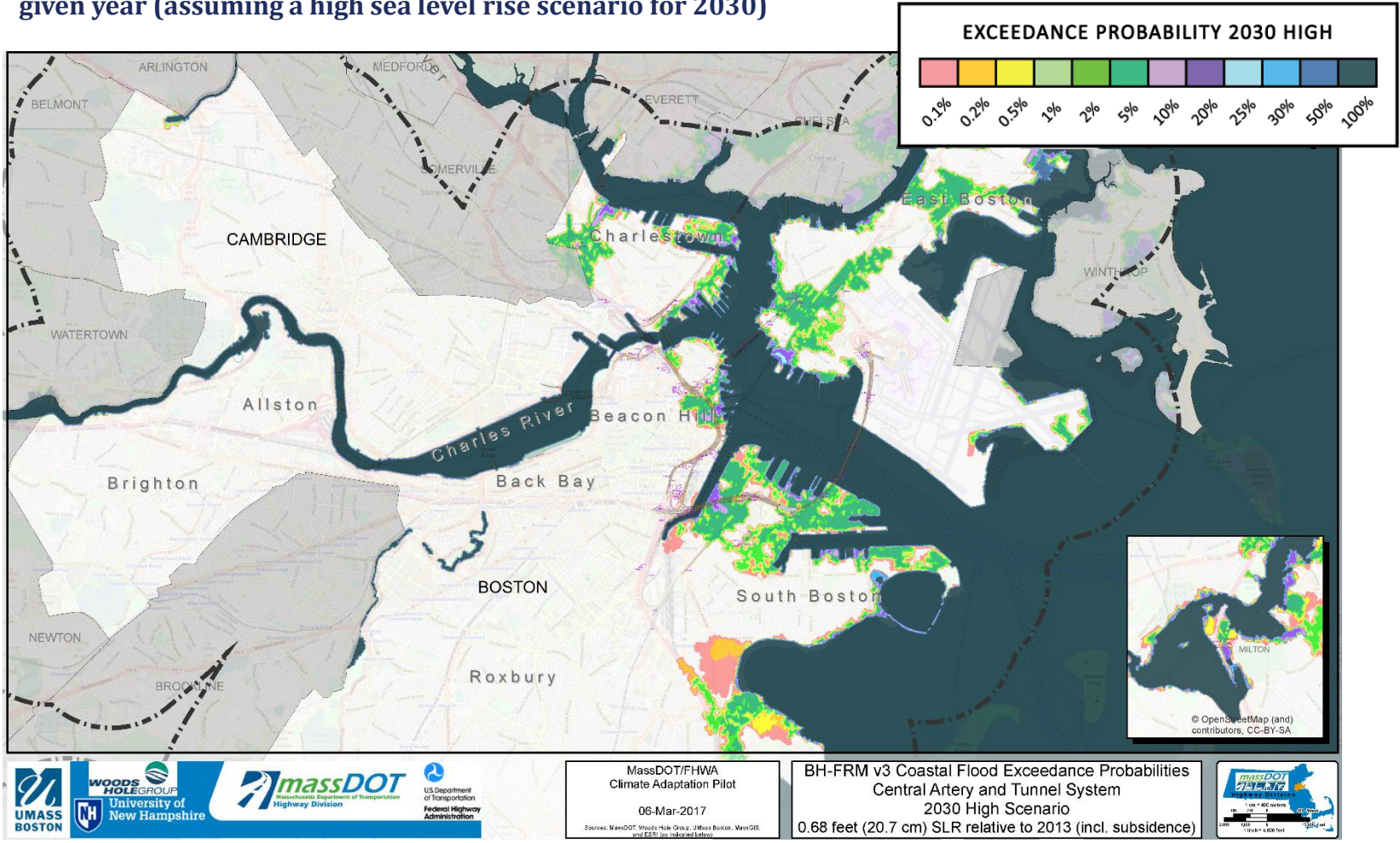
2. Massachusetts Executive Office of Energy and Environmental Affairs. (2018). *Massachusetts State Hazard Mitigation and Climate Adaptation Plan*. <https://www.mass.gov/service-details/massachusetts-integrated-state-hazard-mitigation-and-climate-adaptation-plan>

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- Increasing GHG levels will exacerbate the risk of coastal flooding in the Commonwealth.¹

Boston Harbor Flood Risk Model: Coastal Flood Exceedance Probabilities¹

This map shows the likelihood that a location will be flooded by 2 or more inches of water in any given year (assuming a high sea level rise scenario for 2030)

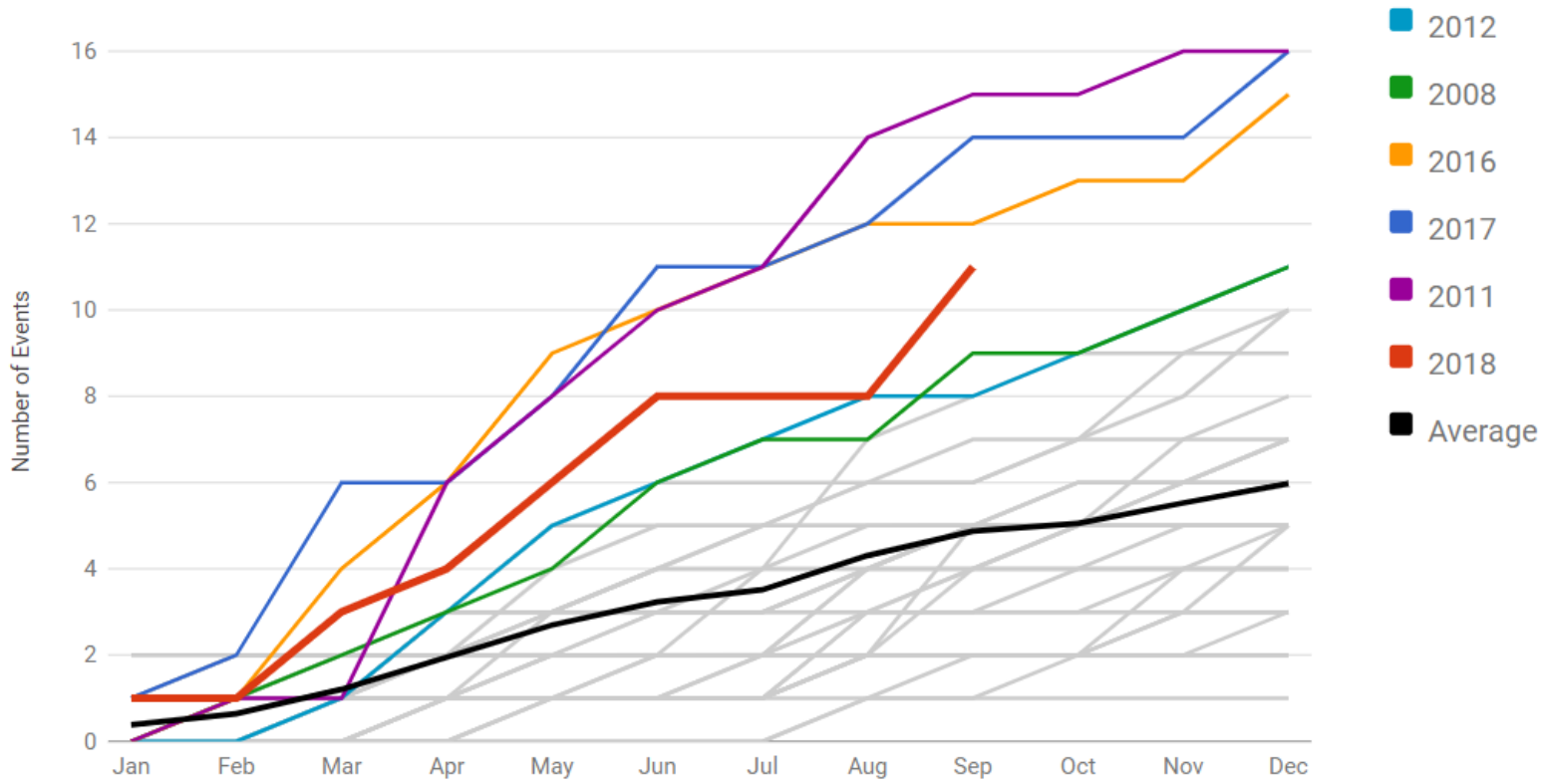


1. Commonwealth of Massachusetts. (2017). *Climate Change Resiliency*. <https://www.mass.gov/info-details/climate-change-resiliency>

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- [Since 1991, Boston has experienced 21 events that triggered federal or state disaster declarations.](#)¹
- [Weather events causing over a billion dollars in damage are increasing nationally.](#)²

1980-2018 Year-to-Date U.S. Billion-Dollar Disaster Event Frequency (CPI-Adjusted)
 Event statistics are added according to the date on which they ended.²



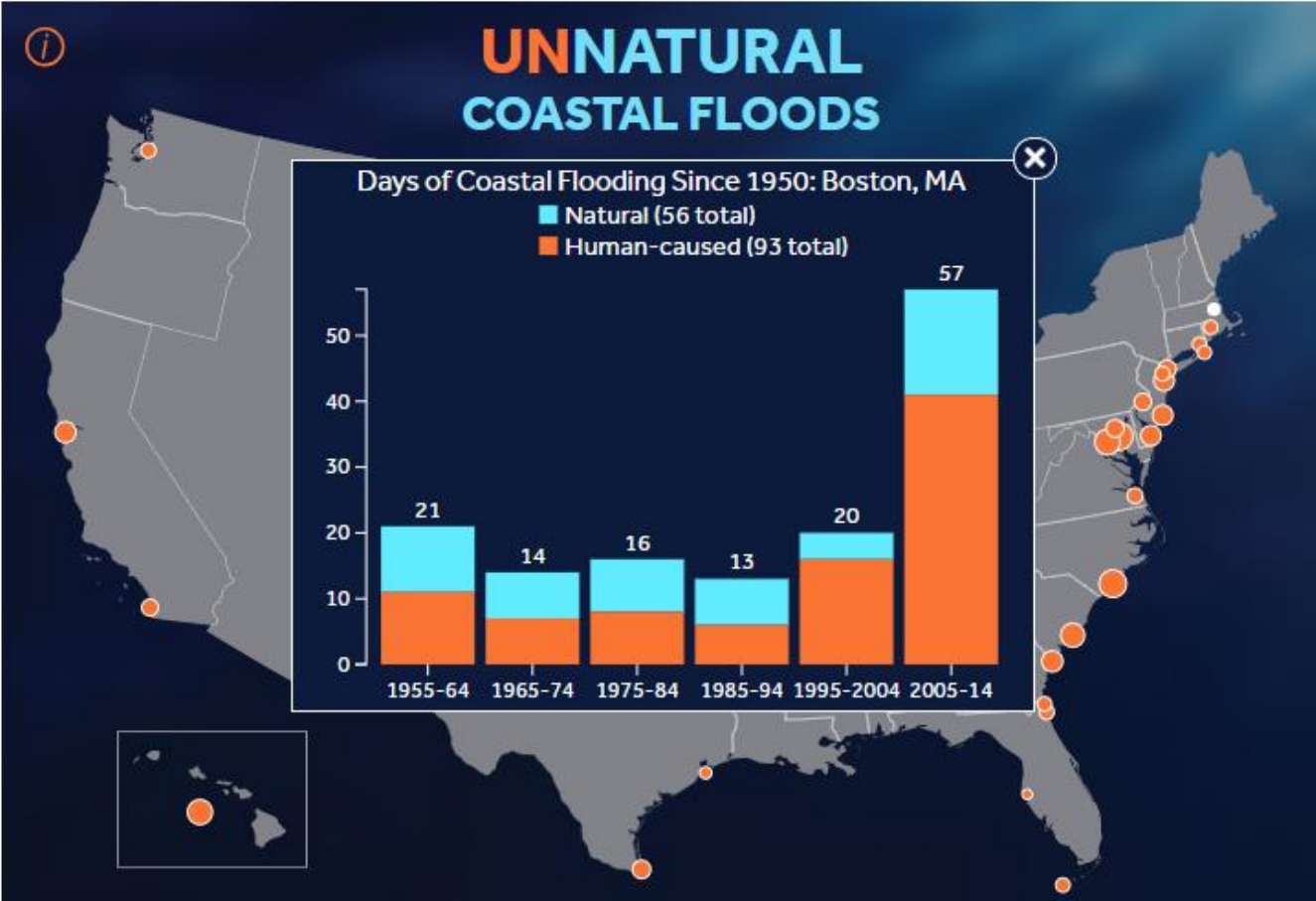
Statistics valid as of October 9, 2018.

1. City of Boston. (2016). *Climate Ready Boston*. https://www.boston.gov/sites/default/files/20161207_climate_ready_boston_digital2.pdf
 2. National Oceanic and Atmospheric Information. (2018). *Billion-Dollar Weather and Climate Disasters: Overview*. <https://www.ncdc.noaa.gov/billions/>

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- [Nuisance flooding will also become an increasing problem for coastal areas.](#)¹
- [Massachusetts experienced 57 flood days from 2005 to 2014, of which 72 percent can be attributed to climate change.](#)²

Trend: Days of Coastal Flooding Increasing²



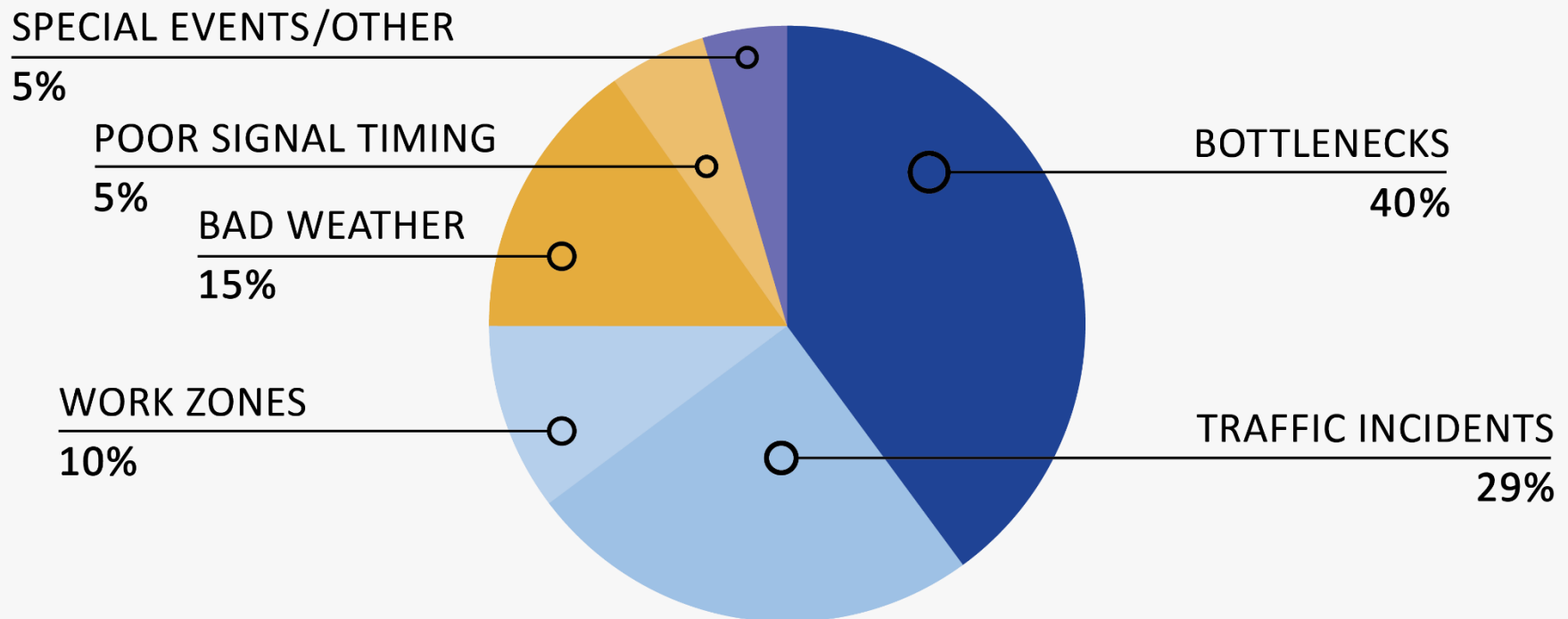
1. Climate Central. (2016). *Sea Level Rise Upping Ante On 'Sunny Day' Floods*. <http://www.climatecentral.org/news/climate-change-increases-sunny-day-floods-20784>

2. State at Risk. (2016). *Massachusetts Coastal Flooding*. <http://statesatrisk.org/massachusetts/coastal-flooding>

2. ...affecting the performance of transportation systems and damaging infrastructure.

- [Bad weather accounts for 15 percent of all roadway congestion nationally.](#)¹
- [Transit agencies cancel trips and service gets delayed due to freezing rain or icy road conditions.](#)²
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The Sources of Traffic Congestion¹
National Summary

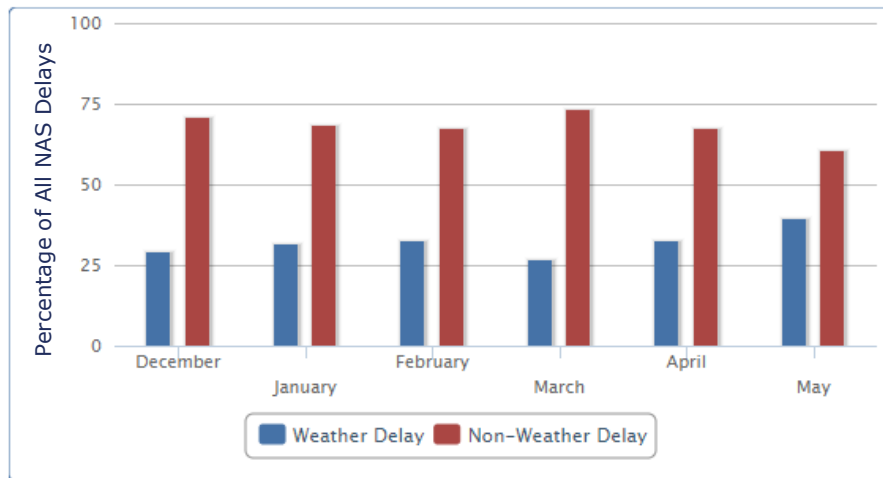


1. FHWA. (2017). *Traffic Congestion and Reliability: Trends and Advanced Strategies for Congestion Mitigation*. https://ops.fhwa.dot.gov/congestion_report/chapter3.htm Data based on 2004 studies by Oak Ridge National Labs and Texas Transportation Institute
2. Pioneer Valley Transit Authority. (2015). *Winter Weather Travel Guide*. <http://www.pvta.com/weatherTravel.php>
3. New York Times. (2018). *New York Subway's On-Time Performance Hits New Low*. <https://www.nytimes.com/2018/03/19/nyregion/new-york-subways-on-time-performance-hits-new-low.html>

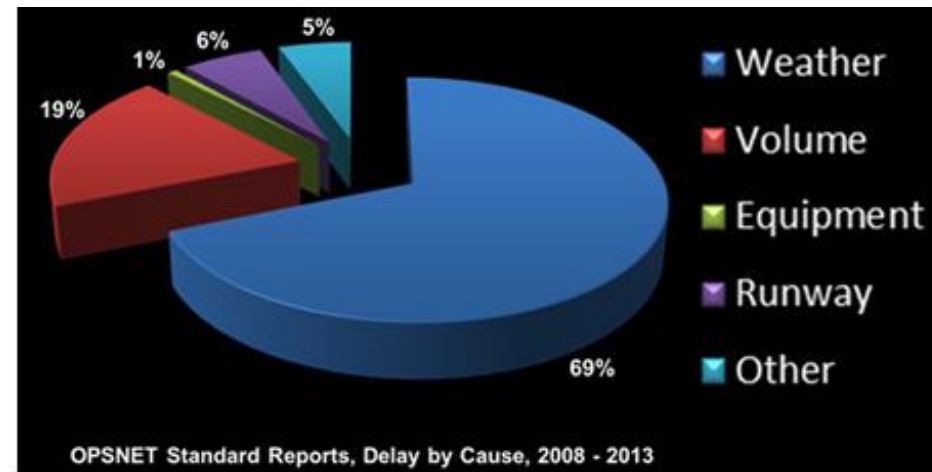
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- [Estimates suggest anywhere from 25 percent¹ to 69 percent of delay in the National Airspace System is caused by weather.²](#)

**Weather's Share of Delayed Flights – National¹
(December 2017-May 2018)**



**Causes of Air Traffic Delay
in the National Airspace System²**



1. Bureau of Transportation Statistics. (2018). *Airline On-Time Statistics and Delay Causes*.

https://www.transtats.bts.gov/OT_Delay/ot_delaycause1.asp?display=chart&pn=1

2. Federal Aviation Administration. (2017). *FAQ: Weather Delay*. <https://www.faa.gov/nextgen/programs/weather/faq/>

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 - [It could increase the availability of shipping lanes and allow heavier vehicles through some channels,](#)²
 - [The world's biggest shipping firm is testing a route through the Russian Arctic,](#)³ and

World's Biggest Shipping Firm to Test Russian Arctic Route³



ASSOCIATED PRESS/FILE 2013

CLAUS BONNERUP/POLFOTO FILE VIA

A.P. Moller-Maersk said it will send a cargo vessel through the Russian Arctic as a result of melting sea ice.

By Jan M. Olsen ASSOCIATED PRESS August 23, 2018

COPENHAGEN — Danish shipping group A.P. Moller-Maersk said Thursday it will send a cargo vessel through the Russian Arctic for the first time as a result of melting sea ice.

Janina von Spalding, spokeswoman for the world's biggest shipping company, said the new ice class container vessel, Venta Maersk, would embark on trial journey in the Arctic route over Russia next month.

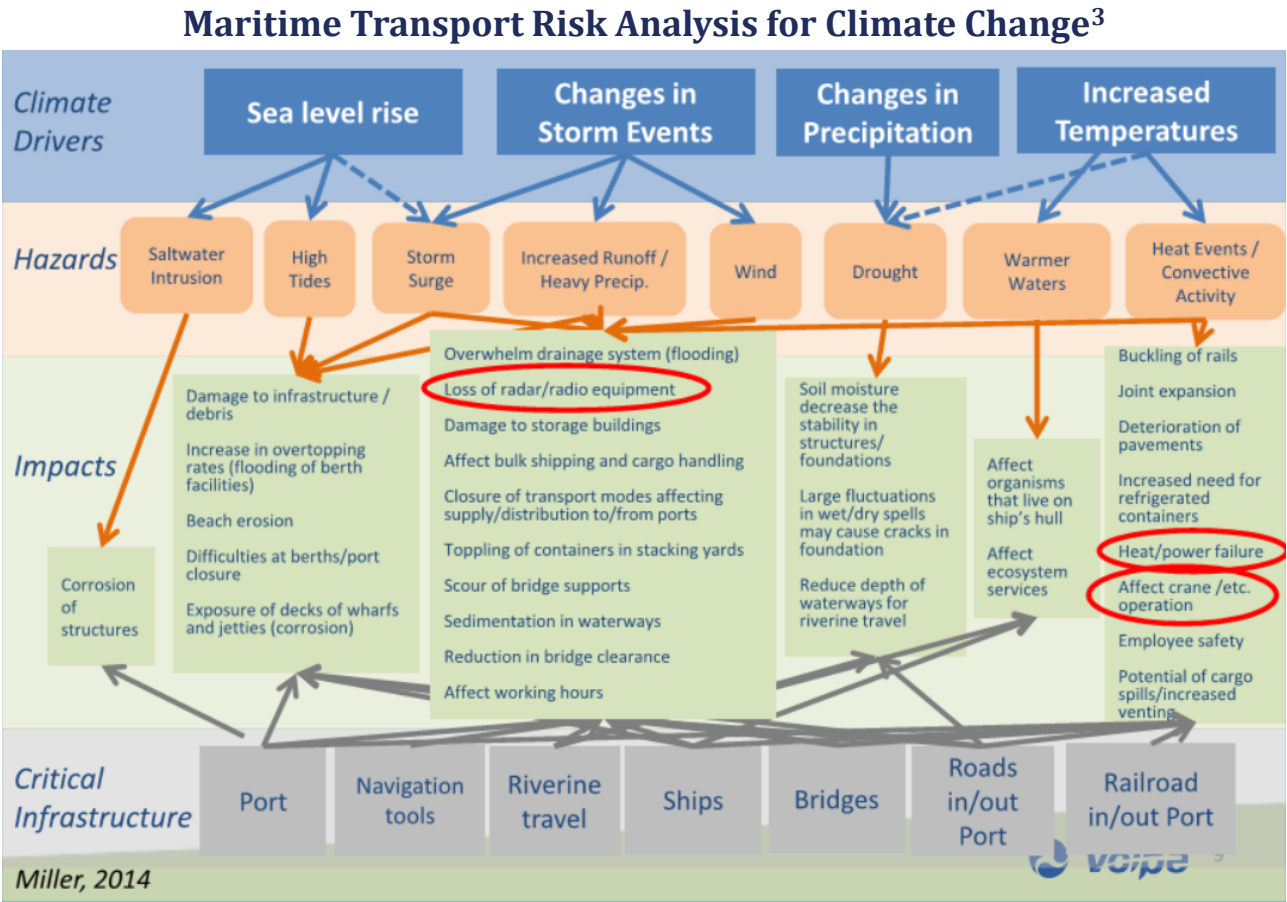
1. EPA. (2017). *Climate Impacts on Transportation*. https://19january2017snapshot.epa.gov/climate-impacts/climate-impacts-transportation_.html

2. Air Sea Containers. (2017). *How Global Warming Is Affecting Shipping Routes*. <http://www.airseacontainers.com/blog/how-global-warming-is-affecting-shipping-routes/>

3. AP News. (2018). *World's biggest shipping firm to test Russian Arctic route*. <https://www.apnews.com/4d7bb220356e408db4613e8e0e9d8e25>

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1. EPA. (2017). *Climate Impacts on Transportation*. https://19january2017snapshot.epa.gov/climate-impacts/climate-impacts-transportation_.html

2. Titus – EPA. (2001). *Does Sea Level Rise Matter to Transportation Along the Atlantic Coast?* https://cms.dot.gov/sites/dot.gov/files/docs/titus_Sea_Level_Rise_Matter_Transportation_Atlantic_Coast.pdf

3. USDOT - Volpe. *Transportation Resilience*. <https://www.mass.gov/doc/transportation-resilience-rawlings-miller-june-6-2018>

2. ...affecting the performance of transportation systems and damaging infrastructure.

- [Heat can degrade all modes of transportation by:](#)¹
 - [Damaging pavement that cars and buses use to get around,](#)²

Summary of Climate-Induced Pavement Deterioration and Consequences²



Climate Change Hazard	Asphalt	Rigid	Modular
Excess water	<ul style="list-style-type: none"> • Binder stripping, particularly at asphalt layer interfaces • Surface scouring • Hydroplaning in water-filled ruts • Accelerated polishing of surfacing 	<ul style="list-style-type: none"> • Water passing through cracks and joints • Surface damage during paving 	<ul style="list-style-type: none"> • Erosion of jointing and bedding sands, resulting in the loss of structural support, rutting, spalling, cracking, movement of modules, and formation of trips.
Soil moisture deficit	<ul style="list-style-type: none"> • Subsidence • Cracking 		
High temperatures	<ul style="list-style-type: none"> • Increased rutting • Fattening, resulting in reduced skid resistance • Binder softening, resulting in a loss of surface integrity • More rapid age hardening of binder, resulting in increased cracking • Contribution to heat island effect 	<ul style="list-style-type: none"> • Warping of concrete • Large seasonal joint movements • Compression failures at joints, in badly constructed or poorly maintained roads • Workability and curing problems with the concrete mixture 	<ul style="list-style-type: none"> • Expansion leading to cracking and spalling at interfaces and possible blow-up with large slabs • Bedding settlement creating warping and trips • Continuous expansion and contraction causing cracking • NB: Effects are greater in larger slabs

1. Better Institutions. (2013). *Extreme Temperatures are Affecting Every Mode of Transportation*. <http://www.betterinstitutions.com/blog/2013/07/extreme-temperatures-are-affecting>

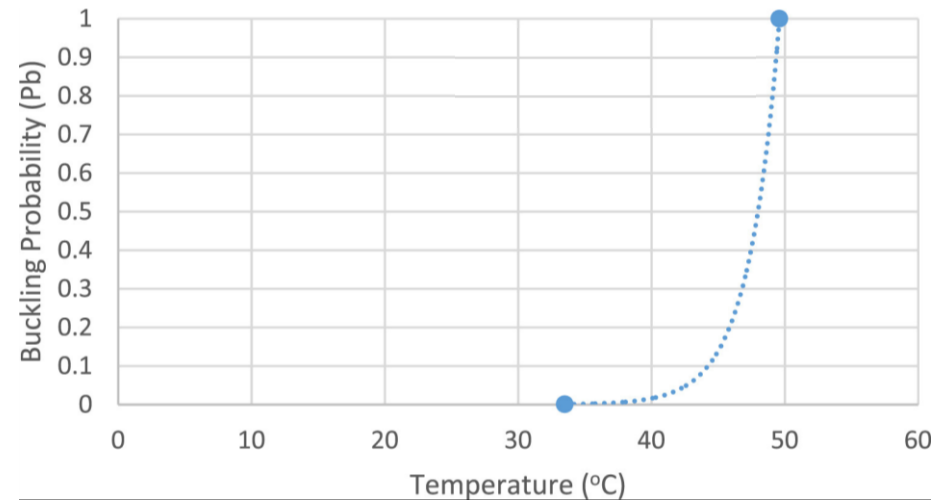
2. TRL. (2008). *The effects of climate change on highway pavements and how to minimize them: Technical report*. https://trl.co.uk/sites/default/files/PPR184_secure.pdf

2. ...affecting the performance of transportation systems and damaging infrastructure.

- [Heat can degrade all modes of transportation by:](#)¹
 - [Warping rail lines on which trains operate,](#)²



Probability of Rail Line Buckling Across Different Temperatures²



1. Better Institutions. (2013). *Extreme Temperatures are Affecting Every Mode of Transportation*. <http://www.betterinstitutions.com/blog/2013/07/extreme-temperatures-are-affecting>

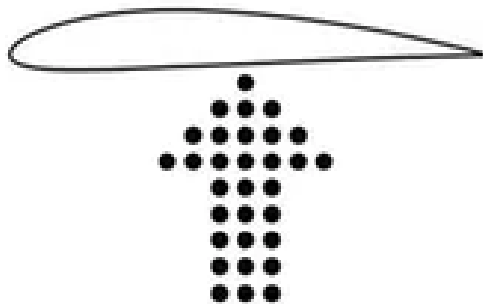
2. Transport Policy. (2017). *Impacts of climate change on operation of the US rail network*. <https://www.sciencedirect.com/science/article/pii/S0967070X16308198>

2. ...affecting the performance of transportation systems and damaging infrastructure.

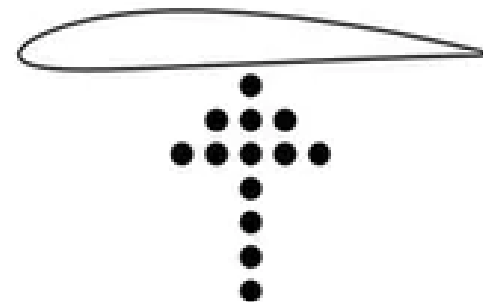
- [Heat can degrade all modes of transportation by:](#)¹
 - [Reducing the lift available to planes, sometimes even forcing airport closures, and](#)²
 - [Discouraging active transportation modes.](#)³
- [Warmer winters could lead to more winter precipitation falling as rain instead of snow, which can increase flooding and run-off, cause more damaging freeze-thaw cycles, and result in icier conditions.](#)⁴

Temperature Impacts Lift Available to Planes²

Cold temperature =
more air, more lift



Hot temperature =
less air, less lift

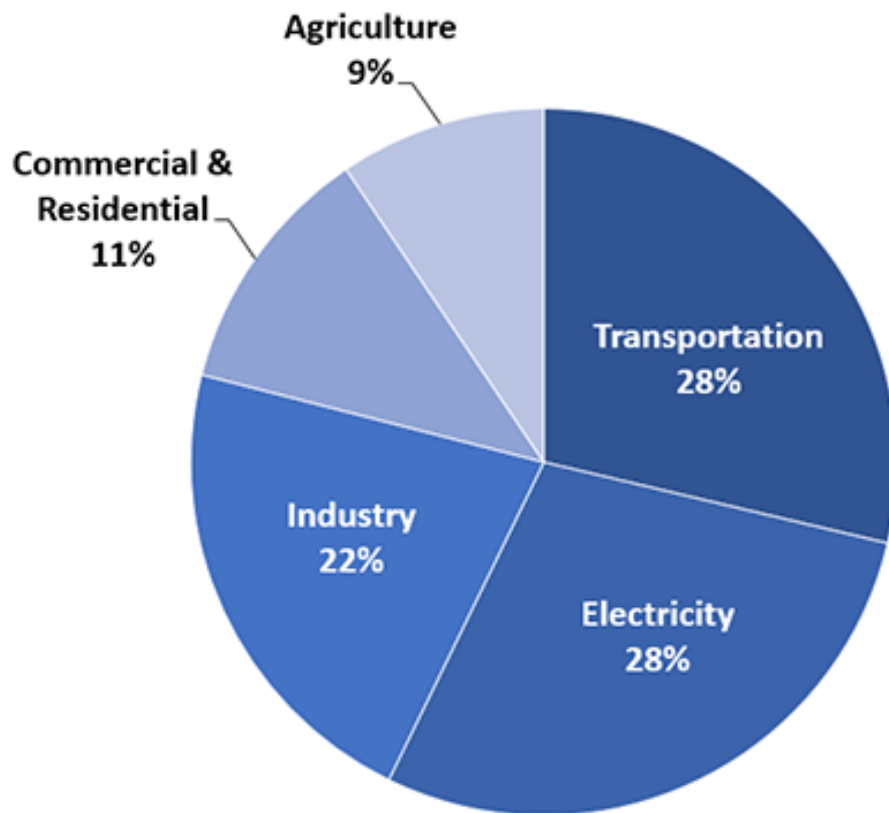


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1. Better Institutions. (2013). *Extreme Temperatures are Affecting Every Mode of Transportation*. <http://www.betterinstitutions.com/blog/2013/07/extreme-temperatures-are-affecting>
 2. The Conversation. (2017). *How hot weather – and climate change – affect airline flights*. <https://theconversation.com/how-hot-weather-and-climate-change-affect-airline-flights-80795>
 3. Transport Reviews. (2013). *Impact of Everyday Weather on Individual Daily Travel Behaviours in Perspective: A Literature Review*. https://www.researchgate.net/publication/262900761_Impact_of_Everyday_Weather_on_Individual_Daily_Travel_Behaviours_in_Perspective_A_Literature_Review
 4. EPA. (2017). *Climate Impacts on Transportation*. https://19january2017snapshot.epa.gov/climate-impacts/climate-impacts-transportation_.html

3. Transportation is a leading producer of greenhouse gas emissions (GHGs).

- [Transportation is the largest producer of GHG emissions among all sectors in the U.S., accounting for 28.5 percent of total production.](#)¹

Total U.S. Greenhouse Gas Emissions by Economic Sector, 2016¹



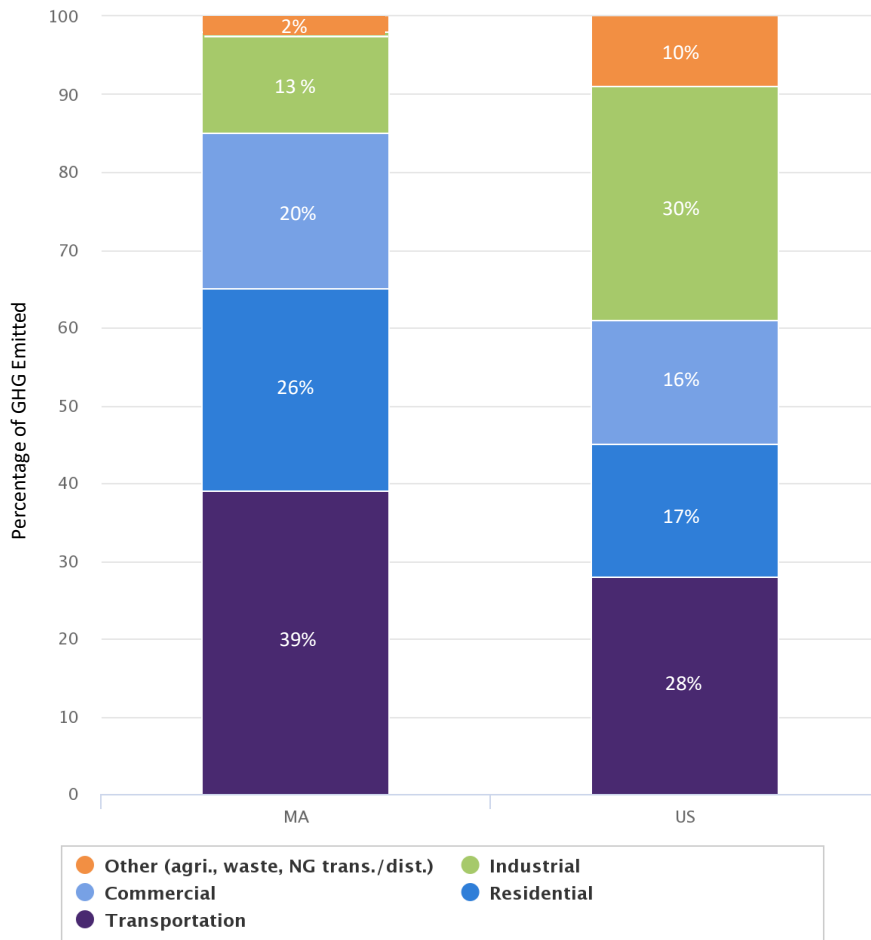
U.S. Environmental Protection Agency (2018). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2016

1. EPA. (2018). Sources of Greenhouse Gas Emissions. <https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions>

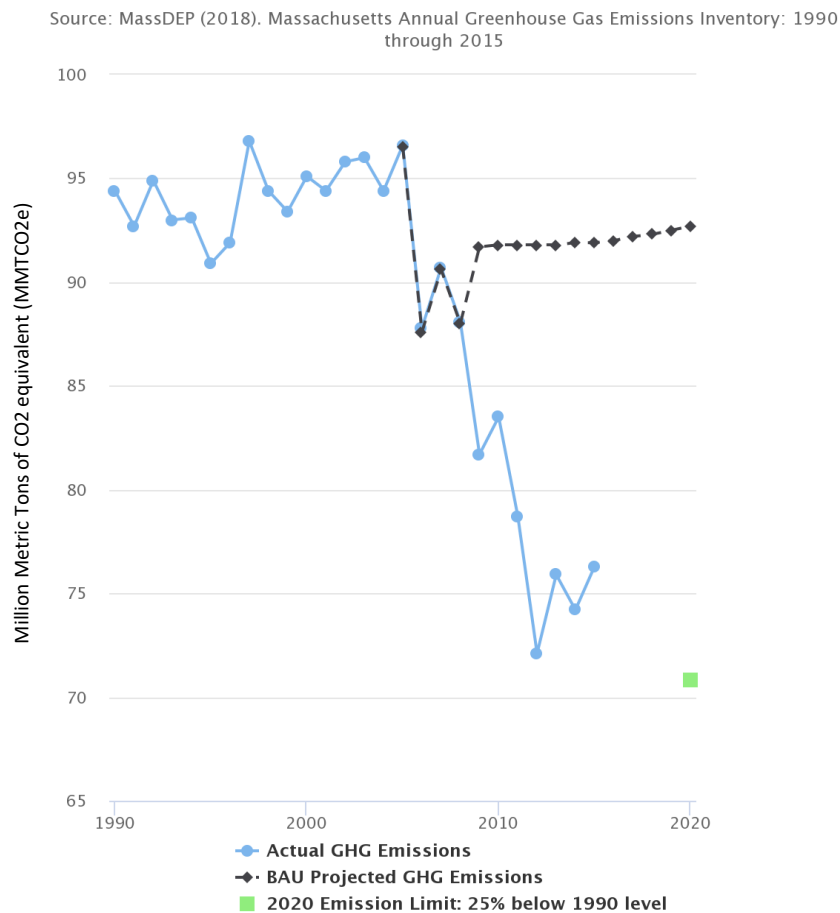
3. Transportation is a leading producer of greenhouse gas emissions (GHGs).

- In 2015, transportation accounted for almost 40 percent of GHG emissions in Massachusetts.¹

Massachusetts and U.S. GHG Emissions by Sector, 2015¹



Massachusetts GHG Emissions, Business-As-Usual (BAU)¹

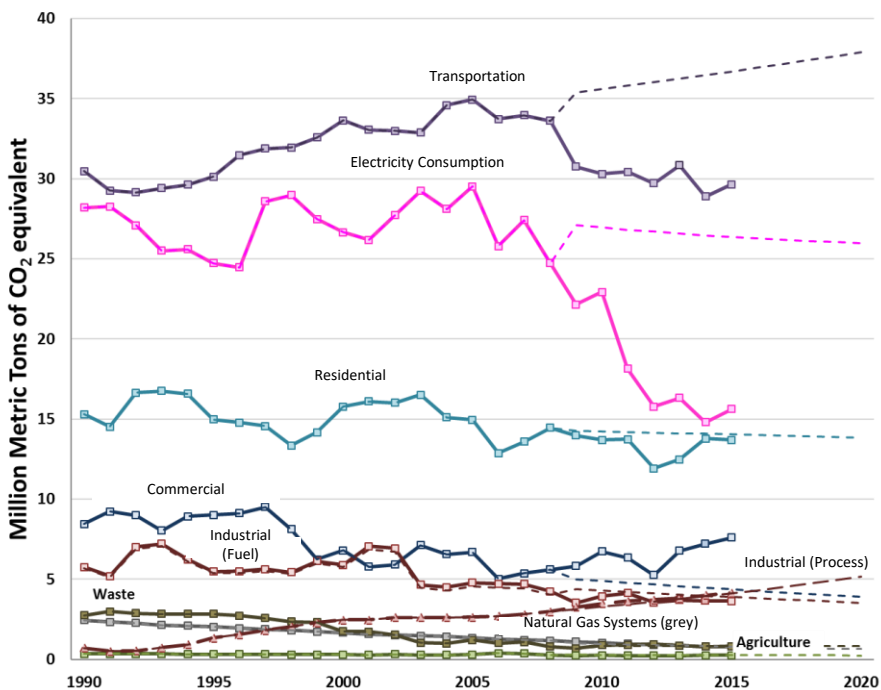


1. Commonwealth of Massachusetts. (2015). MA GHG Emission Trends. <https://www.mass.gov/service-details/ma-ghg-emission-trends/>

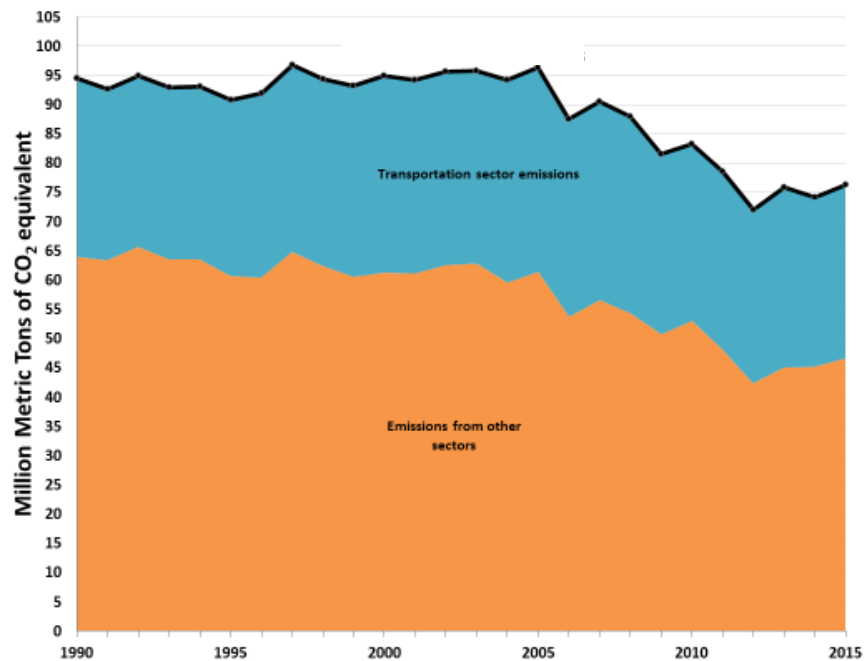
3. Transportation is a leading producer of greenhouse gas emissions (GHGs).

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Massachusetts GHG Emissions from Fuel Combustion (by Sector)¹



Massachusetts Gross GHG Emissions¹

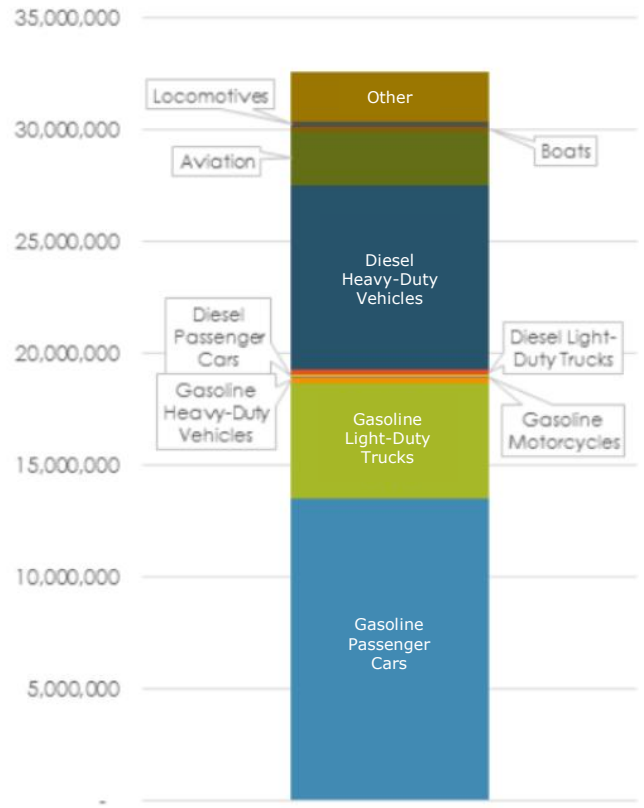


1. Commonwealth of Massachusetts. (2015). MA GHG Emission Trends. <https://www.mass.gov/service-details/ma-ghg-emission-trends>

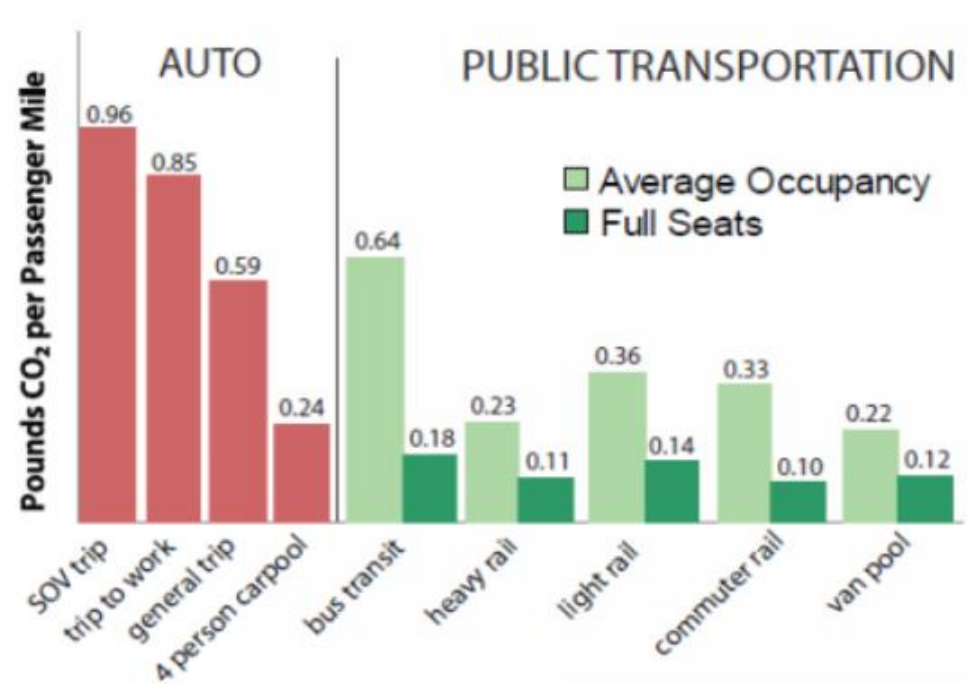
3. Transportation is a leading producer of greenhouse gas emissions (GHGs).

- [Almost half of transportation GHG emissions in Massachusetts are from passenger vehicles.](#)¹

Massachusetts CO₂ Emissions from Mobile Sources (MTCO₂E)¹



CO₂ Emissions Comparison for Different Transportation Modes¹

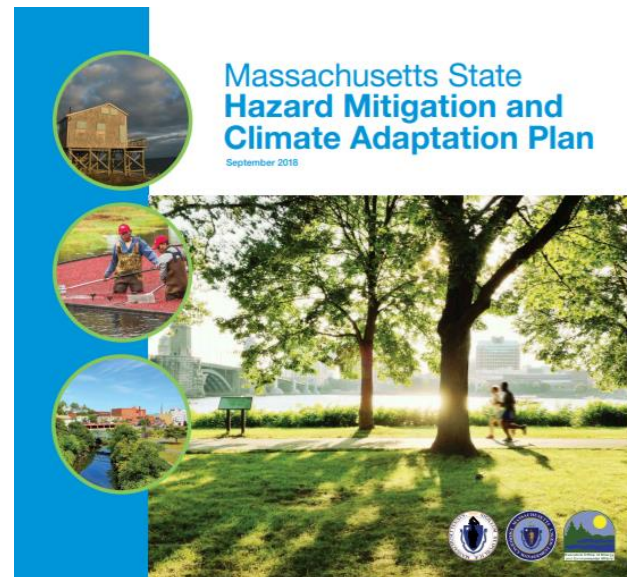


1. MassDOT. (2018). *Decarbonizing Transportation: Challenges and Opportunities*. <https://www.mass.gov/doc/decarbonizing-transportation-challenges-and-opportunities-stephanie-pollack-june-15-2018>

4. Massachusetts has aggressive goals in place to mitigate the effects of and adapt to climate change.

- [In 2008, through the passage of the Global Warming Solutions Act, Massachusetts committed to reduce its GHG emissions by 80 percent below 1990 baseline levels by 2050.](#)¹
- [Massachusetts has several ongoing vulnerability assessments, including a focus on the transportation sector.](#)²
- [Massachusetts is establishing an integrated climate change strategy for the Commonwealth through the implementation of Executive Order 569, which was issued in 2017 and had major elements codified in 2018.](#)^{3,4}
- [The Regional Greenhouse Gas Initiative \(RGGI\) is a cap-and-trade program covering CO₂ Emissions from larger power plants in some Mid-Atlantic and North-Eastern states. The RGGI program issues a limited number of tradable allowances that permit the emission of one ton of CO₂ from a power plant covered by the program.](#)⁵

Massachusetts is Taking Action to Mitigate and Adapt to Climate Change³



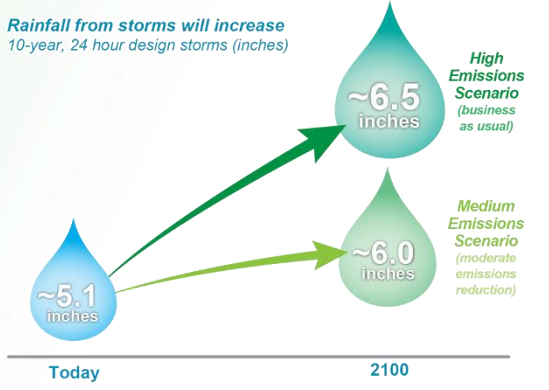
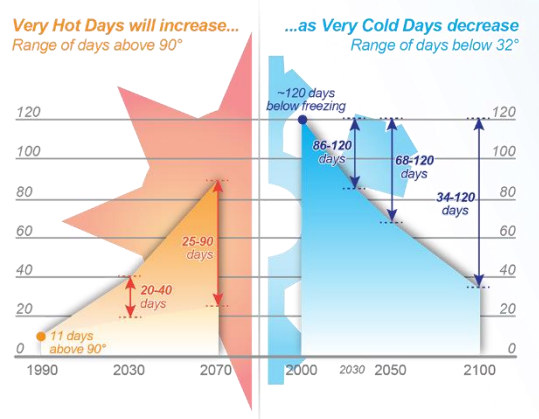
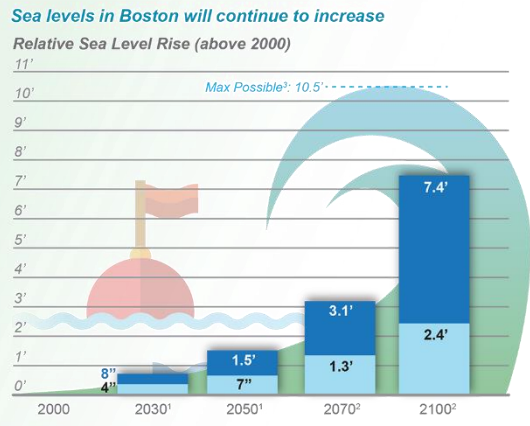
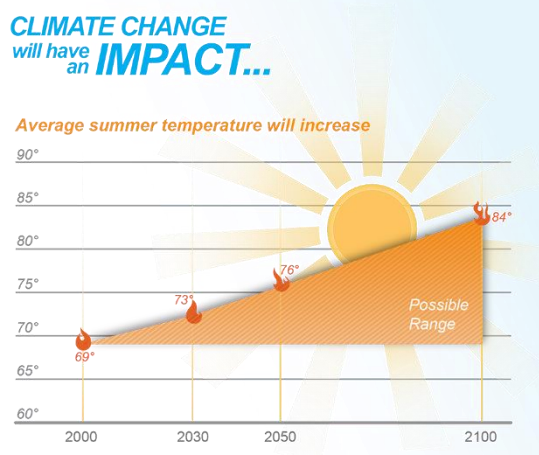
1. Commonwealth of Massachusetts. (2008). *Global Warming Solutions Act Background*. <https://www.mass.gov/service-details/global-warming-solutions-act-background>
2. Commonwealth of Massachusetts. (2018). *Climate change resiliency*. <https://www.mass.gov/info-details/climate-change-resiliency>
3. Commonwealth of Massachusetts. (2018). *MassDOT Statewide Climate Change Adaptation Plan*. <https://www.mass.gov/massdot-statewide-climate-change-adaptation-plan>
4. Commonwealth of Massachusetts. (2018). *Governor Baker Signs Legislation Directing \$2.4 Billion to Climate Change Adaptation, Environmental Protection, and Community Investments*. <https://www.mass.gov/news/governor-baker-signs-legislation-directing-24-billion-to-climate-change-adaptation>
5. Analysis Group (2018). *The Economic Impacts of the Regional Greenhouse Gas Initiative on Nine Northeast and Mid-Atlantic States: Review of RGGI's Third Three-Year Compliance Period (2015-2017)*. http://www.analysisgroup.com/uploadedfiles/content/insights/publishing/analysis_group_rggi_report_april_2018.pdf
6. Compliance Period (2015-2017). http://www.analysisgroup.com/uploadedfiles/content/insights/publishing/analysis_group_rggi_report_april_2018.pdf

4. Massachusetts has aggressive goals in place to mitigate the effects of and adapt to climate change.

- Massachusetts is incorporating climate considerations into other planning processes, including the freight plan¹

The MassDOT Freight Plan Considers Climate Change¹

Drivers of the Future | **CLIMATE**

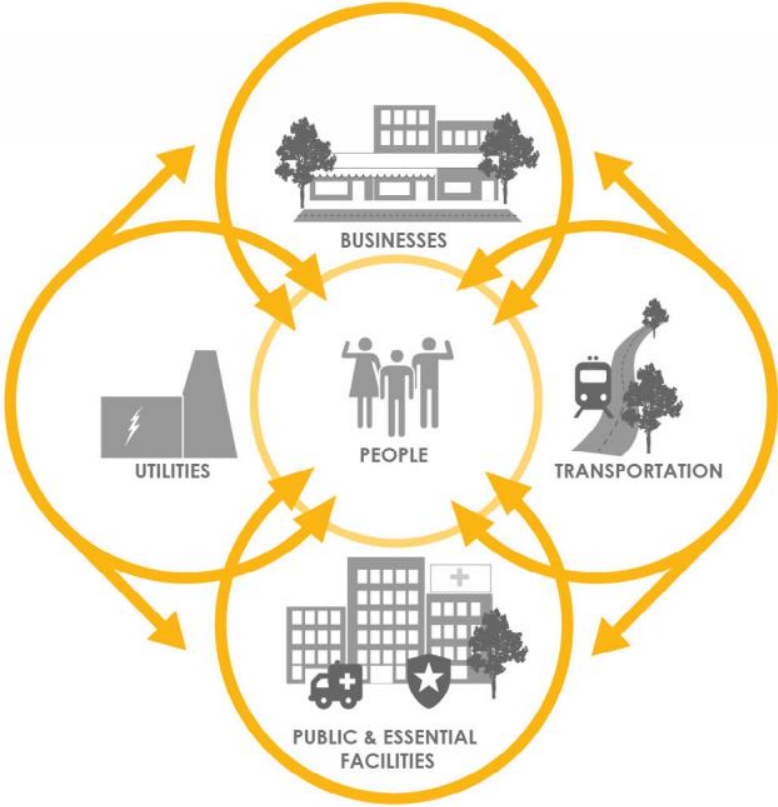


1. MassDOT. (2018). *Freight Plan*. <https://www.mass.gov/service-details/freight-plan>

5. Making infrastructure resilient to climate change will be a complex and ongoing effort.

- [Sea level rise, coupled with storm surge, will continue to increase the risk of major coastal impacts on transportation infrastructure, including both temporary and permanent flooding of airports, ports and harbors, roads, rail lines, tunnels, and bridges.](#)¹
- [Interconnectedness can lead to cascading failures, even in systems that are not directly affected by a storm or extreme weather event, such as healthcare systems or hospitals impacted because of a lack of electricity or clean water.](#)²

Our Daily Lives Depend on a Complex, Interconnected System²



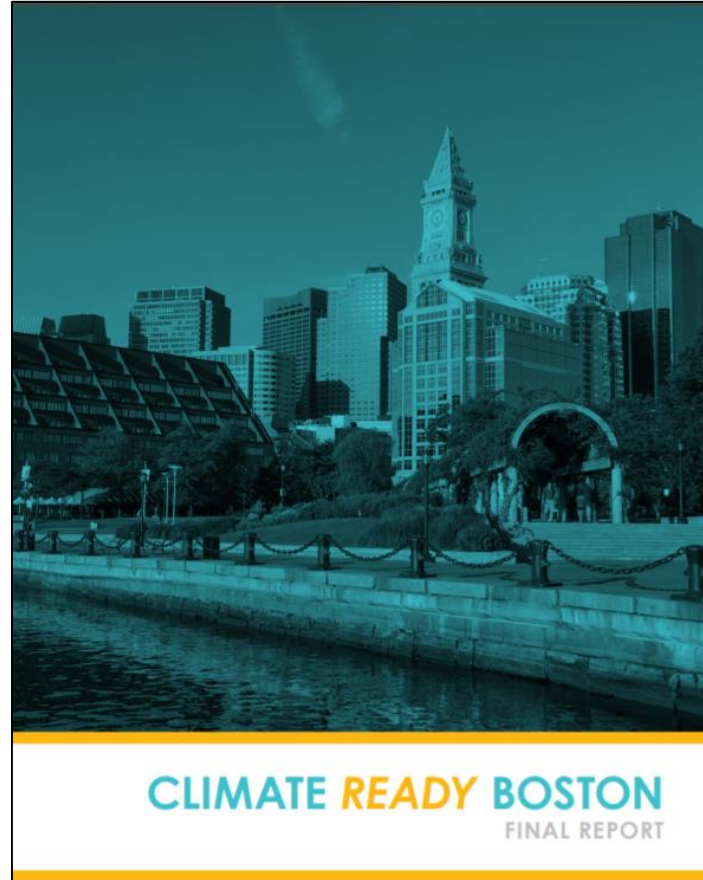
1. U.S. Global Change Research Program. (2014). *Infrastructure*. <https://nca2014.globalchange.gov/highlights/report-findings/infrastructure>

2. Scientific America. (2014). *Infrastructure Threatened by Climate Change Poses a National Crisis*. <https://www.scientificamerican.com/article/infrastructure-threatened-by-climate-change-poses-a-national-crisis/>

5. Making infrastructure resilient to climate change will be a complex and ongoing effort.

- [Telecommunications providers in Boston share critical infrastructure networks to provide service, meaning there is little redundancy; a single critical failure could eliminate all forms of communication except radio in a flood or disaster.](#)¹
- [Thirteen of the 47 largest U.S. airports have at least one runway within 12 feet of sea level \(though Boston is not among these\), and many are within the projected 50-year coastal storm surge.](#)²

Lack of Communication Redundancy is an Identified Concern¹



1. City of Boston. (2016). *Climate Ready Boston*. https://www.boston.gov/sites/default/files/20161207_climate_ready_boston_digital2.pdf

2. EPA. (2017). *Climate Impacts on Transportation*. https://19january2017snapshot.epa.gov/climate-impacts/climate-impacts-transportation_.html

TRANSPORTATION ELECTRIFICATION

Why does transportation electrification matter?

1. [Electric Vehicles \(EVs\) may not be prevalent today...](#)
2. [...but adoption projections have been steadily increasing...](#)
3. [...propelled by cheaper batteries and lower maintenance costs.](#)
4. [EVs will help lower emissions.](#)
5. [EVs will affect the grid.](#)
6. [EVs require infrastructure \(i.e. charging points\).](#)
7. [EVs will likely impact transportation revenue.](#)
8. [Battery EVs \(BEVs\) are not the only EVs.](#)
9. [Massachusetts has EV initiatives in place.](#)
10. [U.S. has significantly less electrified rail than the rest of the world.](#)

Summary

1. Electric Vehicles (EVs) may not be prevalent today...

- [Electric cars account for only a small portion \(.2 percent\) of passenger light-duty vehicles globally.](#)
- [Though they are growing quickly, in 2016 EVs accounted for 2 percent of worldwide sales of new cars \(two out of 86 million\).](#)
- [In 2017, 21 percent of all global EV sales were in just six Chinese cities, making China a driving force for global EV production.¹](#)
 - [China's 'New Energy Vehicle' credit system is the single most important piece of EV policy globally and is shaping automakers' electrification plans.](#)
 - [The bulk of automakers' new investments in EVs are earmarked for China.](#)
- [In the U.S., EVs accounted for only slightly more than 1 percent of new car sales.](#)
- [In 2017, only 12,000 of 2.37 million registered vehicles in Massachusetts were EVs,](#)
- [and 1.35 percent of new light vehicles sold in Massachusetts were electric.](#)

2. ... but adoption projections have been steadily increasing...

- [Energy stakeholders have consistently increased their forecasts of EV adoption over time.](#)
- [Without any major policy changes to incent electrification, Massachusetts' Department of Energy Resources' comprehensive energy planning process assumes that two-thirds of new vehicles will be electric by 2030.²](#)

3. ... propelled by cheaper batteries and lower maintenance costs.

- [Falling battery pack costs will allow EVs to cost less than or equal to comparable internal combustion engine vehicles in 2025.](#)
- [Today's electric bus would have to travel 37,000 miles per year for the total cost of ownership \(TCO\) to be equal to a diesel bus; this assumes an e-bus with the smallest battery and the most expensive wireless charging option.](#)
- [Light-duty electric trucks used in urban and regional settings are expected to reach parity in total cost of ownership with diesel trucks by 2025, with heavier-duty and longer-range trucks reaching parity later.](#)

4. EVs will help lower emissions.

- [In Massachusetts, emissions from electricity have been reduced by 58 percent since 1990, while emissions from the transportation sector are still the same.](#)
- [National Grid published a report on the Pathway to the 2050 emissions target of 80 percent reduction over 1990 levels. It finds that achieving the 2030 target of 40 percent emissions reductions requires all passenger and light truck vehicle sales be electric by no later than 2028.](#)
- [Achieving the 2050 targets requires complete electrification of light duty vehicles by 2050.](#)
- [In terms of emissions impact on global warming, an EV in New England is equivalent to achieving 103 MPG in a gasoline vehicle due to cleaner energy sources for electricity.](#)
- [In Massachusetts, annual CO₂ emissions from internal combustion engine \(ICE\) vehicles \(tailpipe emissions\) are 3.27 times higher compared to EVs \(emissions from electrical power source\).](#)
- [It takes less than two years of use for the reduced emissions from driving an EV to make up for higher emissions for manufacturing EVs \(some shorter-range EVs make this up within six months\).](#)
- [Advances in manufacturing EVs and increased use of cleaner energy lowers lifecycle emissions of EVs compared to ICE vehicles.](#)

5. EVs will affect the grid.

- [On average nationally, introducing an EV to a neighborhood is roughly the same as adding another house in terms of energy consumption.](#)
- [In Massachusetts, EVs will add to electric load, but overall annual electric demand is predicted to continue to fall due to strong efficiency programs and growth of distributed generation.](#)
- [In the U.S., current grid capacity is not an obstacle, but “the last mile” distribution is a challenge \(i.e. the local distribution grid may not be able to handle spikes in demand\).](#)
- [In Massachusetts, the electric grid can likely support light-duty vehicle charging, but growth in EV buses and other heavy-duty vehicles may require costly transmission and distribution system upgrades.](#)
- [To handle spikes, smart charging shifts charging times to align with periods of surplus, thus distributing power in the most efficient way possible.](#)
- [While scheduled charging may reduce infrastructure upgrades and provide cost savings, it also increases the risk of physical damage to the electric grid due to malicious or inadvertent charging controls.](#)
- [Another technology, vehicle-to-grid \(V2G\), adds the ability to discharge energy from an EV back to the grid, which helps balance the grid and creates new revenue streams to consumers.](#)

5. EVs will affect the grid (continued).

- [A utility provider in California has introduced rates based on time of day to incentivize EV charging during non-peak hours.](#)
- [Technology like the Microgrid deployed by Schneider Electric at its Boston One Campus \(BOC\) HQ will help charge EVs during grid failure.](#)
- [Some have expressed concerns about not being able to charge EVs during a power failure, but the same problems occur with ICEs, as service stations are often ill-equipped to maintain critical function during a loss of power.](#)

6. EVs require infrastructure (i.e. charging points).

- [Electric charging points are becoming more prolific, but are still relatively rare compared to other fueling options.](#)
- [Massachusetts is among the top ten states in the U.S. in terms of the number of charging stations \(540 stations\) and outlets \(1,485 outlets\).](#)
- [There are 18,068 charging stations with 48,715 outlets in the U.S.](#)
- [The U.S. will need 600,000 outlets to satisfy future demand, excluding residential outlets.](#)
- [The first 350 kWh fast-charging station in the U.S., which will allow future EVs to add 200 miles of range in 10 minutes, was installed in Chicopee, Massachusetts in May 2018.](#)
- [However, wireless charging pads for parked vehicles may alter the need for charging stations/outlets.](#)
- [The technology exists to provide wireless charging while driving, but deployment would require significant infrastructure investments.](#)

7. EVs will likely impact transportation revenue.

- [Annual gas tax revenue \(all federal and state sources\) would fall by 14 percent \(\\$10 billion dollars\) if EVs grew to 60 percent of U.S. new car sales by 2030.](#)
- [MassDOT is looking into the advisability and feasibility of options for offsetting projected gas tax revenue loss due to EVs.](#)
 - [17 states have imposed annual road user fees on EVs, ranging from \\$50 to \\$300.](#)
 - [Most fees currently imposed on EVs are less than what ICE vehicles generate in gas taxes...](#)
 - [...but EV owners pay more in state taxes due to higher sales prices of EVs.](#)
 - [Some studies have recommended delaying imposing road user fees on EVs to avoid interfering with initial adoption rates.](#)

8. Battery EVs (BEVs) are not the only EVs.

- [Battery EVs \(BEVs\) use lithium-ion batteries that recharge through electric charge points.](#)
- [Hydrogen cars, or fuel cell electric vehicles \(FCEVs\), are EVs with small batteries that are continuously charged from a hydrogen fuel cell using a process that results in water as the only byproduct \(i.e. it is essentially a zero-emission vehicle and that can have much smaller batteries or longer ranges than lithium ion battery EVs\).](#)
- [Current FCEVs are 25 percent to 70 percent less efficient than BEVs, cost more to fill up than ICE vehicles, and are several years behind BEVs in terms of innovation.](#)
- [FCEVs could be cost-competitive with BEVs for over 70 percent of the light-duty vehicle market \(LDV\) by 2030, with FCEVs offering notable cost advantages for larger vehicles and longer distances.](#)
- [Toyota plans to expand sales of hydrogen-powered vehicles, looking to mass produce its FCEV sedan, launch a fuel-cell-powered bus, and test a fuel-cell-powered commercial truck.](#)

9. Massachusetts has EV initiatives in place.

- [Massachusetts has initiatives in place to encourage EV adoption, including a goal of having 300,000 EVs on the road by 2025.](#)
- [To encourage EV adoption, Massachusetts' MOR-EV Program offers a \\$2,500 rebate on EVs.](#)
- [The Massachusetts Electric Vehicle Incentive Program \(MassEVIP\) helps employers acquire EV charging stations.](#)
- [Eversource and National Grid](#) have both been approved for programs to install charging infrastructure throughout Massachusetts, two of the largest utility initiatives outside of California.
- [Transit authorities in Massachusetts are planning to pilot the use of electric buses throughout the state.](#)

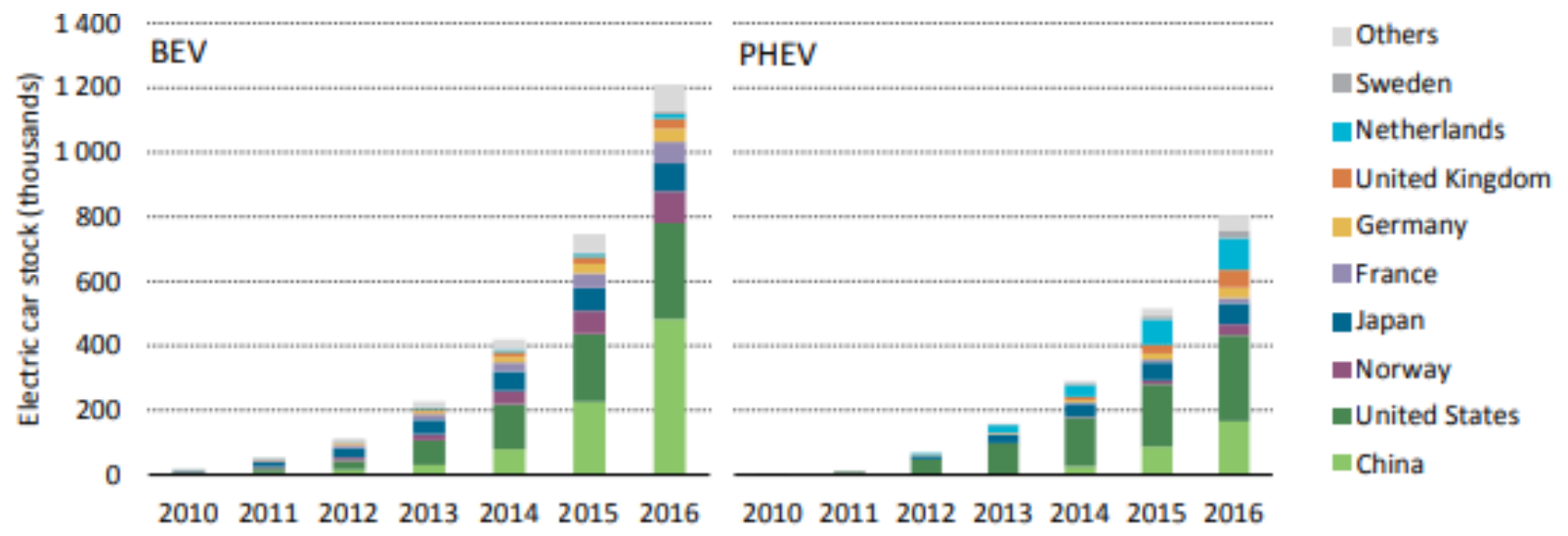
10. U.S. has significantly less electrified rail than the rest of the world.

- [One-third of railroad tracks worldwide are electrified, but less than 1 percent of U.S. railroad tracks are electrified.](#)
- [Rail accounts for 2 percent of GHG emissions from the U.S. transportation sector.](#)
- [If rail was electrified, the added efficiency could draw additional freight from trucks to trains.](#)
- [Electric locomotive engines and maintenance are significantly cheaper than their diesel equivalents on the global market.](#)
- [However, the infrastructure needed to transition to a nationally electrified freight rail system in the U.S. is a major barrier.](#)
- [MBTA's Rail Vision study is examining a wide variety of topics, including the possible electrification of some sections of the commuter rail network.](#)

1. Electric Vehicles (EVs) may not be prevalent today...

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Evolution of the Global Electric Car Stock: Battery Electric Vehicles (BEV) and Plugin Hybrid Electric Vehicles (PHEV) 2010-2016¹

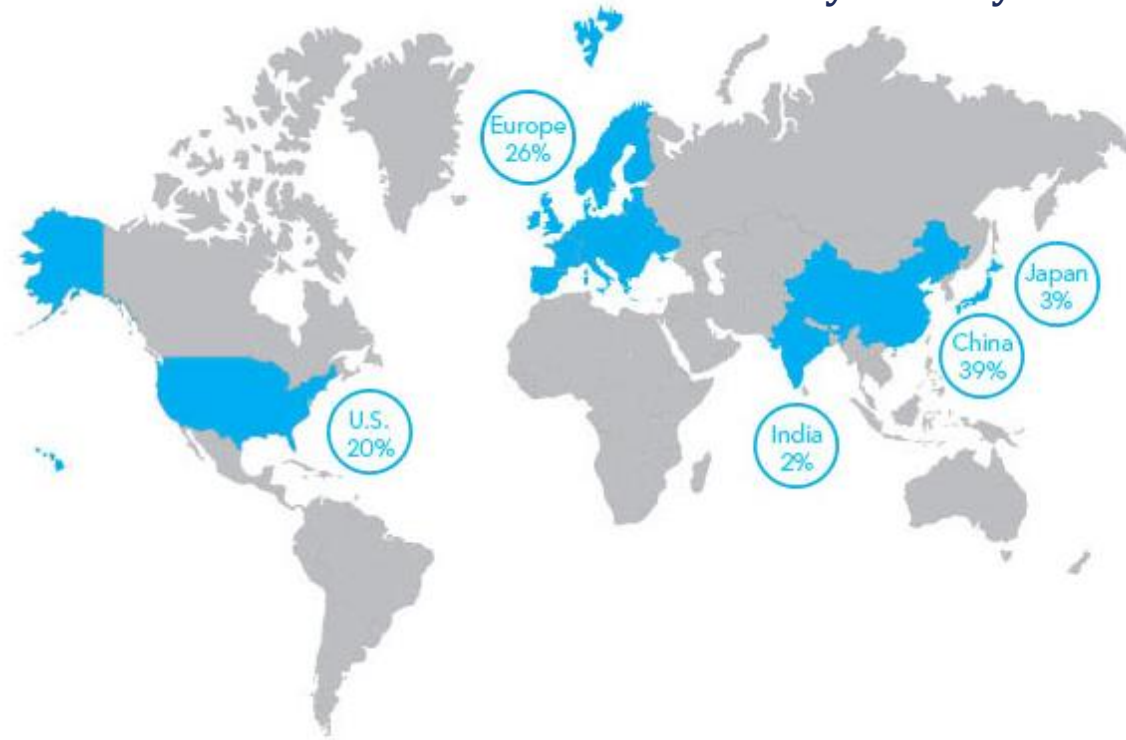


1. International Energy Agency (IEA). (2017). *Global EV Outlook 2017*. <https://www.iea.org/publications/freepublications/publication/GlobalEVOutlook2017.pdf>
2. Institute for Energy Research (IER). (2018). *Study: Electric Vehicle Charging Could Present Grid Challenges*. <https://www.instituteforenergyresearch.org/the-grid/study-electric-vehicle-charging-present-grid-challenges/>

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Share of Global EV Market in 2030 by Country¹



1. Reuters. (2018). *Global carmakers to invest at least \$90 billion in electric vehicles.* <https://www.reuters.com/article/us-autoshow-detroit-electric/global-carmakers-to-invest-at-least-90-billion-in-electric-vehicles-idUSKBN1F42NW>

2. Bloomberg New Energy Finance (BNEF). (2018). *High-level findings of the Electric Vehicle Outlook 2018.* <https://about.bnef.com/electric-vehicle-outlook/#toc-download>

3. The Verge. (2018). *Automakers team up with states to get Americans to buy more electric cars.* <https://www.theverge.com/2018/3/29/17173176/electric-car-marketing-campaign-automakers-northeast-states>

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Summary of EV Sales by State for States with Highest Sales³

State	EV Sales 2016	EV Sales 2017	% YOY Increase	2017 EV Market Share W/in State
California	73,854	94,873	28.50%	5.02%
New York	6,043	10,090	67.00%	1.03%
Washington	5,363	7,068	31.80%	2.51%
Florida	6,255	6,573	5.10%	0.52%
Texas	4,510	5,419	20.20%	0.39%
New Jersey	3,980	5,033	26.50%	0.91%
Massachusetts	2,905	4,632	59.40%	1.35%
Colorado	2,711	4,156	53.30%	1.57%
Oregon	3,486	3,988	14.40%	2.36%

1. Natural Resources Defense Council (NRDC). (2017). *Massachusetts Approves Precedential Electric Vehicle Program*. <https://www.nrdc.org/experts/noah-garcia/massachusetts-approves-precedential-electric-vehicle-program>

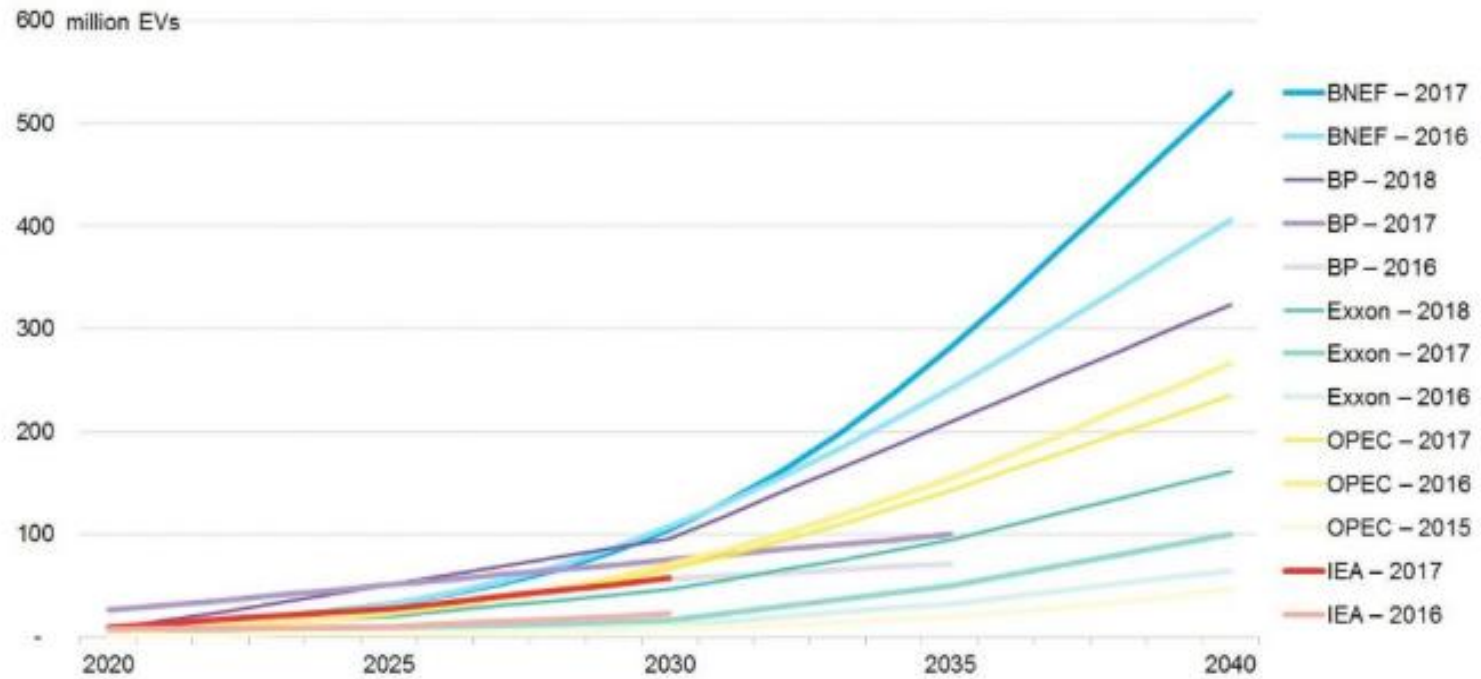
2. Statista. (2018). *Number of registered automobiles in Massachusetts in 2016*. <https://www.statista.com/statistics/196050/number-of-registered-automobiles-in-massachusetts/>

3. EVAdoption. (2018). *EV Market Share by State*. <http://evadoption.com/ev-market-share/ev-market-share-state/>

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How Electric Vehicle Fleet Size Forecasts Have Changed Over Time¹

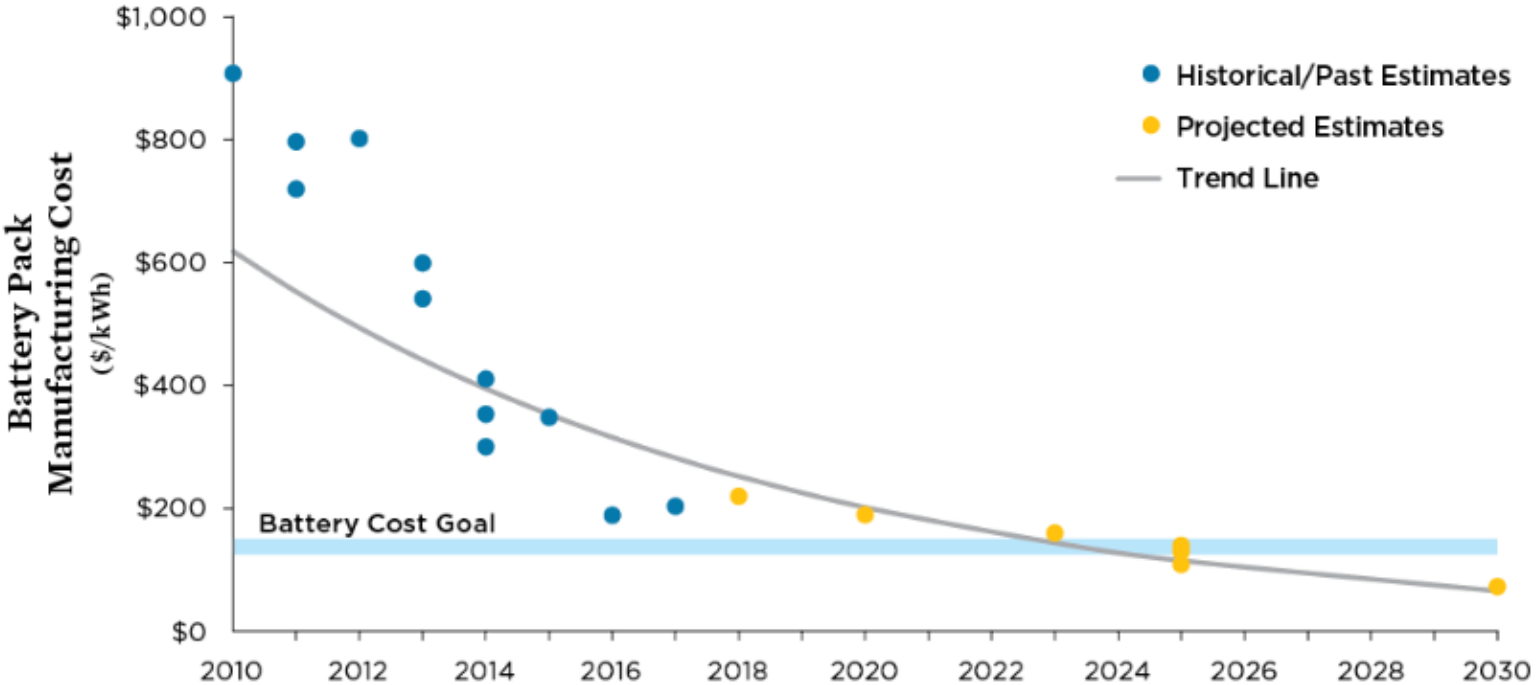


1. Bloomberg New Energy Finance (BNEF). (2018). *McKerracher: BP's Energy Outlook and the Rising Consensus on EV Adoption*. <https://about.bnef.com/blog/bps-energy-outlook-and-the-rising-consensus-on-ev-adoption/>
2. Synapse Energy Economics, Inc. (2018). *Massachusetts Comprehensive Energy Plan Stakeholder Meetings Presentation*. <https://www.mass.gov/files/documents/2018/07/20/CEP%20Stakeholder%20Meetings%20Presentation.pdf>

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Electric Vehicle Battery Cost: Trend and Projections¹



Source: Union of Concerned Scientists

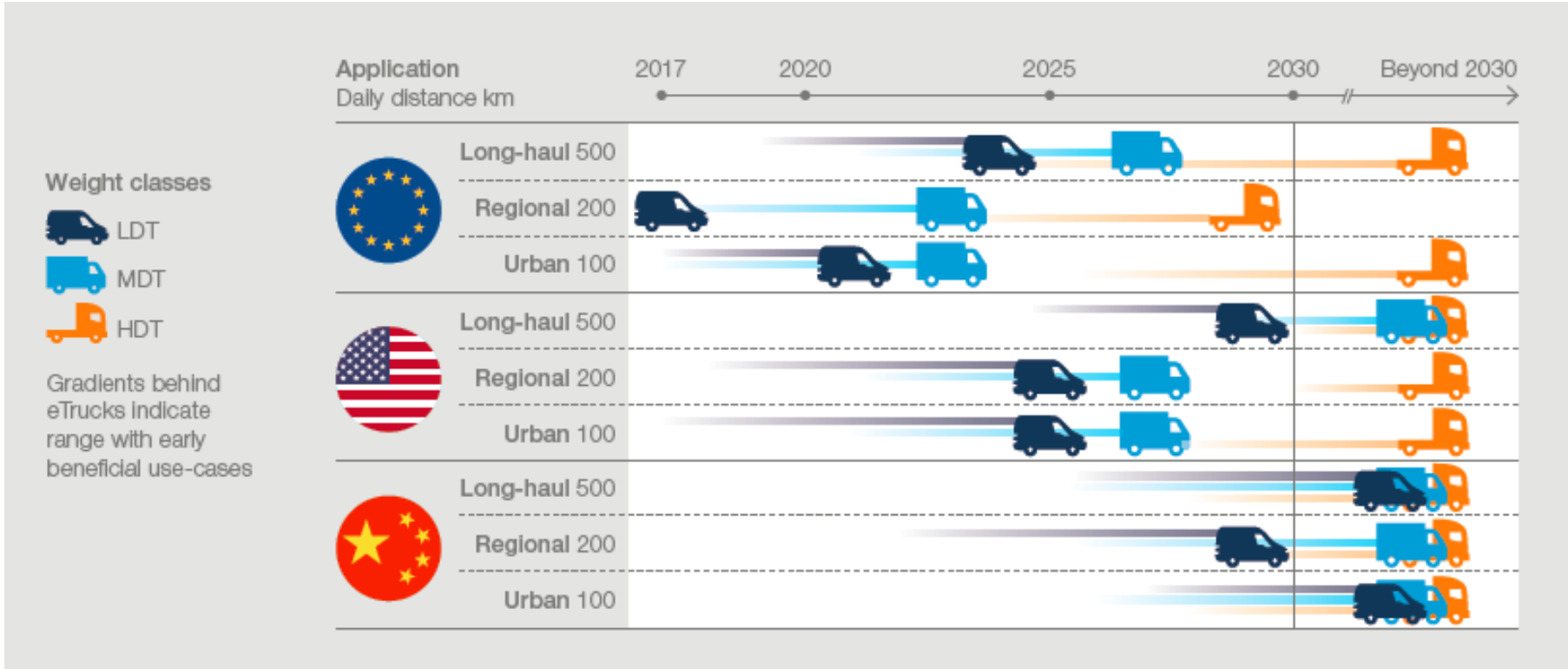
1. Union of Concerned Scientists. (2018). *Electric Vehicle Battery: Materials, Cost, Lifespan*. <https://www.ucsusa.org/clean-vehicles/electric-vehicles/electric-cars-battery-life-materials-cost>

2. Bloomberg New Energy Finance (BNEF). (2018). *High-level findings of the Electric Vehicle Outlook 2018*. <https://about.bnef.com/electric-vehicle-outlook/#toc-download>

3. ...propelled by cheaper batteries and lower maintenance costs.

- Light-duty electric trucks used in urban and regional settings are expected to reach parity in total cost of ownership with diesel trucks by 2025, with heavier-duty and longer-range trucks reaching parity later.¹

Timing of Average Cost Parity Between Battery Electric vs Diesel Trucks¹

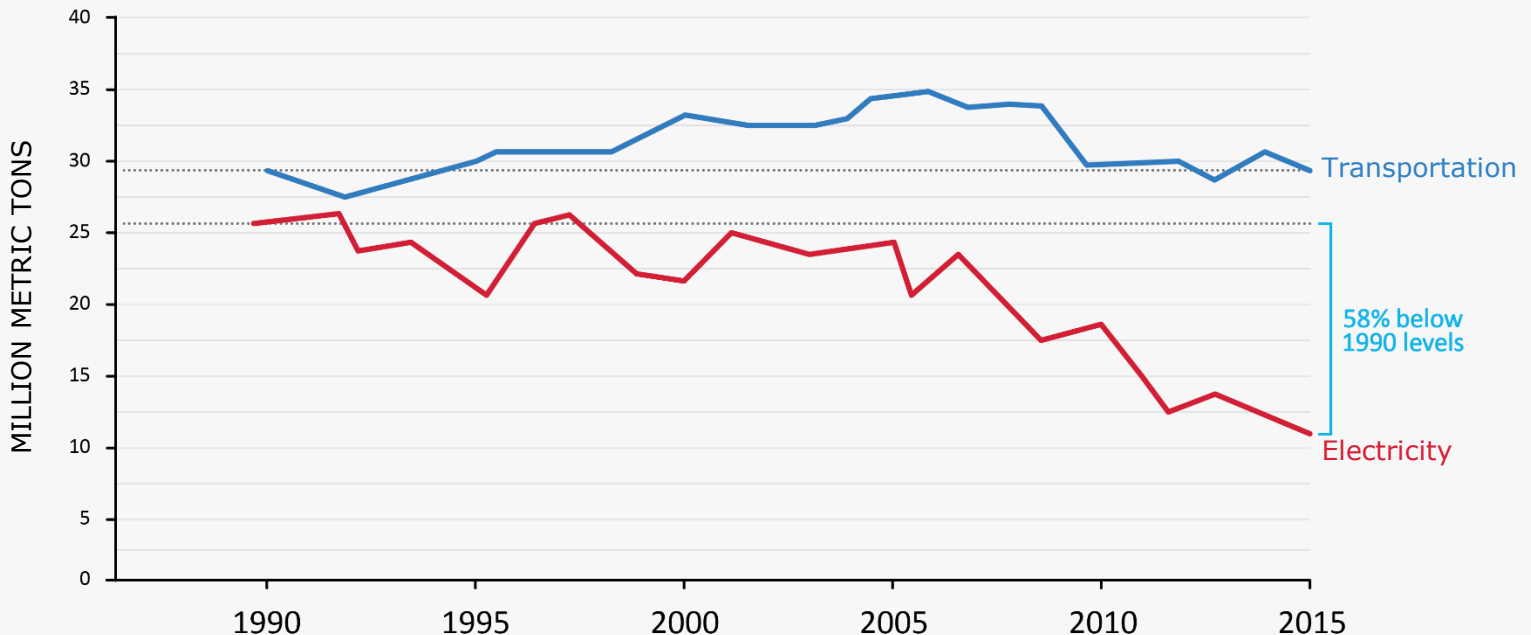


1. McKinsey. (2017). *New reality: electric trucks and their implications on energy demand*. <https://www.mckinseyenergyinsights.com/insights/new-reality-electric-trucks-and-their-implications-on-energy-demand/>

4. EVs will help lower emissions.

- [In Massachusetts, emissions from electricity have been reduced by 58 percent since 1990, while emissions from the transportation sector are still the same.](#)¹
- [National Grid published a report on the Pathway to the 2050 emissions target of 80 percent reduction over 1990 levels. It finds that achieving the 2030 target of 40 percent emissions reductions requires all passenger and light truck vehicle sales be electric by no later than 2028.](#)²
- [Achieving the 2050 targets requires complete electrification of light duty vehicles by 2050.](#)³

Transportation and Electricity CO2 Emissions Massachusetts¹



1. Union of Concerned Scientists. (2018). *Massachusetts Senate Unanimously Endorses a Bold Vision for Clean Transportation*. <https://blog.ucsusa.org/daniel-gatti/massachusetts-senate-unanimously-endorses-a-bold-vision-for-clean-transportation>

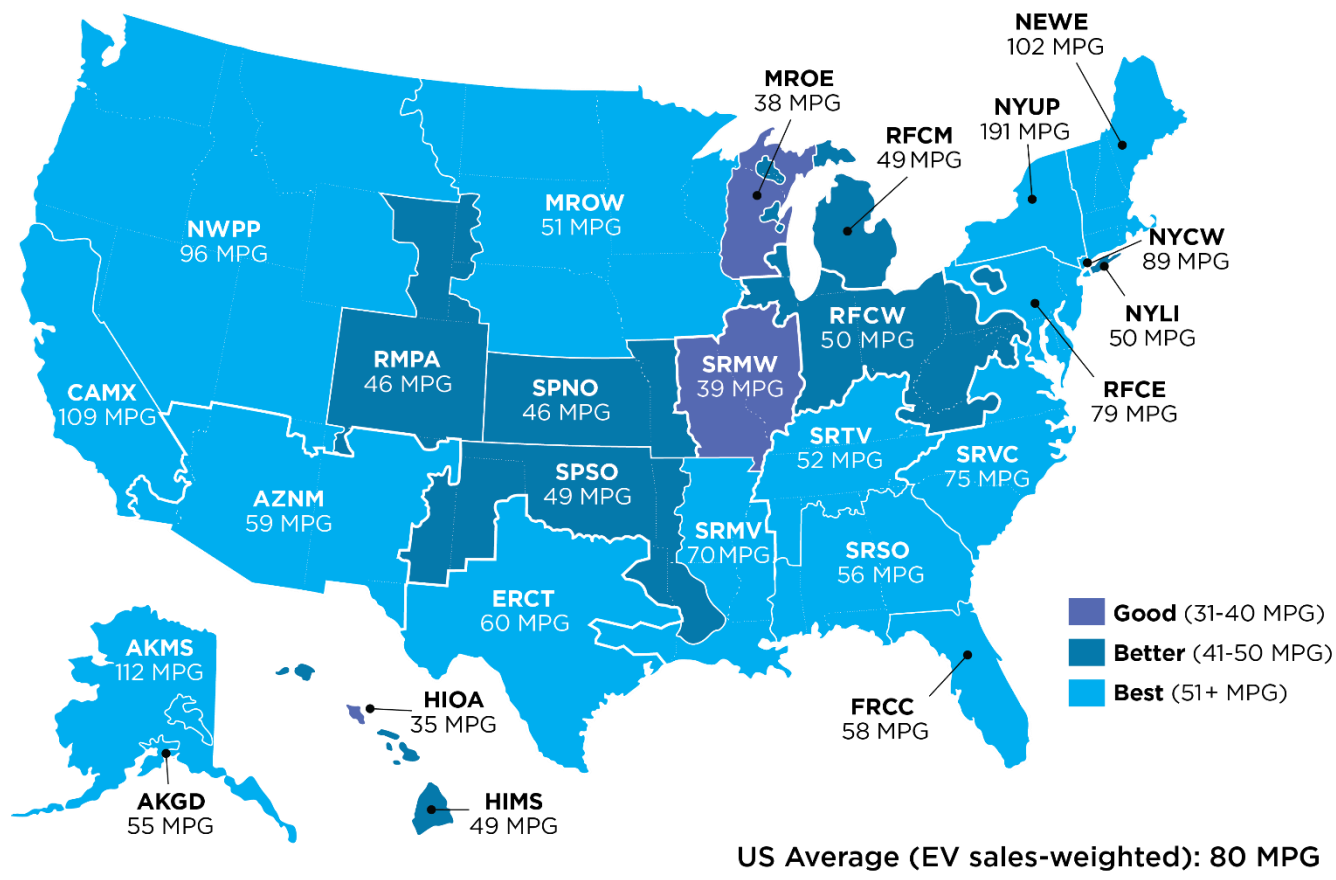
2. National Grid. (2018). *Northeast 80x50 Pathway*. <http://news.nationalgridus.com/wp-content/uploads/2018/06/80x50-White-Paper-FINAL.pdf>

3. Sustainable Development Solutions Network Evolved Energy Research Hydro-Québec. (2018). *Deep Decarbonization in the Northeastern United States and Expanded Coordination with Hydro-Québec*. <http://unsdsn.org/wp-content/uploads/2018/04/2018.04.05-Northeast-Deep-Decarbonization-Pathways-Study-Final.pdf>

4. EVs will help lower emissions.

- In terms of emissions impact on global warming, an EV in New England is equivalent to achieving 103 MPG in a gasoline vehicle due to cleaner energy source for electricity.¹

Electric Vehicle Global Warming Pollution Ratings and Gasoline Vehicle Equivalents By Electricity Grid Region¹



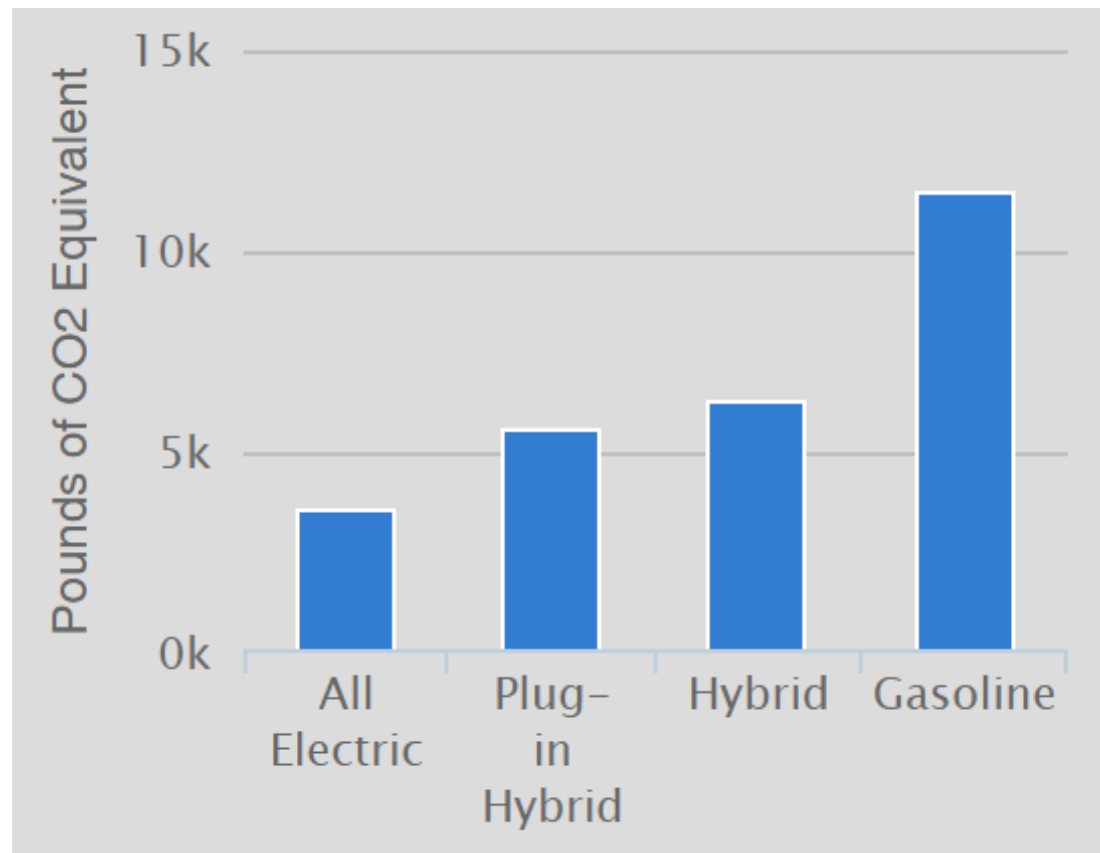
NOTE: The MPG (miles per gallon) value listed for each region is the combined city/highway fuel economy rating of a gasoline vehicle that would have global warming emissions equivalent to driving an EV. Regional global warming emissions ratings are based on 2014 power plant data in the EPA's eGRID 2014 database (the most recent version). Comparisons include gasoline and electricity fuel production emissions. The 73 MPG U.S. average is a sales-weighted average based on where EVs were sold in 2018.

1. Union of Concerned Scientists. (2017). *New Numbers Are In and EVs Are Cleaner Than Ever*. <https://blog.ucsusa.org/dave-reichmuth/new-numbers-are-in-and-evs-are-cleaner-than-ever>

4. EVs will help lower emissions.

- [In Massachusetts, annual CO₂ emissions from internal combustion engine \(ICE\) vehicles \(tailpipe emissions\) are 3.27 times higher compared to EVs \(emissions from electrical power source\).¹](#)

State Averages for Massachusetts – Annual Emissions per Vehicle.¹

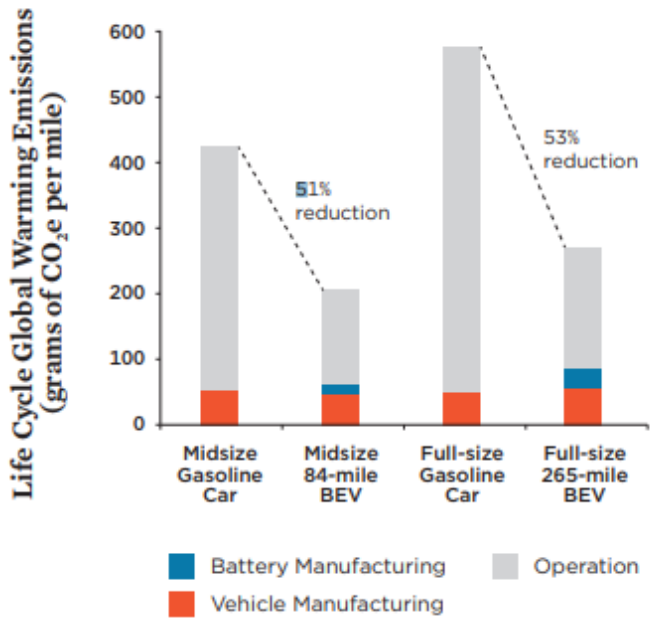


1. U.S. Dept of Energy - Office of Energy Efficiency & Renewable Energy (EERE). (2018). *Emissions from Hybrid and Plug-In Electric Vehicles*. https://www.afdc.energy.gov/vehicles/electric_emissions.php

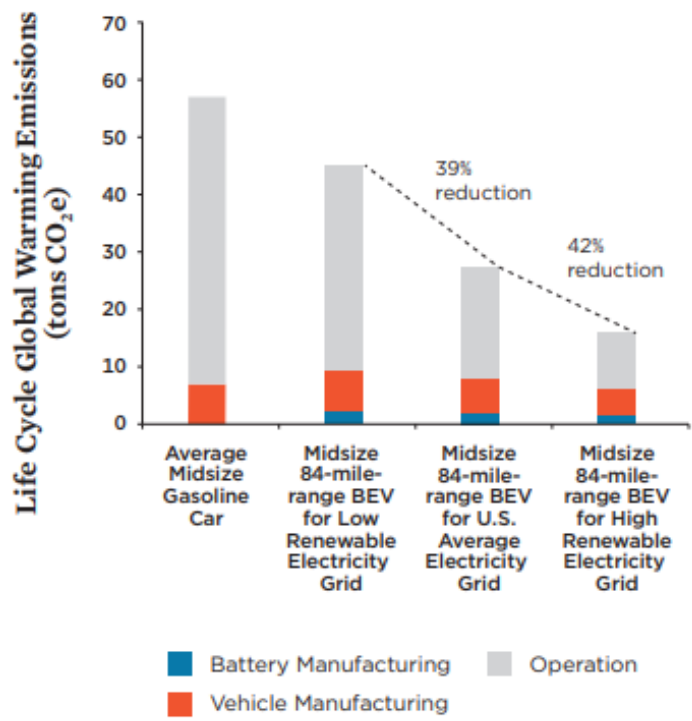
4. EVs will help lower emissions.

- It takes less than two years of use for the reduced emissions from driving an EV to make up for higher emissions for manufacturing EVs (some shorter-range EVs make this up within six months).¹
- Advances in manufacturing EVs and increased use of cleaner energy lowers lifecycle emissions of EVs compared to ICE vehicles.¹

Life Cycle Global Warming Emissions from the Manufacturing and Operations of Gasoline and Battery-Electric Vehicles¹



Life Cycle Global Warming Emissions for a Midsize BEV for Three Different Electricity Grid Mixes¹

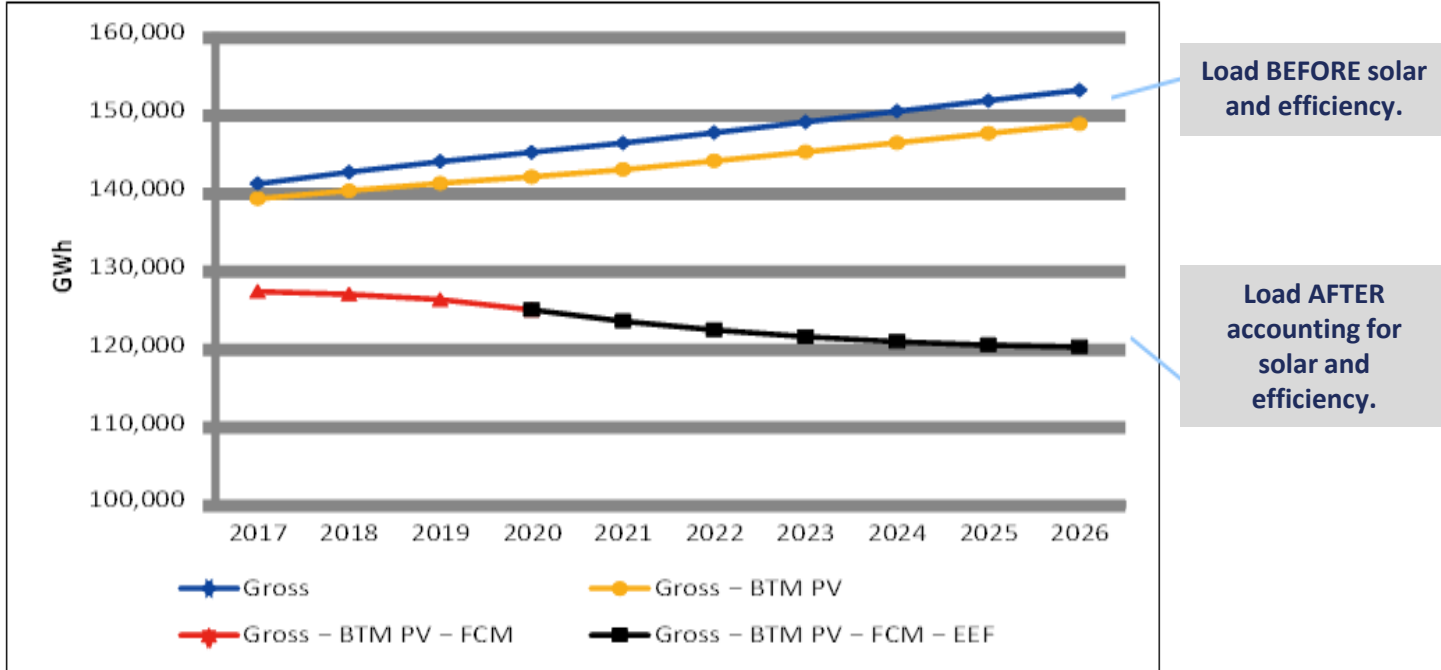


1. Union of Concerned Scientists. (2015). *Cleaner Cars from Cradle to Grave*. <https://www.ucsusa.org/clean-vehicles/electric-vehicles/life-cycle-ev-emissions>

5. EVs will affect the grid.

- [On average nationally, introducing an EV to a neighborhood is roughly the same as adding another house in terms of energy consumption.](#)¹
- [In Massachusetts, EVs will add to electric load, but overall annual electric demand is predicted to continue to fall due to strong efficiency programs and growth of distributed generation.](#)²

Electricity Load Forecast for ISO New England²



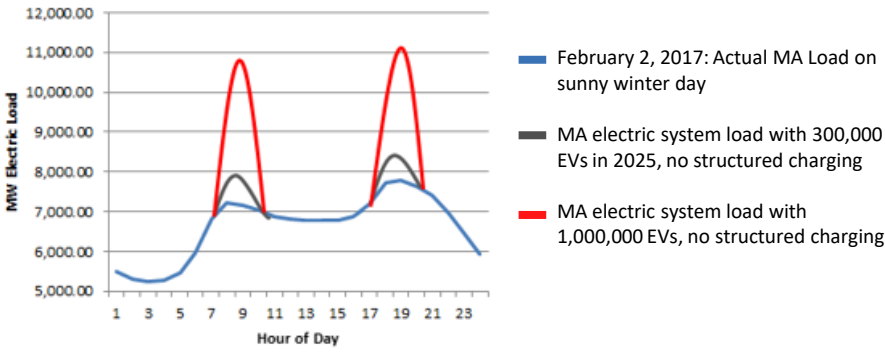
High EV Growth Street Test. ISO assumed 2.5 million Plugin Hybrid Electric Vehicles (PHEVs) in 2025 and modelled an August month of charging at night that year. The addition significantly adds to night loads, but does not contribute to peak events.

1. FleetCarma. (2017). *The Impact Of Growing Electric Vehicle Adoption On Electric Utility Grids.* <https://www.fleetcarma.com/impact-growing-electric-vehicle-adoption-electric-utility-grids/>
2. Commonwealth of Massachusetts. (2018). *Beneficial Electrification Issues - Future of Transportation Commission.* <https://www.mass.gov/doc/beneficial-electrification-issues-eea-september-2018>

5. EVs will affect the grid.

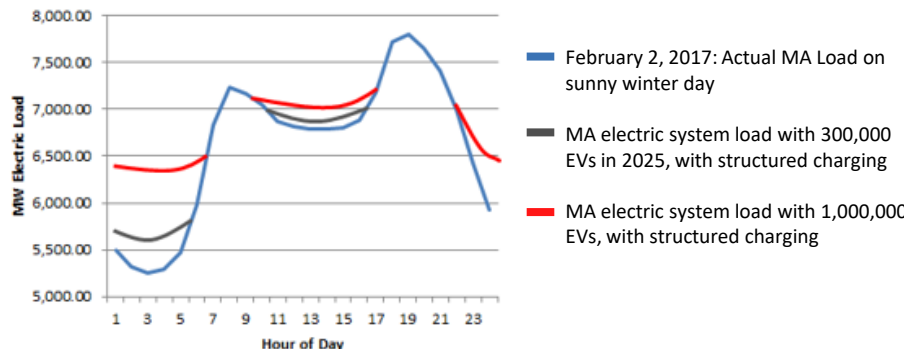
- [In the U.S., current grid capacity is not an obstacle, but “the last mile” distribution is a challenge \(i.e. the local distribution grid may not be able to handle spikes in demand\).](#)¹
- [In Massachusetts, the electric grid can likely support light-duty vehicle charging, but growth in EV buses and other heavy-duty vehicles may require costly transmission and distribution system upgrades.](#)²
- [To handle spikes, smart charging shifts charging times to align with periods of surplus, thus distributing power in the most efficient way possible.](#)³

Massachusetts Real Time Electric Load EVs Adopted – No Charging Controls Sunny Winter Day²



Uncontrolled: Charge on arrival
Exacerbate peaks, significant cost

Massachusetts Real Time Electric Load EVs Adopted – With Charging Controls Sunny Winter Day²



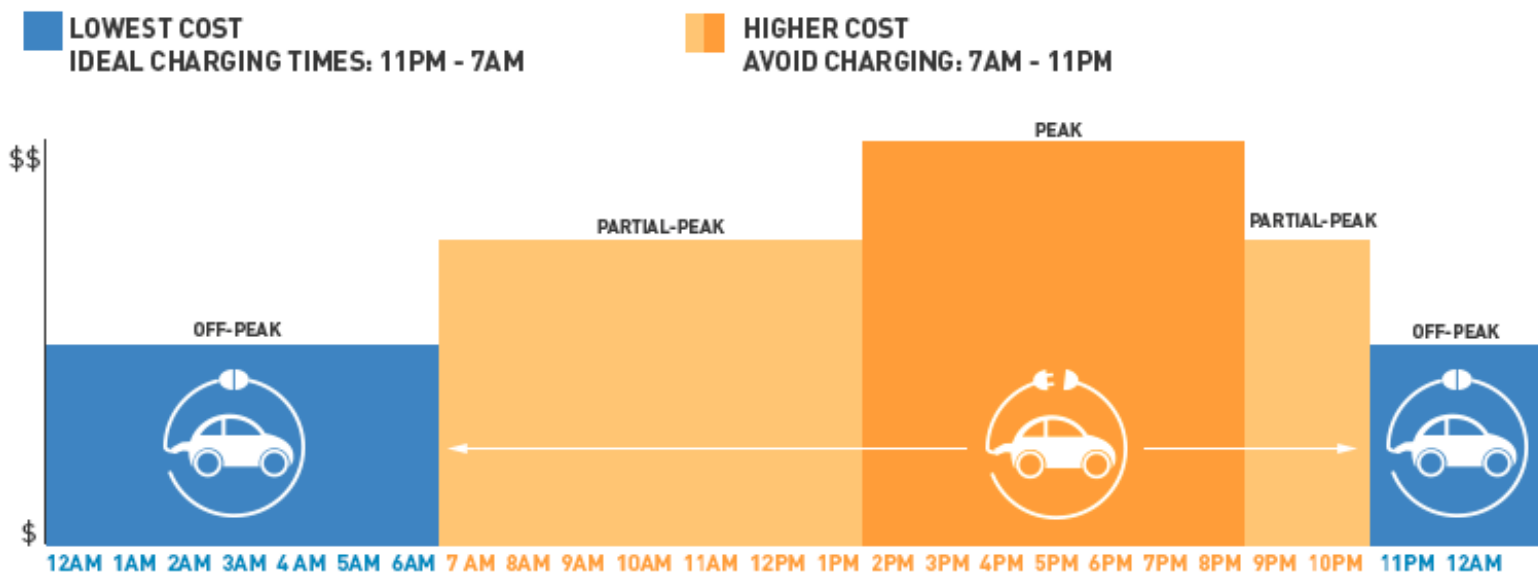
Controlled: Coordinate with grid demand
Flatten grid load and save money

1. FleetCarma. (2017). *The Impact Of Growing Electric Vehicle Adoption On Electric Utility Grids*. <https://www.fleetcarma.com/impact-growing-electric-vehicle-adoption-electric-utility-grids/>
 2. Commonwealth of Massachusetts. (2018). *Beneficial Electrification Issues - Future of Transportation Commission*. <https://www.mass.gov/doc/beneficial-electrification-issues-eea-september-2018>
 3. FleetCarma. (2018). *Are EV Fleets The Answer To Controllable Loads And Grid Efficiency?* <https://www.fleetcarma.com/electric-vehicle-fleets-will-manage-loads-save-dollars/>

5. EVs will affect the grid.

- [While scheduled charging may reduce infrastructure upgrades and provide cost savings, it also increases the risk of physical damage to the electric grid due to malicious or inadvertent charging controls.](#)¹
- [Another technology, vehicle-to-grid \(V2G\), adds the ability to discharge energy from an EV back to the grid, which helps balance the grid and creates new revenue streams to consumers.](#)²
- [A utility provider in California has introduced rates based on time of day to incentivize EV charging during non-peak hours.](#)³

Preferred Electric Vehicle Charging Times Based on Electricity Cost³



NOTE: Weekends and holidays only include Peak (3-7 p.m.) and Off-Peak (all other hours) periods.

1. Commonwealth of Massachusetts. (2018). *Beneficial Electrification Issues - Future of Transportation Commission*. <https://www.mass.gov/doc/beneficial-electrification-issues-eea-september-2018>

2. FleetCarma. (2018). *Are EV Fleets The Answer To Controllable Loads And Grid Efficiency?* <https://www.fleetcarma.com/electric-vehicle-fleets-will-manage-loads-save-dollars/>

3. PG&E. (2018). *Electric Vehicle (EV) rate plans*. https://www.pge.com/en_US/residential/rate-plans/rate-plan-options/electric-vehicle-base-plan/electric-vehicle-base-plan.page?WT.mc_id=Vanity_pevrates

5. EVs will affect the grid.

- [Technology like the Microgrid deployed by Schneider Electric at its Boston One Campus \(BOC\) HQ will help charge EVs during grid failure.](#)¹
- [Some have expressed concerns about not being able to charge EVs during a power failure, but the same problems occur with ICEs, as service stations are often ill-equipped to maintain critical function during a loss of power.](#)²

Schneider Electric's BOC Microgrid.¹



Photo credit: <http://microgridmedia.com/schneider-electric-unveils-hybrid-microgrid-boston-one-campus/>

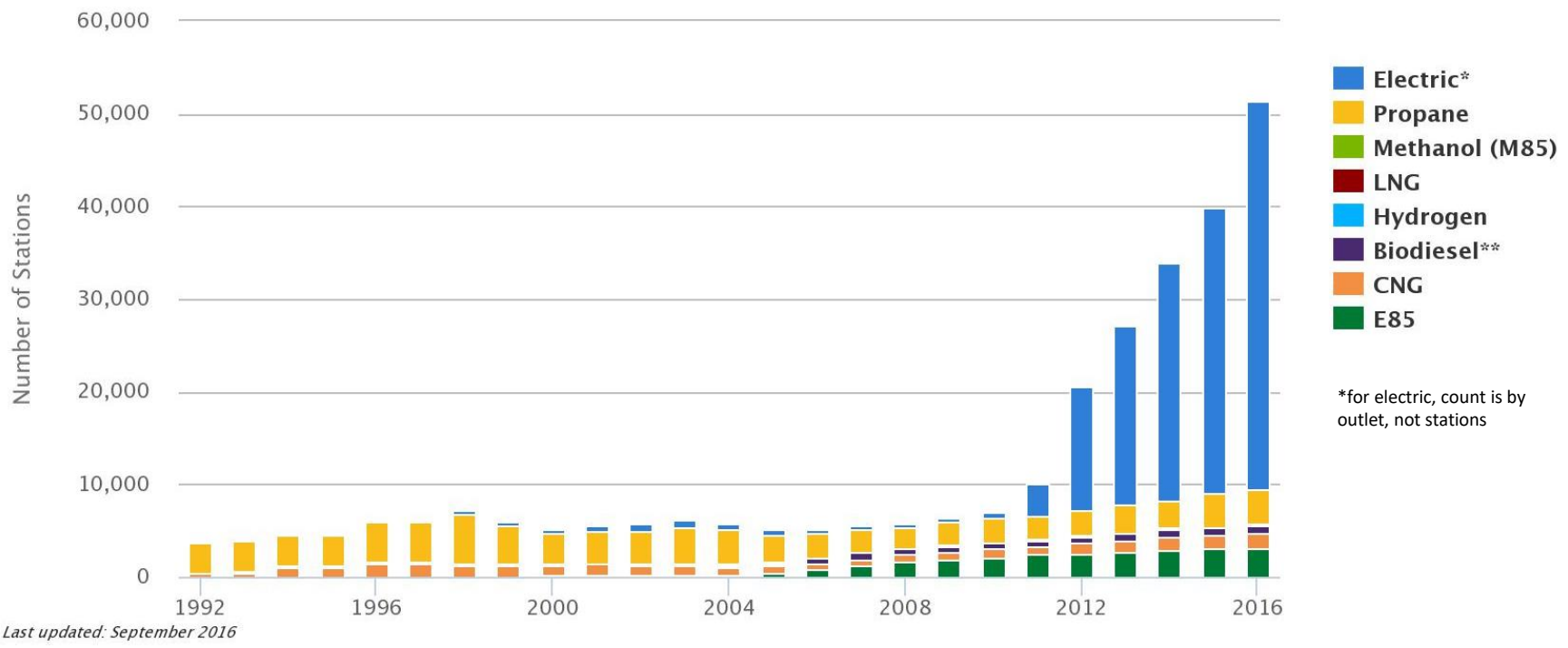
1.Schneider Electric. (2017). *Schneider Electric Unveils Advanced Microgrid at Boston One Campus HQ*. <https://www.prnewswire.com/news-releases/schneider-electric-unveils-advanced-microgrid-at-boston-one-campus-hq-300436051.html>

2.Massachusetts Clean Energy Center. (2017). *Request for Proposals – Resilient Service Stations Challenge*. <http://www.masscec.com/request-proposals-resilient-stations-challenge>

6. EVs require infrastructure (i.e. charging points).

- [Electric charging points are becoming more prolific, but are still relatively rare compared to other fueling options.](#)¹

U.S. Alternative Fueling Stations by Fuel Type.¹

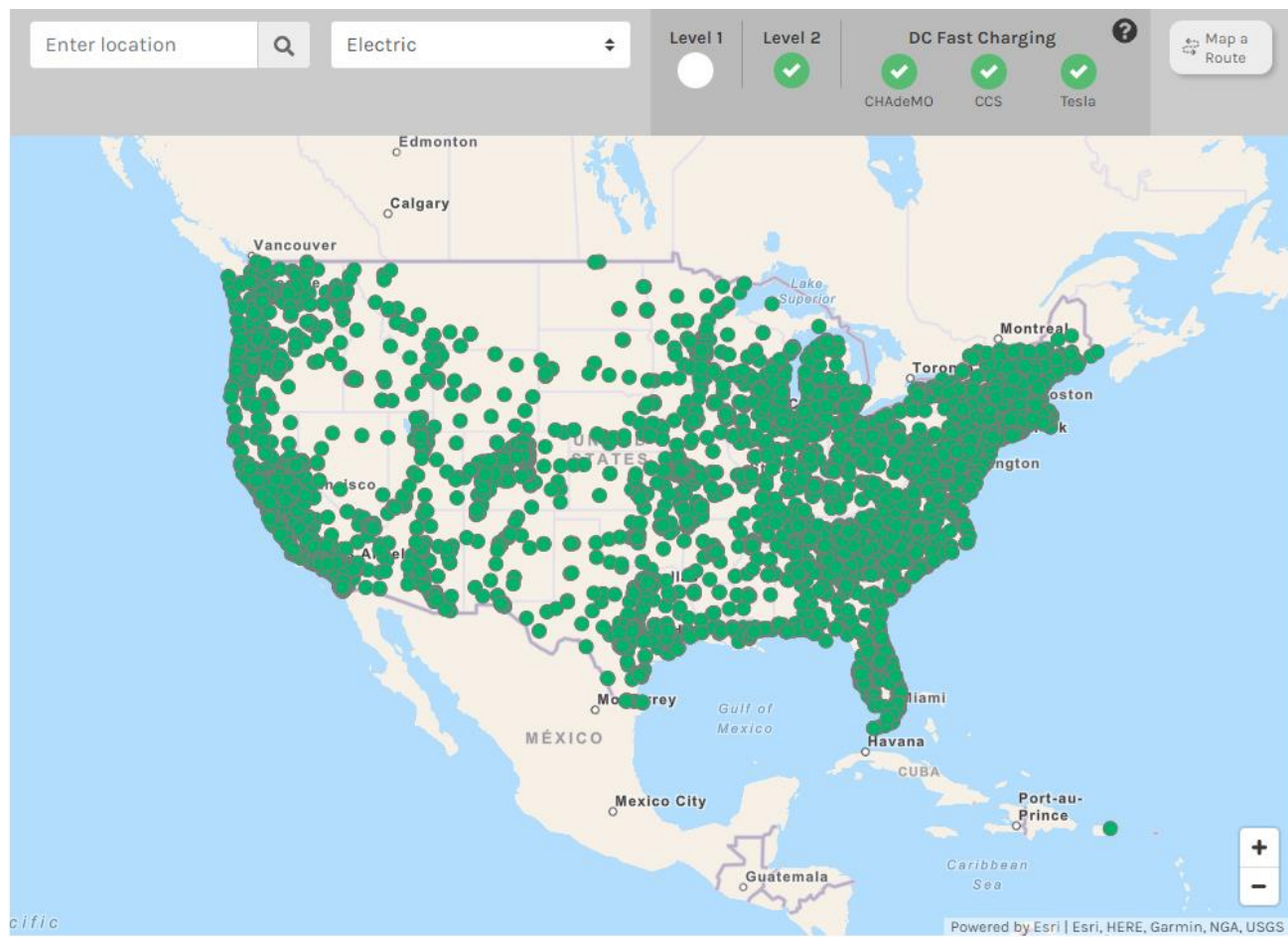


1. Alternative Fuels Data Center (AFDC). (2018). *U.S. Alternative Fueling Stations by Fuel Type*. https://www.afdc.energy.gov/fuels/electricity_locations.htm#/analyze?fuel=ELEC&ev_levels=all®ion=MA

6. EVs require infrastructure (i.e. charging points).

- [Massachusetts is among the top ten states in the U.S. in terms of the number of charging stations \(540 stations\) and outlets \(1,485 outlets\).](#)¹
- [There are 18,068 charging stations with 48,715 outlets in the U.S.](#)¹
- [The U.S. will need 600,000 outlets to satisfy future demand, excluding residential outlets.](#)²

Charging Station Locations in the U.S.¹



1. Alternative Fuels Data Center (AFDC). (2018). *Electric Vehicle Charging Station Locations*. https://www.afdc.energy.gov/fuels/electricity_locations.html#/analyze?fuel=ELEC
2. U.S. Dept of Energy - Office of Energy Efficiency & Renewable Energy (EERE). (2017). *National Plug-In Electric Vehicle Infrastructure Analysis*. <https://www.nrel.gov/docs/fy17osti/69031.pdf>

6. EVs require infrastructure (i.e. charging points).

- [The first 350 kWh fast-charging station in the U.S., which will allow future EVs to add 200 miles of range in 10 minutes, was installed in Chicopee, Massachusetts in May 2018.](#)¹
- [However, wireless charging pads for parked vehicles may alter the need for charging stations/outlets.](#)²
- [The technology exists to provide wireless charging while driving, but deployment would require significant infrastructure investments.](#)³

Visualization of Wireless Induction Charging.⁴



1. Green Car Reports. (2018). *Electrify America switches on the first 350 KW Fast Charging station in Chicopee, Mass.*

https://www.greencarreports.com/news/1116550_electrify-america-switches-on-the-first-350-kw-fast-charging-station-in-chicopee-mass

2. The Drive. (2018). *Wireless Electric Car Charging Is Coming—And It Could Help Stabilize the Power Grid.* <http://www.thedrive.com/tech/19995/wireless-electric-car-charging-is-coming-and-it-could-help-stabilize-the-power-grid>

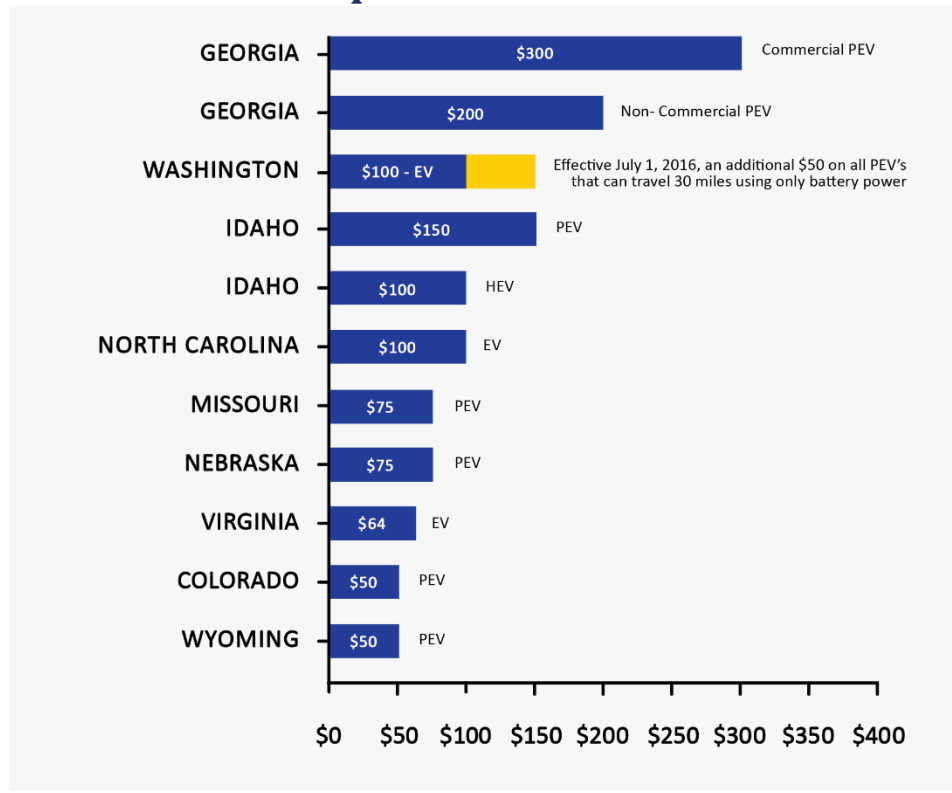
3. The Drive. (2017). *Qualcomm Demonstrates Road-to-Car Wireless Charging for EVs.* <http://www.thedrive.com/tech/10405/qualcomm-demonstrates-road-to-car-wireless-charging-for-evs>

4. The Drive. (2017). *BMW Announces Plans to Bring Wireless Charging to the 530e iPerformance Plug-In Hybrid.* <http://www.thedrive.com/sheetmetal/14641/bmw-is-bringing-wireless-charging-to-the-530e-iperformance-plug-in-hybrid>

7. EVs will likely impact transportation revenue.

- [Annual gas tax revenue \(federal and state\) would fall by 14 percent \(\\$10 billion dollars\) if EVs grew to 60 percent of U.S. new car sales by 2030.](#)¹
- [MassDOT is looking into the advisability and feasibility of options for offsetting projected gas tax revenue loss due to EVs](#)²
 - [17 states have imposed annual road user fees on EVs, ranging from \\$50 to \\$300](#)¹
 - [Most fees currently imposed on EVs are less than what ICE vehicles generate in gas taxes...](#)²
 - [...but EV owners pay more in state taxes due to higher sales prices of EVs.](#)²
 - [Some studies have recommended delaying imposing road user fees on EVs to avoid interfering with initial adoption rates](#)²

Annual State Fees for EV Owners as of September 2015.¹



EV = All Electric Vehicle
 PHEV = Plug-in Hybrid Electric Vehicle
 PEV = Plug-in Electric Vehicle (includes both EV and PHEV)
 HEV = Hybrid Electric Vehicle (no plug)

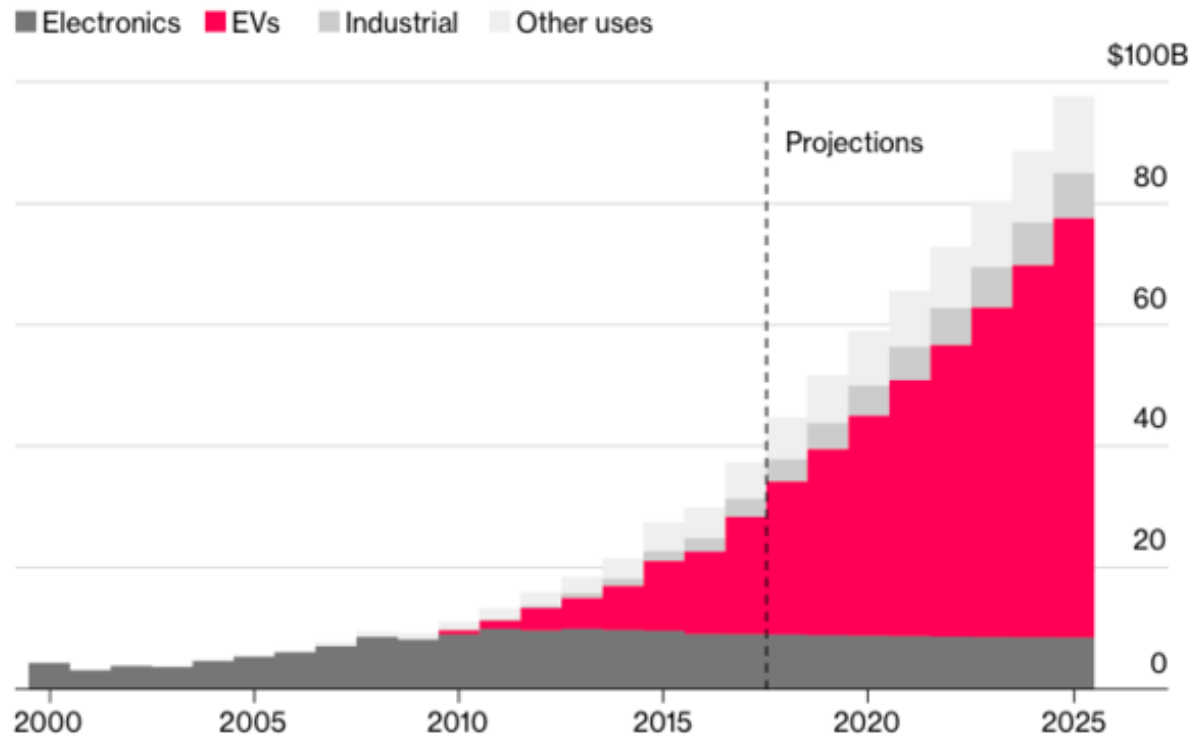
1. Institute for Energy Research (IER). (2017). *Gas Tax Revenues Will Plummet With Large Increase in Electric Vehicles.*
<https://www.instituteforenergyresearch.org/uncategorized/gas-tax-revenues-will-plummet-large-increase-electric-vehicles/>
 2. MassDOT. (2017). *Electric Vehicle: Impacts on Transportation Infrastructure —A Review of Other States.*
<http://www.umasstransportationcenter.org/umtc/Publications1.asp>

8. Battery EVs (BEVs) are not the only EVs.

- [Battery EVs \(BEVs\) use lithium-ion batteries that recharge through electric charge points.](#)¹

Global Lithium-Ion Battery Sales¹

Pack-level sale estimates by product type



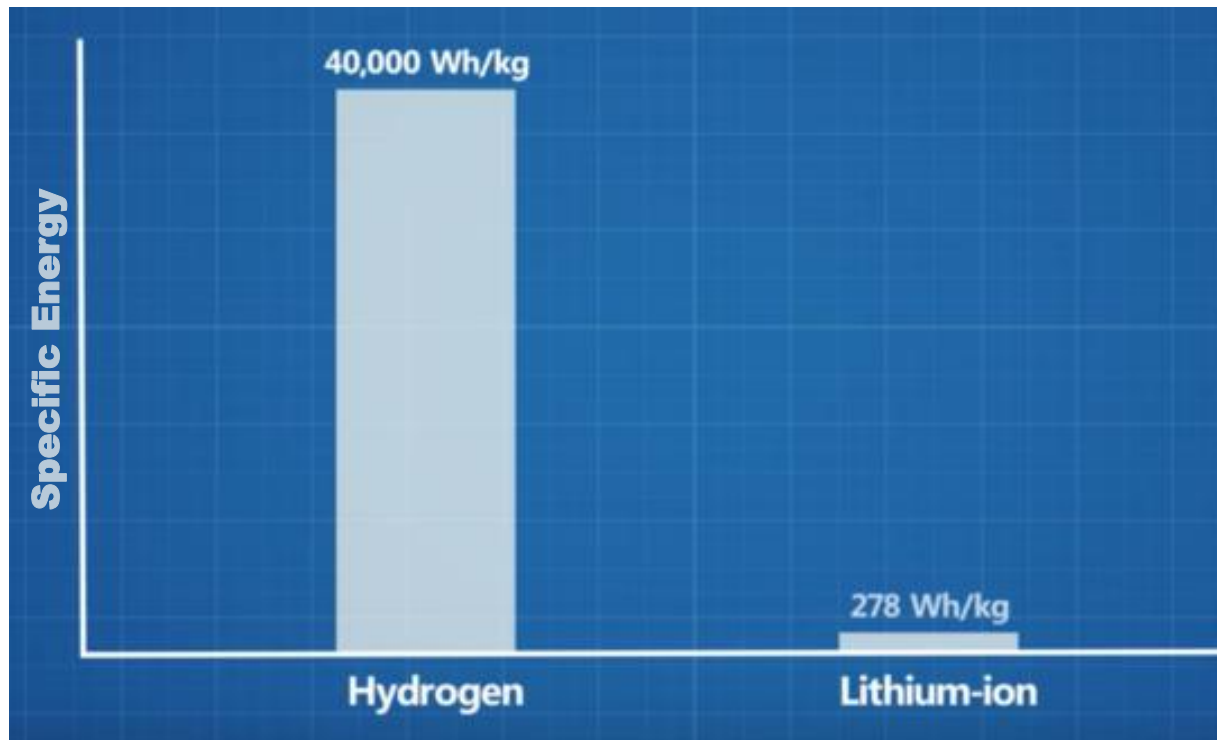
Source: Avicenne
Note: EVs refers to cars and buses

1. Clean Technica. (2018). *The World's "New Oil" — Batteries.* <https://cleantechnica.com/2018/07/09/the-worlds-new-oil-batteries/>

8. Battery EVs (BEVs) are not the only EVs.

- [Hydrogen cars, or fuel cell electric vehicles \(FCEVs\), are EVs with small batteries that are continuously charged from a hydrogen fuel cell using a process that results in water as the only by-product \(i.e. it is essentially a zero-emission vehicle and that can have much smaller batteries or longer ranges than lithium-ion battery EVs\).](#)¹
- [Current FCEVs are 25 percent to 70 percent less efficient than BEVs, cost more to fill up than ICE vehicles, and are several years behind BEVs in terms of innovation.](#)¹

Available Energy (which effects the vehicle's range) per Pound of Weight for Hydrogen Fuel Cells Compared to Standard Lithium Ion Batteries¹

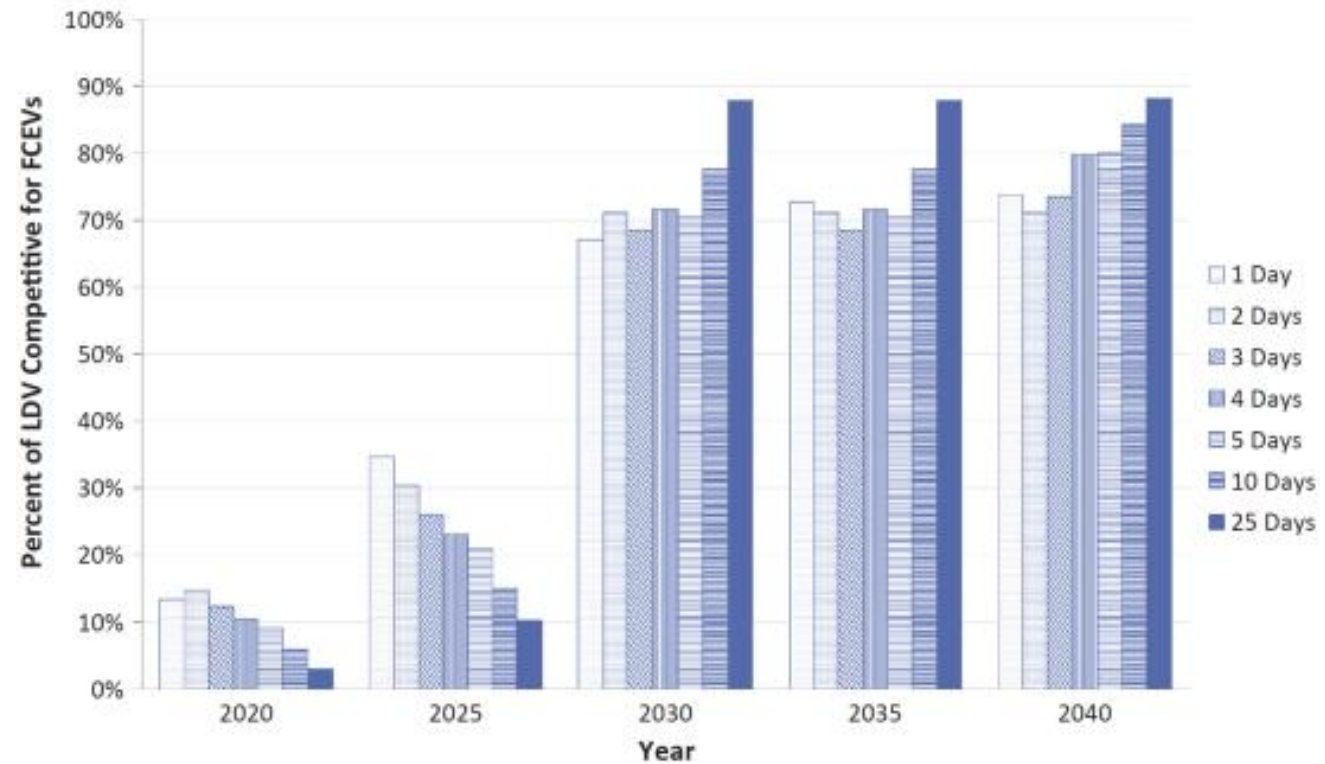


1. Clean Technica. (2018). *Hydrogen Fuel Cell & Battery Electric Vehicles — Technology Rundown*. <https://cleantechnica.com/2018/08/11/hydrogen-fuel-cell-battery-electric-vehicles-technology-rundown/>

8. Battery EVs (BEVs) are not the only EVs.

- [FCEVs could be cost-competitive with BEVs for over 70 percent of the light-duty vehicle market \(LDV\) by 2030, with FCEVs offering notable cost advantages for larger vehicles and longer distances.](#)¹
- [Toyota plans to expand sales of hydrogen-powered vehicles, mass produce its FCEV sedan, launch a fuel-cell-powered bus, and test a fuel-cell-powered commercial truck.](#)²

Fraction of LDV Market that is Competitive for FCEVs vs. BEVs by Year and Number of Inconvenience Days¹



1. Green Car Congress. (2018). DOE analysis suggests rapid convergence of FCEV and BEV TCOS; FCEVs less expensive for majority of LDV fleet by 2040; mass compounding.

<http://www.greencarcongress.com/2018/01/20180114-doe.html>

2. CNET. (2018). Toyota working to mass produce, lower costs of fuel-cell vehicles. <https://www.cnet.com/roadshow/news/toyota-fuel-cell-mass-production/>

9. Massachusetts has EV initiatives in place.

- [Massachusetts has initiatives in place to encourage EV adoption, including a goal of having 300,000 EVs on the road by 2025.](#)¹
- [To encourage EV adoption, Massachusetts' MOR-EV Program offers a \\$2,500 rebate on EVs.](#)²
- [The Massachusetts Electric Vehicle Incentive Program \(MassEVIP\) helps employers acquire EV charging stations.](#)³
- [Eversource](#)⁴ and [National Grid](#)⁵ have both been approved for programs to install charging infrastructure throughout Massachusetts, two of the largest utility initiatives outside of California.
- [Transit authorities in Massachusetts are planning to pilot the use of electric buses throughout the state.](#)^{6,7}

Massachusetts Electric Vehicle Incentive Program (MassEVIP) assisted the City of New Bedford.³



Photo credit: <https://www.flickr.com/photos/masdep/19578649535/in/album-72157655293256568/>

1. Common Wealth of Massachusetts. (2014). *Zero Emissions Vehicles (ZEC) Commission*. <https://www.mass.gov/service-details/zero-emission-vehicle-zev-commission>
2. Center for Sustainable Energy. (2016). *MOR-EV Massachusetts Offers Rebates for Electric Vehicles: Year Two Final Report (May 2015-June 2016)*. <https://mor-ev.org/>
3. Commonwealth of Massachusetts. (2018). *MassEVIP: Workplace Charging*. <https://www.mass.gov/how-to/massevip-workplace-charging>
4. Natural Resources Defense Council (NRDC). (2017). *Massachusetts Approves Precedential Electric Vehicle Program*. <https://www.nrdc.org/experts/noah-garcia/massachusetts-approves-precedential-electric-vehicle-program>
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7. Commonwealth of Massachusetts. (2018). *Volkswagen Diesel Settlements & Environmental Mitigation*. <https://www.mass.gov/guides/volkswagen-diesel-settlements-environmental-mitigation>

10. U.S. has significantly less electrified rail than the rest of the world.

- [One-third of railroad tracks worldwide are electrified, but less than 1 percent of U.S. railroad tracks are electrified.](#)¹
- [Rail accounts for 2 percent of GHG emissions from the U.S. transportation sector](#)²
- [If rail was electrified, the added efficiency could draw additional freight from trucks to trains.](#)²
- [Electric locomotive engines and maintenance are significantly cheaper than their diesel equivalents on the global market.](#)³
- [However, the infrastructure needed to transition to a nationally electrified freight rail system in the U.S. is a major barrier.](#)¹
- [MBTA's Rail Vision study is examining a wide variety of topics, including the possible electrification of some sections of the commuter rail network.](#)³

MBTA's Rail Vision Study examines a variety of topics, including electrification.⁵



Source: <https://www.mbta.com/projects/rail-vision>

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1. Environmental and Energy Study Institute (EESI). (2018). *Electrification of U.S. Railways: Pie in the Sky, or Realistic Goal?* <https://www.eesi.org/articles/view/electrification-of-u.s.-railways-pie-in-the-sky-or-realistic-goal>
 2. CityLab. (2017). *Can Trains Drive Clean Energy?* <https://www.citylab.com/transportation/2017/03/can-trains-drive-clean-energy/519441/>
 3. MassDOT. (2017). *MBTA Launching Study of Future Needs of Commuter Rail.* <https://blog.mass.gov/transportation/mbta/mbta-launching-study-of-future-needs-of-commuter-rail/>

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- American City & Country. (2017). Millennials in transit. <http://americancityandcountry.com/public-transit/millennials-transit>
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