A New Way Forward

Envisioning a Transportation System without Carbon Pollution

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Written by

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Table of Contents

Executive Summary

World leaders made a bold commitment at the 2015 Paris climate talks to limit global warming to 2° Celsius above pre-industrial levels, with an aspiration to limit temperature rise to 1.5° Celsius. Fulfilling that promise will require the United States to reduce emissions of greenhouse gases starting now, with reductions exceeding 80 percent by mid-century.

America's transportation system produces more greenhouse gas pollution than any entire nation in the world other than China, India and Russia. Reducing pollution from transportation in the U.S. is essential to prevent the worst impacts of global warming.

America has made progress in cutting pollution from cars and trucks over the last decade as a result of improved vehicle fuel economy and slower growth in driving. But eliminating greenhouse gas emissions from our urban transportation systems is going to require more than incremental change – it will require transformation.

The good news is that transformation to a zero-carbon transportation system is possible. New technologies and emerging social trends make it easier to envision a transition to a zero-carbon transportation system than ever before.

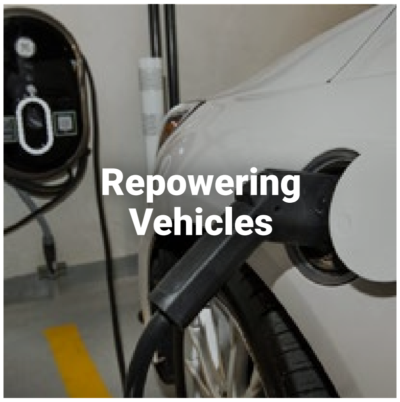
By employing smart strategies to repower our vehicles with electricity, reduce growth in vehicle travel, and optimize the efficiency of our transportation network, America's urban areas can reduce energy demand for light-duty vehicles by as much as 90 percent below anticipated levels by 2050.

Now is the time for federal, state and local officials in the U.S. – as well as citizens and the private sector – to adopt the policies and tools that can enable America to transition to a zero-carbon urban transportation system by the middle of the 21st century.

A zero-carbon transportation system is possible.

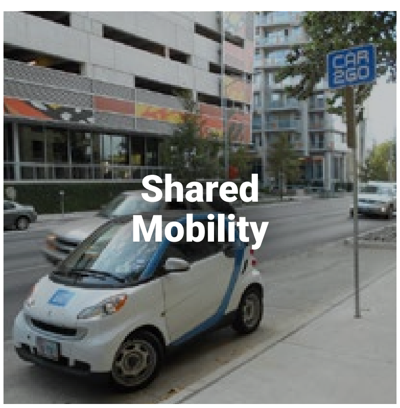
The past decade has seen dramatic advances in technology that are transforming transportation. New shared mobility services, improved electric vehicles, and advances in information technology and technologies for autonomous vehicles open up new avenues by which America can pursue decarbonization of our transportation system. At the same time, renewed interest in walkable communities and broad demographic shifts create new opportunities for building sustainable, low-carbon communities.

America has the tools it needs to transition to a zero-carbon transportation system – and to do it in time to prevent the worst impacts of global warming. Among those tools are:



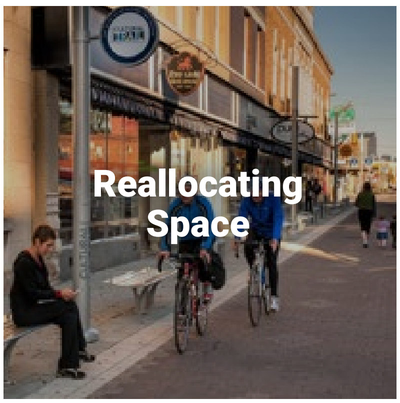
Efficient electric vehicles that can be powered by clean, renewable electricity are entering the marketplace faster than the hybrid cars of a decade ago and technology continues to improve, reducing costs and increasing travel range. Electric vehicles reduce carbon emissions using electricity from today's grid, and will deliver greater benefits in the years to come as America transitions to electricity provided by clean, renewable sources of energy.

American cities – especially their downtowns – are experiencing a renaissance, driven by demographic changes and a desire for walkable living among young people and others. A future in which most new development takes place in urban and walkable neighborhoods could reduce transportation greenhouse gas emissions by 9 to 15 percent by mid-century, according to research by the Urban Land Institute.

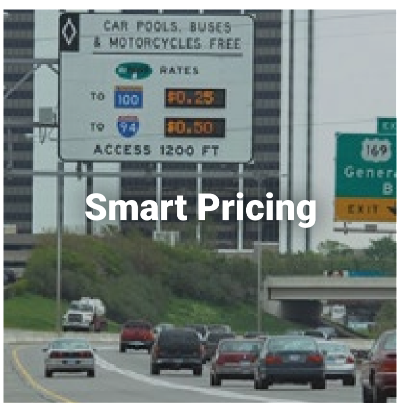


Over the last decade, an explosion of technology-enabled services – from carsharing to bikesharing to Lyft and Uber – has revolutionized transportation in many cities. Some of these "shared mobility" services have been shown to reduce vehicle ownership and driving, while the effects of others are just beginning to be studied.

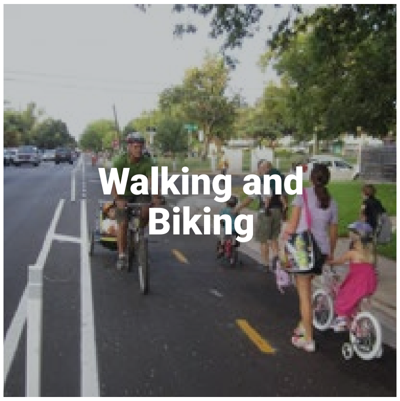
Transit ridership hit a modern high in 2014, the result of recent transit expansion projects and growing urban population and employment. Current public transportation services reduce vehicle travel (and GHG emissions) by about 10 percent in U.S. cities, according to research conducted for the Transportation Research Board.



The vast majority of street space in American cities is devoted to moving or storing cars, pushing people who walk, bike or take transit to the margins. Cities in the United States and around the world are reallocating space formerly devoted to cars to other public purposes, encouraging the use of low-carbon modes of transportation. U.S. cities with good bicycling infrastructure have nearly twice as many bike commuters as the national average.



Americans typically pay nothing to drive on most roads and enjoy the lowest gas taxes in the industrialized world. Government subsidies for driving and free access to roads create economic signals that encourage Americans to drive and put competing low-carbon transportation modes at an economic disadvantage. Cities around the world have shown that smart pricing policies can reduce congestion and encourage the use of low-carbon modes of travel.



Americans prefer walking to any other mode of transportation, according to a recent survey, and the number of people traveling by bicycle in many cities has grown dramatically in the last decade. The Institute for Transportation and Development Policy estimates that bicycling alone could curb global carbon dioxide emissions from transportation by 11 percent by 2050.

Advances in technology are enabling Americans to plan, schedule and pay for trips via low-carbon modes as easily as traveling by car. Real-time transit information has already been shown to trigger modest increases in transit ridership.

Driverless cars can potentially be deployed in ways that can be supportive of efforts to reduce greenhouse gas emissions – especially if they facilitate the use of shared mobility services, vehicle electrification and smart pricing, and do not undermine other emission-reduction strategies.

Numerous academic, non-profit and government studies have shown that ***large-scale reductions in carbon pollution from transportation are technically possible in the next three decades***. New transportation technologies and tools create the opportunity for even greater emission reductions, if they are implemented intelligently.

Transformational change is possible.

Our current, auto-dominated transportation system seems like it has been with us forever, but it is largely the product of rapid, transformational change that occurred over the course of just a few decades in the mid-20th century. Transformational change can occur through incremental steps that grow in ambition and scope over time or through dramatic policy shifts that occur during narrow windows of opportunity.

There are many possible pathways for transforming our transportation system to eliminate greenhouse gas pollution:

» Some cities might choose to **build up**, expanding the availability of housing and commercial space in dense, transit-oriented neighborhoods and investing in robust public transportation systems to accommodate growth and reduce reliance on personal cars.

» Other cities might **fix up** – employing scarce resources to regrow walkable neighborhoods that have fallen victim to disinvestment and decay. Creating grassroots shared-economy services and shifting spending from highway expansion to urban infrastructure repair and reinvestment can help these cities to become the focus of future low-carbon development in their regions.

» Growing cities might **link up,** using public transportation to facilitate the growth of walkable communities and slow the onrush of sprawl. These cities might choose to advance electrification of their transportation system, taking advantage of locally abundant supplies of clean, renewable energy.

» Still other growing cities might **sync up** – developing systems of shared, driverless and connected cars that are managed for optimal environmental performance and efficient use of existing infrastructure. Areas no longer needed for parking could be repurposed to support the development of pleasant, walkable communities in areas formerly famous for sprawl.

Smart strategies can reduce light-duty vehicle energy demand in urban areas roughly 90 percent by 2050, enabling our transportation system to operate efficiently on clean, renewable energy.

New transportation tools and strategies reduce greenhouse gas emissions by curbing growth in vehicle travel; shifting travel to vehicles and modes powered by zero-carbon sources, such as efficient electric vehicles powered by renewable energy; and employing vehicles in ways that maximize energy efficiency.

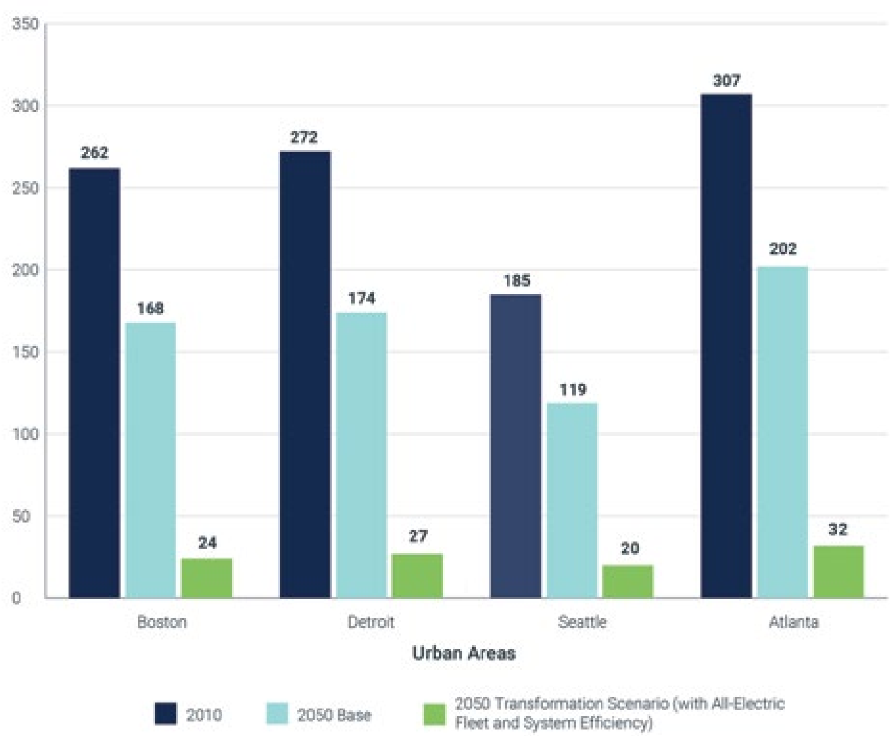
» Changes in transportation investments and behavior consistent with the narratives presented in this report could reduce per-capita light-duty vehicle travel in four major U.S. metro areas by 28 to 41 percent, resulting in changes in total light-duty vehicle travel of -10 percent to +8 percent (compared to 2010 levels) in those areas by 2050.

» Transitioning to efficient electric vehicles could further reduce energy consumption in light-duty vehicles, as could taking advantage of the potential for shared fleets of driverless cars to adopt lightweight vehicle designs, "rightsized" to meet the specific demands of individual trips, and operated in ways that optimize energy efficiency.

» The combined effect of these three steps could be to reduce light-duty vehicle energy demand by 89 to 91 percent compared to 2010 levels – enabling our transportation system to be powered by clean, renewable forms of energy.

» Transforming transportation can play a supporting role in helping other sectors of the economy to decarbonize – providing a source of energy storage to support the integration of renewable sources of energy to the grid, and reducing "upstream" greenhouse gas emissions from oil and gas production, processing and transportation.

Figure ES-1. Light-Duty Vehicle Energy demand (trillion Btu)



The transition to a zero-carbon transportation system won't happen on its own, and there is no guarantee that technological change alone will get the job done. Achieving a zero-carbon transportation system that delivers the greatest possible benefits for America will require a fresh approach to transportation policy. Important steps include:

» Adopting greenhouse gas targets for transportation and evaluating infrastructure investments and transportation policy choices for their climate impacts.

» Shifting the emphasis of transportation policy from infrastructure construction to systems management – enabling transportation agencies to maximize the potential of today's emerging information technology systems and shared mobility tools to improve the efficiency of the transportation network.

» Empowering local leadership, recognizing that metropolitan areas may pursue different pathways to decarbonization based on their distinct histories, cultures, built environments and community aspirations.

» Emphasizing "win-win-win" reforms that support multiple strategies for decarbonization. Smart land-use policies, for example, unlock the potential for several low-carbon modes of transportation – from walking to carsharing – and can support efforts to repower our transportation system with clean sources of energy.

» Ensuring quality transportation service and accessibility for all, recognizing that a zero-carbon transportation system must provide transportation options for people of all ages, abilities and income levels.

» Turbocharging innovation, through aggressive technology standards that drive progress in vehicles and fuels and an embrace of pilot projects and innovative service offerings that provide opportunities to test out new transportation ideas and prepare the public for change.

» Recognizing the co-benefits of transforming transportation. The same tools that can be used to transform transportation for the benefit of the climate can also be used to achieve an array of other important goals – saving taxpayers and consumers money; reducing air pollution, vehicle crashes and other public health and safety threats; ensuring fair and equitable access to transportation; and more. These benefits should be considered and taken into account as policy-makers consider steps toward transforming transportation.

A New Sense of Urgency: Transportation and Global Warming

Preventing the worst impacts of global warming will require the transformation of America's transportation system from one of the world's largest sources of greenhouse gas emissions to one with little to no impact on the climate over the next generation. As time runs short for the world to stop the worst impacts of global warming, the United States must act to curb greenhouse gas emissions from transportation and begin building a zero-carbon transportation system.

The Paris Challenge

World leaders, meeting in Paris in December 2015, committed to take action to limit global warming to 2° Celsius, with an aspiration to further limit temperature rise to 1.5° C, above pre-industrial levels.[1] Meeting that goal will require the near elimination of greenhouse gas (GHG) emissions from America's transportation sector by mid-century.

Global warming is already altering the climate in ways that endanger people, precious ecosystems and our future. The planet has gotten warmer. Storms have become more powerful, with the biggest rain and snow storms in the U.S. having produced 10 percent more rainfall in 2011 than they did in 1948.[2] Sea level is rising – since the late 1800s, global sea level has risen at least 7 inches.[3] And climate scientists warn that even greater impacts are yet to come.

America's transportation system produces more greenhouse gas pollution than that of any other country in the world. Our cars, trucks, planes and trains produce 26 percent of U.S. greenhouse gas emissions and 4 percent of all *greenhouse gas emissions worldwide.*

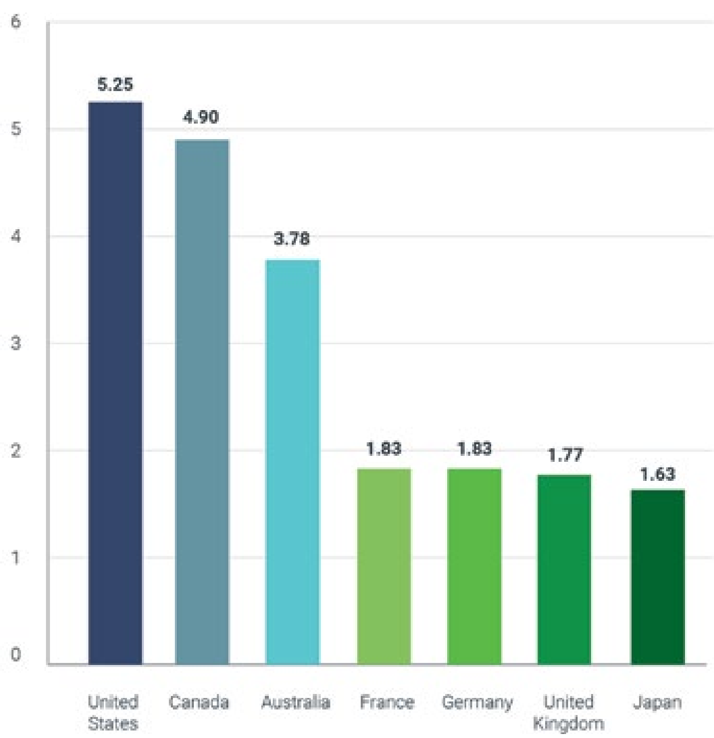
To avoid the worst impacts of global warming, the world must limit the increase in global average temperatures to less than 3.6° F (2° C) above pre-industrial levels. Achieving the 2° C target would require the globe's annual greenhouse gas emissions to fall from more than 49 billion metric tons in 2010[4] to no more than 40 billion metric tons in 2030, with further, dramatic reductions to follow.[5] For the United States, achieving these targets will require a reduction in GHG emissions of 80 percent or more by 2050[6] – a target that will be impossible to meet without major efforts to reduce greenhouse gas emissions from the transportation sector.

America's Transportation System Is Driving Global Warming

America's transportation system produces more greenhouse gas pollution than that of any other country in the world.[7] Our cars, trucks, planes and trains produce 26 percent of U.S. greenhouse gas emissions and 4 percent of *all* greenhouse gas emissions worldwide.[8]

America's transportation sector is exceptionally polluting when compared with those of other industrialized nations. In 2012, the U.S. produced more carbon dioxide pollution per capita from transportation than any major industrialized nation. America produces 9 percent more carbon dioxide per capita from transportation than Canada, nearly a third more than Australia, and nearly three times as much as the United Kingdom, France or Germany.[9]

Figure 1. Transportation Carbon Dioxide Emissions per Capita by Country[10] (metric tons)



The United States has taken important actions to curb greenhouse gas emissions from transportation, including the adoption of strong fuel economy and greenhouse gas emission standards for light-duty and heavy-duty vehicles. Between 2000 and 2012, America's per-capita emissions of carbon dioxide from transportation fell by 12 percent – an important down-payment on the larger emission reductions that must follow for the nation to uphold its climate commitments.[11]

But while current measures, including fuel economy standards, are expected to lead to a slight decline in carbon pollution from transportation between now and 2040, they are nowhere near enough to meet America's obligations to stabilize the climate.[12]

Road emissions of carbon dioxide in urban areas – the focus of this report – accounted for more than half of the nation's transportation carbon dioxide emissions in 2012.[13] These emissions are significant on a global scale, exceeding the *total* carbon dioxide emissions produced by the nations of Canada, Brazil, France or the United Kingdom.[14]

Reducing emissions from all forms of transportation – in both urban and rural areas – is necessary for the United States to achieve its greenhouse gas emission reduction targets. In this report, we focus on emissions from road travel in large urban areas.

Decarbonizing our transportation system within 35 years will require transformation of our cities, our vehicles, and the sources of energy we use to power them. Recent advances in technology and changes in society, however, create new hope for transformation and new opportunities to build a transportation system that preserves a stable climate for ourselves and future Americans.

New Opportunity: Innovation and Social Change

The past decade has seen dramatic shifts in technology and society that create opportunities for transformative change in transportation. Smart public policy can harness these opportunities to move the nation toward a zero-carbon transportation system.

Technology Is Advancing

The early 21st century has witnessed dramatic advances in an array of technologies with the potential to contribute to a zero-carbon transportation system.

A decade ago, in 2006, there were no mass-market electric vehicles, the iPhone was still a year away from introduction, and solar energy was a miniscule part of the nation's electric mix. A decade later, more than a dozen models of plug-in electric vehicles are available on the mass market, more than two-thirds of all American adults own a smartphone,[15] and the nation has more than 25 gigawatts of solar photovoltaic capacity, 12 times more than it had in 2010.[16]

New waves of technological change – including continued advances in battery technology and the advent of autonomous vehicles – are visible on the horizon.

New waves of technological change – including continued advances in battery technology and the advent of autonomous vehicles – are visible on the horizon.

These technological changes unlock vast new possibilities for organizing our society, our economy and our transportation system in less carbon-intensive ways:

- Technology-enabled shared mobility services (see page 29) can potentially free Americans from the financial burden of car ownership, while the spread of open-road tolling, smart parking meters and "mobility as a service" options provides new tools to manage our transportation systems to alleviate congestion and reduce environmental impact (see page 35).
- Advances in electric vehicle technology (see page 26) are hastening the day when the electric car can successfully challenge the internal combustion engine vehicle – and enable us to envision a transportation system powered completely by clean, renewable energy.
- Autonomous vehicle technology opens a vast array of new opportunities to move people and goods more efficiently around our metropolitan areas (see page 42).

Technology is also changing our daily lives in ways that may ultimately reduce travel demand. Telework, replacement of physical items with virtual products, and online shopping are changing patterns of transportation demand, though whether these changes will lead to increases or decreases in driving over the long run is unclear.[17]

This is an exciting moment, brimming with potential. But history tells us that technological advances do not automatically lead to benefits for the environment.

From the 1980s to the 2000s, automakers made continual improvements to their internal combustion engine cars – improvements sufficient to improve the fuel economy performance of those vehicles by as much as 60 percent. In reality, however, vehicle fuel economy barely improved at all. The reason: automakers used those technological advances to build bigger, heavier and more powerful cars, while using their political clout to oppose stronger fuel economy standards that might have translated those technological improvements into energy savings.[18]

The moral of the story: technological advances create the *potential* to achieve broad social and environmental benefits. But that potential can only be fully realized through smart public policy.

Society Is Changing

The "American Dream" has long been associated with a house in the suburbs and a two-car garage (with two cars in it). That dream never appealed to all Americans, and, in recent years, a newer vision of the American Dream has firmly taken place beside it.

In this new vision, embraced particularly (but not exclusively) by many younger Americans, the freedom that had once been symbolized by the car is now represented by the freedom to function without one. The new American Dream is characterized by the freedom to travel via foot or on bike, to be part of an authentic community in a distinctive place, and to avoid the often crushing financial burden of car ownership.

Well-educated young adults have disproportionately moved to urban core neighborhoods since 2000. In the nation's largest metropolitan areas, the population of young adults with a college degree increased by 37 percent in close-in urban core neighborhoods between 2000 and 2010, compared with an overall population increase of 19 percent. The population of college-educated young adults even increased in the core areas of several Rust Belt cities that were undergoing population declines.[19] These shifting migration patterns have raised concerns about

The postwar American Dream was characterized by privately owned automobiles and car-dependent suburban lifestyles – both of which have declining relevance and appeal in the early 21st century.

housing affordability in the cities experiencing the most dramatic changes. However, they represent a reversal of the dominant trend of the late 20th century, in which investment poured out of cities into low-density, carbon-intensive suburbs.

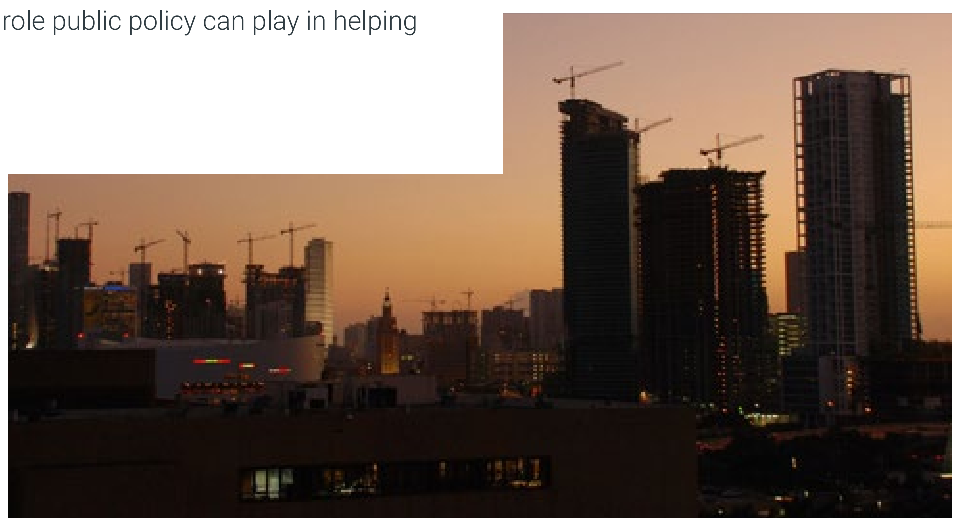
Surveys of transportation preferences and behaviors show broad differences between younger and older Americans. Americans 18 to 34 years of age prefer walking to driving by 12 percentage points – the most of any age group[20] – and adults under 30 are three times more likely to use public transit regularly than those over the age of 50.[21] Younger people are also the most likely to favor having access to walkable amenities and public transportation when choosing a place to live.[22]

These trends are reinforced by broader demographic and socioeconomic shifts. Suburbs are often conceived of, in the American imagination, as the ideal place for families with young children. Yet, married couples with children accounted for only 26 percent of all households in 2010, compared with more than half of all households in 1950.[23] By contrast, single-person households, which represented less than 10 percent of all households in 1950, accounted for more than 27 percent by 2010; a figure that the Harvard Joint Center for Housing Studies projects will increase to 29 percent by 2035.[24]

Charles Street in Baltimore, one of many streets in cities nationwide that have attracted new residents and businesses in the 21st century. *Photo credit: Charles Street Development Corporation*

A decade ago, the task of decarbonizing transportation seemingly stood in direct opposition to prevailing technological and societal trends, as Americans increasingly settled in distant suburbs and traveled ever-longer distances in ever-larger, less fuel efficient vehicles. Today, advancing technology and changes in consumer preferences and demographics open new doors for constructing a low-carbon future.

Taking advantage of that opportunity requires that we explore how societal transformations happen, and evaluate the role public policy can play in helping transformation to occur.



The skyline of many booming cities across America – from Miami (pictured here) to Seattle – is changing, as new residential and commercial development is focused in downtown areas. *Photo credit: Flickr user James Good, CC BY-NC-ND 2.0*

Transforming Transportation: Making it Happen

"It's not that we're incapable of designing a sustainable future. It's that we don't allow ourselves to imagine it. And what we can't imagine, we can't build."
—Sustainability writer Alex Steffen[25]

America's transportation system must be transformed into one that enables people to meet their daily needs using low- and zero-carbon forms of transportation, while preserving a vibrant economy and high quality of life. Public policy has an essential role in enabling this transformation.

In this section, we discuss what transformation looks like, why it is possible, how it might occur, and how to encourage and guide it for the benefit of the climate.

Transformation Is Possible

Transportation can seem slow to change. Transportation behaviors often seem rigid and unchanging when viewed in the aggregate, investments in vehicles and transportation infrastructure are long-lasting, and the public policies that guide transportation seem to be resistant to change, making efforts to decarbonize the transportation system – especially within a short period of time – seem exceedingly difficult.

Yet, transportation behaviors are often more fluid and varied than superficial study would suggest.[27] And there are many examples of transformations in transportation that have occurred within periods similar to the roughly 35 years America has to move to a zero-carbon transportation system. The stories of those transformations suggest pathways by which America can aspire to make the even greater transformation that lies ahead.

"People have patterns of things that they do and usual ways of doing these things. However, they do not always do them in the same way, at the same time, in the same places, with the same people or using the same modes."
—Fleximobility (UK) "green paper"[26]

Building a Bike Mecca

Now known worldwide as a leading bicycling city, as recently as the 1970s, Amsterdam was headed along the same path toward auto dependence as most other Western cities. For decades, the car had been prioritized by policy-makers, with old buildings leveled to widen roads, and bicyclists and pedestrians increasingly pushed to the margins.

But in the early 1970s, Amsterdam faced two crises that led it to change direction. One was a sudden spike in deaths among cyclists and pedestrians – many of them children – as a result of ever-increasing car traffic. The second was the 1973 oil crisis, which drove Dutch leaders to consider a wider range of policy options that might otherwise have been off the table.

Initially, Dutch officials responded to the crises by redesigning residential streets to slow traffic, establishing car-free Sundays, and creating the first bike paths through major cities. Those measures led to an increase in the number of people cycling, which drove political demands for further rounds of increasingly ambitious incremental changes, creating a "virtuous circle" that repeated over the

"Automobile traffic in Amsterdam had increased dramatically. On our street there was a primary school and children were run over frequently ... I thought: my God, what kind of society are we creating?"

—Dutch activist Maartje van Putten, quoted in a Dutch magazine[28]

next several decades. Gradually, cycling came to take on a central role in the transportation system and in transportation policy.[29] Today, more than 60 percent of people in Amsterdam cycle on a daily basis, a third of all traffic movement is by bike, and there are more than 300 miles of bike paths within the city.[30]

Putting a Nation on Wheels

Car dependence and exurban sprawl are so ingrained in the American psyche that it feels as though they have always been with us. But America's current transportation and land-use patterns are, in part, the result of conscious policy decisions with transformative effects, including the decision to build the Interstate Highway System.

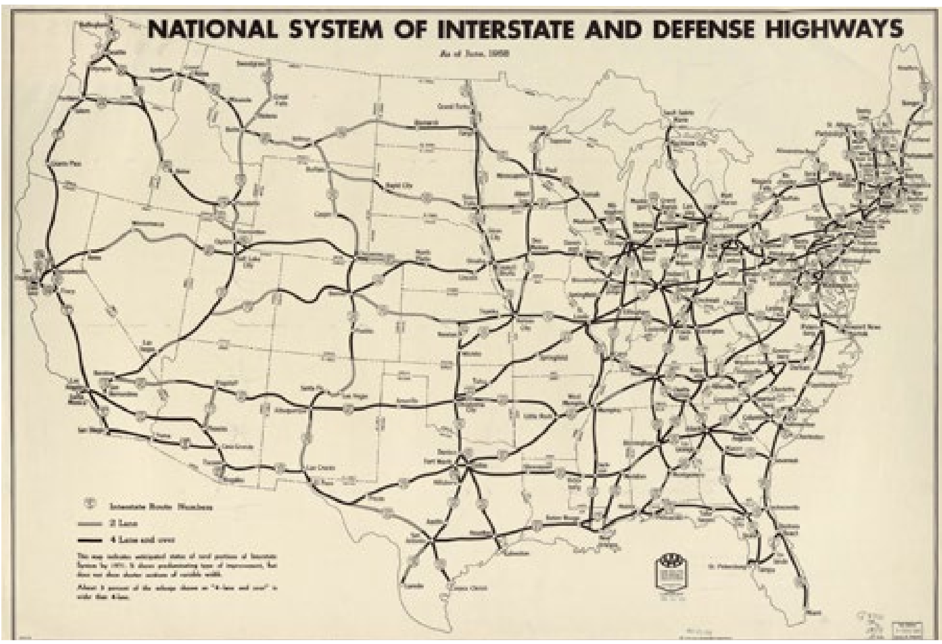
A national network of high-speed highways had been discussed for decades during the early 20th century. But it took the election of a leader particularly committed to the cause (President Dwight Eisenhower), the emergence of an urgent threat (the Cold War, which created a perceived need for high-speed transportation across the country for military purposes), and the careful construction of a winning coalition to deliver the Federal-Aid Highway Act of 1956, which authorized construction of the system and funded it through the federal gasoline tax.

Over the next 36 years, the nation would embark on one of the largest public works projects in human history, building more than 45,000 miles of limited access highways from coast-to-coast[31] and, in the process, changing America's economy, its cities, and its transportation system forever. Over a span of 30 years, from 1960 to 1990, the population of America's suburbs increased by 50 percent while the population of its central cities declined.[32] By 1990, the average American was driving more than twice as many miles each year as he or she did in 1960, and many transportation services that had once been central to American life – from passenger railroads to streetcars – had all but disappeared.[33]

Antoniesbreestraat in Amsterdam, circa 1980 (above) and today. Facing a crisis of traffic deaths in the 1970s, Amsterdam activists and policymakers transformed the city into a mecca for active transportation. *Photo credits: 1980 photo: City of Amsterdam Archives; 2013 photo: Flickr user Allie_Caulfield, CC BY 2.0*

Disrupting Mobility

In 1980, household personal computers were uncommon, the World Wide Web did not exist, and the cellular phone had yet to be commercialized. The first Blockbuster Video rental store would not open for another five years.



The Interstate Highway Network, one of the largest public works projects in the history of the world, was substantially completed over the course of three and a half decades. *Image credit: Library of Congress.*

The technological changes of the last 35 years have been dramatic and have affected our lives in ways that could not easily have been anticipated. New technologies haven't just enabled us to do the same things we did in 1980 better, but they have also facilitated the creation of entirely new social and economic arrangements that have fundamentally challenged established business models.

As will be discussed in greater detail in the next section, technological innovation has begun to disrupt established business models in transportation, just as it has in other areas of American life. Lyft and Uber have challenged the dominance of taxis in major cities, carsharing has shown the potential to undermine historical models of car ownership, and new entrants are continuing to experiment with new ways to disrupt the mobility marketplace.

Little of this could have been envisioned even 10 years ago and it remains difficult to envision how deeply transformative these changes might turn out to be for American life 10 years from now.

Pathways to Transformation

The examples above illustrate the variety of pathways by which transformative change can occur: through incremental changes that build in scope and ambition over time;[34] or through major shifts in in the broader society that open windows of opportunity to alter the policy landscape in lasting ways.[35]

Both pathways share one thing in common: they rely on changes that, prior to their realization, would have appeared impossible. A Dutch parent agitating for safer streets in the 1970s could not have anticipated the chain of events by which incremental reform would lead to Amsterdam's transformation into a world-leading cycling city. New Deal-era lawmakers could not have predicted the emergence of a unique window of opportunity enabling their dream of a national

Few anticipated the explosion of on-demand transportation options now available in many American cities.

network of high-speed highways to become a reality. Few anticipated the explosion of on-demand transportation options now available in many American cities.

How can America prepare for and help to shape a transformation to zero-carbon transportation? Traditional policy analysis tools – which are rooted in assumptions developed from past experience – are of limited help.

Instead, we need to tap the power of imagination.

Planning for Transformation

The effects of transportation innovations and policy changes are complex and can play out over long periods of time. Here, for example, are two narratives for how the arrival of a ridesourcing service like Uber or Lyft might affect transportation in a given city.

1. Ridesourcing is seen as a valuable urban amenity, making a city a marginally more attractive place to live relative to its more carbon-intensive suburbs. The influx of new residents attracts new private investment and generates increased tax revenue, resulting in improved amenities and services that attract more new residents and businesses. Politically, the presence of ridesourcing lends support to a campaign to lift minimum parking requirements for new construction within the city, which, by extension, reduces the cost of housing construction. This, in turn, allows the city to absorb population growth that might otherwise be dispersed into auto-dependent suburbs, leading to reduced greenhouse gas emissions over time.

2. Ridesourcing siphons off a small but significant share of riders from an already fiscally-strained public transportation system. The loss of fare revenue leads to an increasing share of transit costs being covered through general taxation, which eventually proves politically intolerable. Service cuts and fare increases reduce the usefulness of the system to transit riders, leading to further defections from transit to other modes – including ridesourcing services, which see their business grow as the best of a series of increasingly bad alternatives. Transit disappears as a viable transportation option for many residents, representing the loss of a valuable urban amenity and leaving many of those who previously depended on transit worse off and dependent on higher-carbon options for transportation.

Narratives like these are common in media coverage of innovative technologies and new transportation services, and are based on the assumption that only one of these futures – utopia or dystopia – is the inevitable result of the introduction of a new technology or service.

A more nuanced review of the narratives, however, reveals that *either result* – utopia or dystopia – may be possible. Innovations such as ridesourcing may be good for cities and the climate if they are part of an overall policy strategy to reduce dependence on private automobiles. Or, they may be bad for the climate if policy-makers allow them to destabilize existing forms of low-carbon transportation on which many people currently depend.

Policy-makers need new tools to enable them to understand, shape and initiate transformative change if they hope to harness the power of innovative technologies and emerging social trends to meet climate goals.

Playing out the future implications of policies and technological changes through narrative can shed light on critical questions policy-makers must answer if they are to make smart transportation decisions in an era of rapid change and growing urgency around global warming. Where do policies work synergistically to achieve societal goals and where do they conflict? What tipping points might emerge that policy action can help either to hasten or delay? What unexpected consequences might policy-makers need to watch out for? What interests within society are likely to be allies of transformation, which are likely to resist, and how can policies be shaped to create winning coalitions?

Policy-makers need new tools to enable them to understand, shape and initiate transformative change if they hope to harness the power of innovative technologies and emerging social trends to meet climate goals. Narratives, scenarios and other tools to explore alternative futures can help.

About this Report

In this report, we explore the potential for transformation to a zero-carbon transportation system in three ways:

» We identify the tools that can help America build a zero-carbon urban transportation system over the next 35 years.

» We present a series of narratives illustrating how various types of urban areas might create viable pathways to decarbonization.

» We run the numbers to illustrate how changes such as those illustrated in the narratives might combine to eliminate greenhouse gas emissions from urban transportation by mid-century.

The purpose of this report is not to provide a blueprint or roadmap for decarbonization, but rather to demonstrate that transformation to a zero-carbon transportation system is possible, that a variety of pathways can be envisioned to achieve it, and that smart and strategic public policy can help to bring it into being.

The New Transportation Toolbox

The past decade has seen an explosion of new transportation technologies and services, as well as the resurgence of traditional low-carbon transportation strategies. America now has a wealth of tools that can play a role in eliminating carbon dioxide emissions from transportation.

Repowering Vehicles

Vehicle electrification is a core element of a zero-carbon transportation system. By 2050, travel in motorized vehicles must be powered by zero-carbon sources of energy, including electricity generated from zero-carbon renewable sources. Transitioning to electric vehicles now can help ensure the nation has the technology and systems in place to tap renewable energy for transportation by mid-century.

After years of false starts, fully electric vehicles are finally making rapid inroads into the nation's vehicle fleet. As of late 2015, approximately 360,000 battery-electric vehicles and plug-in hybrid vehicles had been sold in the United States, with the pace of growth faster than that of the hybrid vehicles of a decade earlier.[36] The unveiling of the Tesla Model 3 – a more affordable version of the company's luxury electric vehicle offerings – attracted more than a quarter of a million pre-orders within several days in April 2016. The car is expected to go on sale in fall 2017.[37]

As of late 2015, approximately 360,000 battery-electric vehicles and plug-in hybrid vehicles had been sold in the United States, with the pace of growth faster than that of hybrid vehicles of a decade earlier.

Electrification reduces emissions from transportation in several ways:

- Electric vehicles replace inherently inefficient internal combustion engines (which lose 62 percent of the energy they consume in friction and heat[38]) with efficient electric motors;
- Electric vehicles replace a high-carbon source of fuel (oil) with lower-carbon sources, including renewable energy;
- Electrification can allow for greater flexibility in vehicle design, potentially enabling the creation of a range of new vehicle types that can meet a variety of transportation needs in efficient ways.

Electric vehicles generally produce lower emissions over their lifecycle than conventional gasoline powered cars under current grid conditions.[39] Powering electric vehicles with energy from a cleaner future grid would deliver additional emission reductions. A 2015 report by the Natural Resources Defense Council and the Electric Power Research Institute found that, under a scenario in which 53 percent of U.S. vehicles are electric by the year 2050, transportation greenhouse gas emissions could be reduced by 52 to 60 percent.[40]

Key barriers to wider public acceptance of electric vehicles – such as high initial prices, lack of recharging infrastructure, and limited travel range between charges[41]– are beginning to fall. Between 2007 and 2014, the cost of batteries declined by 8 percent annually, with further cost declines anticipated.[42] New vehicle models are beginning to address concerns about vehicle travel range.[43] Manufacturers have been incrementally extending the range of vehicles such as the Nissan LEAF,[44] while the next generation of mass-market electric cars, available within the next two to three years, could boast all-electric ranges of greater than 200 miles at a price point competitive with conventional vehicles.[45]

The next generation of electric vehicles will be able to travel up to 200 miles on one charge and will be cost competitive with gasoline vehicles. *Image credit: Flickr user Robert Couse-Baker, CC BY 2.0*

Personal cars are not the only vehicles that can run on electricity. Electric public transportation – in the form of streetcars, subways and commuter rail lines – has existed in the United States for more than a century. Technological advances are making electric and fuel cell buses a more cost-effective option for transit agencies, with zero-emission buses expected to make up 20 percent of the transit fleet by 2030.[46]

In order for electric vehicles to support full decarbonization of transportation, the electricity used to fuel them must come from zero-carbon sources such as clean, renewable energy. A series of recent studies has suggested viable pathways by which the United States could transition to a largely or fully renewable electric grid by mid-century.[47]

Urbanization and Smart Growth

Smart growth strategies – land-use strategies that encourage density, diversity of land uses, connected and attractive design, destination accessibility, and reasonable distance to transit[48] – have long been considered promising strategies for reducing transportation greenhouse gas emissions. What is new, however, is the perceived attractiveness of walkable urbanism to a broad swath of Americans.

This light rail station in Charlotte, NC is next to a large public market, museums, the convention center and apartment complexes. *Photo Credit: Flickr user James Willamor, CC BY-SA*

Traditionally designed neighborhoods, "new urbanist" developments and urban and suburban infill developments had long been considered niche markets. That has changed. "We used to think walkable urban use was a niche market," according to Chris Leinberger, a professor at George Washington University. "Now it *is* the market."[49]

Over the last decade, cities across the country have experienced a surge in development in downtown areas and dramatic shifts in the composition of urban neighborhoods. Demand for walkable neighborhoods has been driven by several factors, including the rising preference for urban living among educated young adults.

Urbanization and smart growth foster the creation of compact, connected communities. In Lancaster, California, a dilapidated six-lane road was transformed into a tree-lined, walkable, community space. This project was given the award for Overall Excellence in 2012 by the EPA's Smart Growth Achievement project. *Photo credit: EPA*

The influx of young adults into city centers and walkable neighborhoods has lured major employers and been a key driver of new housing construction. According to the Commercial Real Estate Developers Association, 84 percent of businesses leasing office space would prefer to be in a vibrant center with commercial, residential and civic amenities, versus the single-use commercial and office parks that flourished in the late 20th century.[50] In the 2010s, central cities have added population roughly as fast as suburbs in the nation's largest metropolitan areas, a dramatic contrast from the previous decade, in which suburbs grew three times faster than central cities.[51]

The connection between compact development and lower greenhouse gas emissions is well-established. The 2007 study *Growing Cooler* found that people living in compact neighborhoods drive 20 to 40 percent less than those living in sprawling neighborhoods.[52] A later study, *Moving Cooler*, concluded that if 60 to 90 percent of new development were built as compact development and coordinated with transit, it could result in a 9 to 15 percent reduction in U.S. transportation carbon dioxide emissions by 2050.[53]

Compact and mixed land uses are also a prerequisite for the success of other transportation emission-reduction strategies. Increasing the density of jobs and residents near transit stops increases transit demand,[54] makes the expansion of transit service more cost-effective,[55] and maximizes the economic benefits of transit. High density, mixed land uses and limited availability of parking were all identified as factors in the early success of roundtrip carsharing programs.[56] Density and mixed-use development, meanwhile, have been associated with higher rates of bicycling[57] and with higher propensity to walk for transportation.[58]

The influx of young adults and others into the core areas of cities has created demand for walkable urbanism that, in some cases, is growing faster than the supply. The results have been steep rent increases and the conversion of low-income housing into housing for middle- to upper-income people, resulting in displacement of established communities in some cities. The urban affordable housing crisis poses a direct challenge to the nation's ability to allow all of those who wish to live low-carbon lifestyles to do so. To continue the momentum toward walkable urbanism, cities need effective frameworks for addressing housing supply and affordability concerns.

Shared Mobility

The past decade has seen an explosion of technology-enabled "shared mobility" services. Carsharing, bikesharing and ridesourcing services provided by transportation network companies (TNCs) such as Uber and Lyft enable people to travel in urban areas without owning a personal car – providing a potentially powerful alternative to individual car ownership as a model of mobility.

Since 2005:

- U.S. membership in carsharing services has increased 19-fold, to more than 1 million.[59]
- The number of modern bikesharing systems in the U.S. has increased from zero to at least 54, with more than 24,000 bikes in use.[60]
- Ridesourcing apps have emerged as an important part of the urban mobility ecosystem. As of late 2014, Uber reported providing 1 million rides per day around the world, while Lyft was providing 2.5 million rides per month as of early 2015.[61]

Bikesharing systems across the United States have grown rapidly in recent years, offering people the opportunity to "check-out" shared bicycles, like these in Nashville. *Photo credit: Flickr user El Cajon Yacht Club, CC BY 2.0.*

There is much room for further growth. It has been estimated that between 3 percent and 26 percent of U.S. adults are potential candidates to join carsharing systems.[62] According to a report from Deloitte University Press, there are nearly 19 million Americans in major metro areas who could potentially "switch from driving to ridesharing if current barriers to ridesharing were eliminated."[63]

Shared mobility services have diversified in recent years, creating a dizzying array of services and business models that cater to a variety of transportation needs.

» **Carsharing:** Traditional *round-trip* carsharing, exemplified by Zipcar, has recently been joined by *free-floating one-way* carsharing, which allows users to pick up cars on demand and return them to any approved parking space within a city. *Station-based carsharing* allows users to make a one-way trip and return the vehicle to designated parking spots throughout the city. In *peer-to-peer car sharing*, individuals share their private cars with one another.

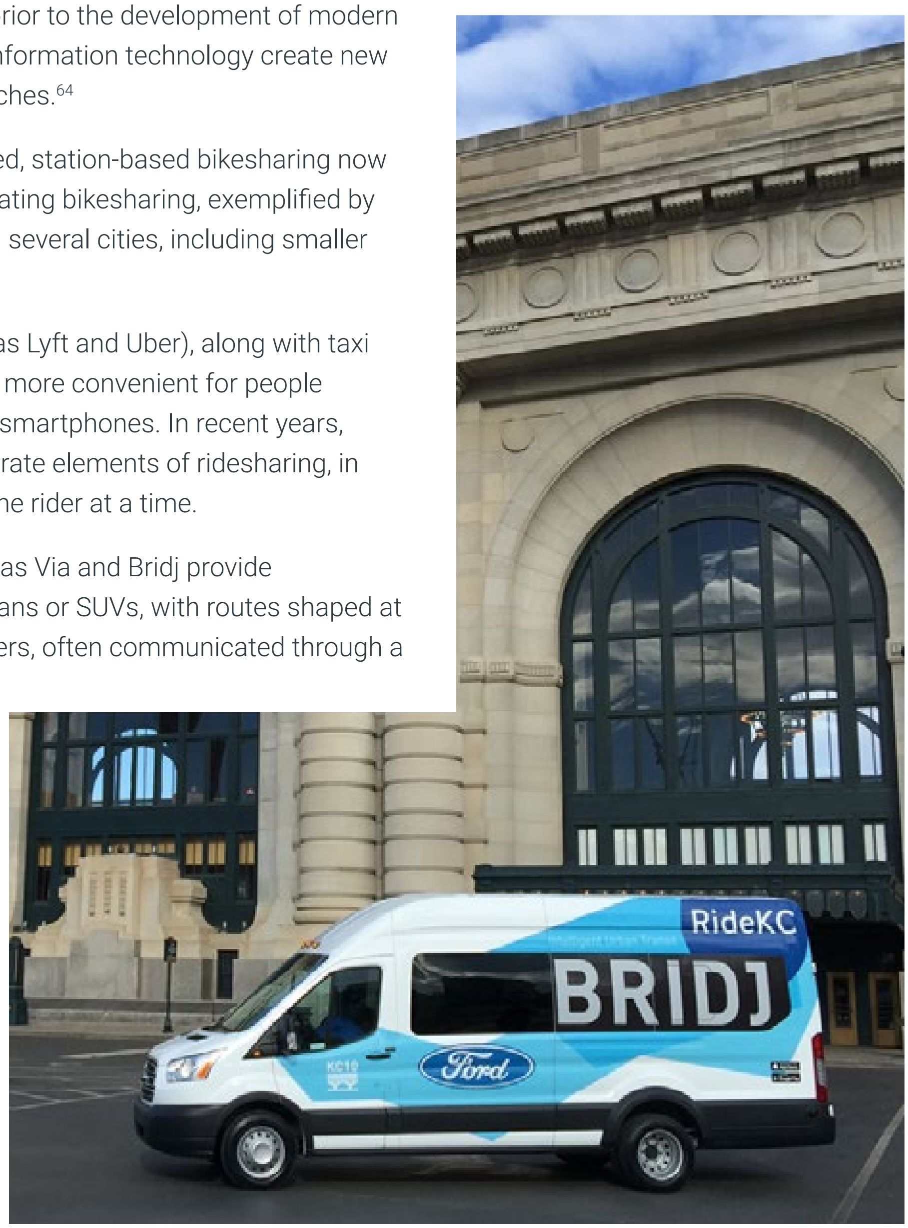
» **Ridesharing:** Ridesharing allows people going to the same destination or to destinations along a shared route to travel together, thereby eliminating a duplicative car trip. Ridesharing – in the form of both organized and spontaneous (casual) carpools – has been a common form of transportation in the United States for generations, well prior to the development of modern information technology, but advances in information technology create new opportunities to facilitate shared-ride matches.[64]

» **Bikesharing:** In addition to the tech-enabled, station-based bikesharing now common in many American cities, free-floating bikesharing, exemplified by Social Bicycles, has now been rolled out in several cities, including smaller U.S. cities.

» **Ridehailing:** Ridesourcing services (such as Lyft and Uber), along with taxi e-hailing apps, make it less expensive and more convenient for people to access on-demand mobility using their smartphones. In recent years, ridehailing services have begun to incorporate elements of ridesharing, in which a single vehicle serves more than one rider at a time.

» **Microtransit:** "Microtransit" services such as Via and Bridj provide transportation to multiple passengers in vans or SUVs, with routes shaped at least in part based on the needs of the riders, often communicated through a smartphone app.

In February 2016, the Kansas City Area Transportation Authority teamed up with the company Bridj to provide city residents with a microtransit service that sets routes based in part on data collected from users. *Photo credit: Kansas City Area Transportation Authority*



Shared mobility services can reduce greenhouse gas emissions in several ways.

» Shared mobility services may enable the use of a lower-carbon mode of travel for a particular trip, either by substituting travel in a low-emitting vehicle (a shared bike or energy efficient car) for a trip in a high-emitting vehicle, or by providing a first-mile/last-mile connection that enables a rider to use public transportation instead of driving for the bulk of his or her trip.

- Shared mobility services may enable individuals to substitute "mobility as a service" for personal car ownership, upending the economics of daily trip-making decisions. Private cars are expensive to buy, maintain and garage but relatively cheap to run, a situation that incentivizes those who own cars – which, in the United States, is almost everyone – to use them for as much of their daily transportation needs as possible. Shared mobility services, on the other hand, often cost little or nothing up front, but have significant per-trip costs, providing a disincentive for their overuse. Even if members of car-free households occasionally use a higher-carbon mode – such as a crosstown Uber trip – their *overall* transportation behavior may change in ways that reduce their total carbon footprint.
- Shared mobility may accelerate the uptake of advanced, low-carbon technologies into the vehicle fleet, since shared vehicles have higher utilization rates and are replaced more frequently, and since the capital costs of advanced technologies can be amortized over a greater number of users.
- Shared mobility may – especially when combined with new vehicle designs made possible by electrification and automation – support vehicle "rightsizing," enabling users to be matched with the most energy efficient vehicle available for their immediate needs.

Shared mobility may – especially when combined with new vehicle designs made possible by electrification and automation – support vehicle "rightsizing," enabling users to be matched with the most energy efficient vehicle available for their immediate needs.

Not all shared mobility services reduce greenhouse gas emissions, or do so in all circumstances. Shared mobility may increase greenhouse gas emissions by inducing additional travel (especially among populations that previously did not have access to low-cost, on-demand mobility) or by attracting users to higher-carbon modes who would otherwise have taken lower-carbon modes, such as transit, biking and walking.

The real-world effects of some shared mobility services on individual trip-making, on household vehicle ownership, and on greenhouse gas emissions have been measured in a series of recent studies.

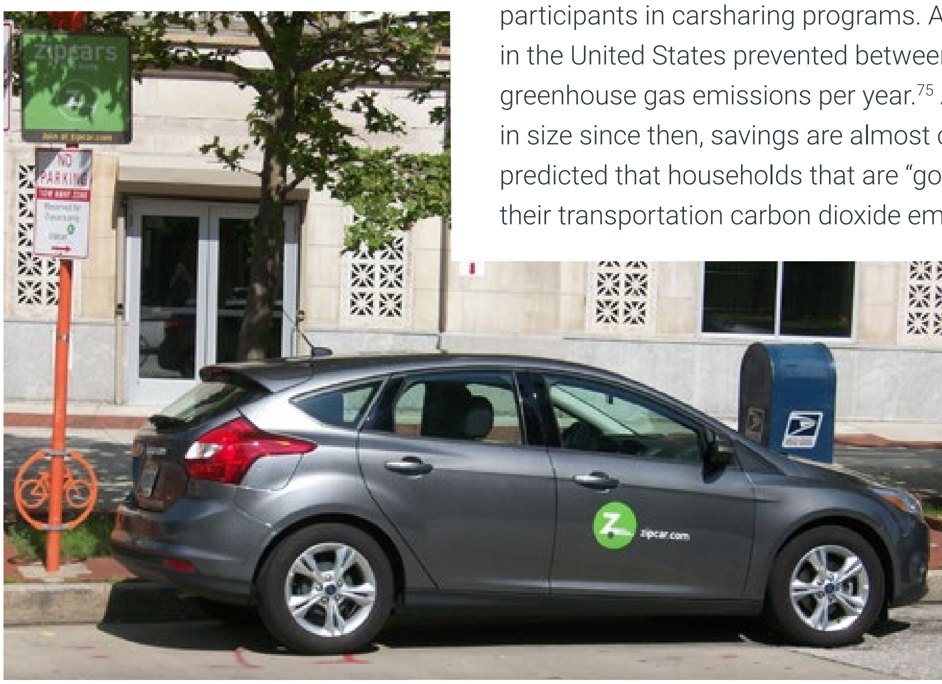
Trip-making: Shared mobility services have been shown to change how people get around, either by increasing or reducing their use of low-carbon modes of travel. A 2013 survey of bikesharing members in five North American cities found that as many as 55 percent of respondents reported reducing their driving, while effects on transit use and walking varied by city.[65] Bikesharing tends to complement transit in small- and medium-sized cities and suburbs by offering convenient connections to transit service, but competes with transit in larger cities with more established transit networks.[66] A study of ridesourcing services in San Francisco found that people were more likely to share rides with others in ridesourcing vehicles than in taxis, with half of all trips including more than one passenger (though the difference may result from the frequent use of ridesourcing for social trips.)[67]

Vehicle ownership: Researchers at the University of California, Berkeley, reported in 2010 that carsharing had likely taken between 90,000 and 130,000 vehicles taken off the roads, representing a reduction of 9 to 13 personal vehicles for every carshare vehicle.[68] Reductions in vehicle travel resulting from individuals' decisions to sell or forgo the purchase of a vehicle range from 27 to 43 percent.[69] A 2015 joint study in Europe by one-way carsharing services DriveNow and Car2Go found that 37 percent of responding members gave up a vehicle since joining a flexible car sharing program.[70] Early studies of bikesharing suggest a very limited impact on vehicle ownership (on the order of a 2 to 4 percent reduction), while a study of ridesourcing in San Francisco found no detectable impact on vehicle ownership.[71]

Transit connections: An early study of ridesourcing in the Bay Area suggested the potential of ridesourcing to both complement and compete with transit for riders.[72] Anecdotal evidence from U.S. cities suggests that transit stations are major access points for shared mobility services. The ridesourcing firm Lyft reports that 25 percent of its riders use the service to connect to public transportation.[73] Bikesharing systems in Boston and Washington, D.C., report that stations outside those cities' commuter and intercity rail terminals are among the busiest in their respective systems.[74] This experience suggests that shared mobility is serving as a first-mile/last-mile connection to transit, though the extent to which this results in a net increase in transit use is still unclear.

Greenhouse gas emissions: Changes in travel behavior and vehicle ownership result in large reductions in transportation carbon dioxide emissions for participants in carsharing programs. A 2010 study estimated that carsharing in the United States prevented between 160,000 and 225,000 metric tons of greenhouse gas emissions per year.[75] As the U.S. carsharing market has tripled in size since then, savings are almost certainly greater today. A 2015 analysis predicted that households that are "good candidates" for carsharing could reduce their transportation carbon dioxide emissions by 51 percent.[76]

Shared use mobility services like Zipcar (shown here in Baltimore, Maryland) can provide an alternative to private car ownership. *Photo credit: Wikimedia user Deanlaw, CC BY-SA 3.0*



Most shared mobility modes are relatively new, meaning that their impacts on greenhouse gas emissions are not fully understood.[77] Additional third-party study is needed to assess their impacts and provide valuable information to policy-makers seeking to determine the role these services can play in reducing greenhouse gas emissions from transportation.[78]

Public Transit

For more than a century, public transportation has enabled millions of people in American cities to reduce their dependence on cars. Recent years have seen a resurgence of transit use, with ridership up 40 percent since 1995, a pace almost double that of population growth.[79] Cities around the country have expanded their transit systems, with several cities in the Western U.S. in the midst of, or planning, further major expansion.

Public transit can reduce greenhouse gas emissions in several ways:

» It enables large numbers of people to share trips, increasing the energy efficiency of travel.

» It supports the creation of compact neighborhoods where people can live car-free or car-light lifestyles.

» Many forms of transit use electricity, which can be generated with zero-carbon, renewable energy.

Among America's current transit systems, subways and light rail lines typically carry people more efficiently than private cars.[80] On a per-passenger-mile basis, rail transit uses 24 percent less energy than a car and 43 percent less energy than a light truck or SUV.[81] Bus service, on average, does not provide direct energy savings relative to car use, but buses with high occupancy do save energy and can support low-carbon forms of land use.

Transit supports compact land-use patterns and car-light lifestyles, in part because transit is an extremely space-efficient way to move people in cities. A bus in motion uses about one-eighth as much space as moving cars carrying the same number of passengers.[82] When public transit's influence on land-use patterns is considered, transit in the United States reduces transportation greenhouse gas emissions in U.S. cities by about 10 percent.[83]

Light rail in San Jose, CA. On a per-passenger-mile basis, rail transit uses 24 percent less energy than a car and 43 percent less energy than a light truck or SUV. *Photo credit: Flickr user Richard Masoner, CC BY-SA 2.0*

The United States currently lags behind much of the world in transit use – the result of historical investment policies that prioritized highway construction, ongoing subsidies and incentives for vehicle use, and inadequate transit in many cities. Germany, for example, provides roughly three times the amount of transit service per capita as the United States, including nearly four times the metro/subway and regional rail service, along with higher-quality, more comfortable service. Partly as a result, the average German takes more than five times as many transit trips per year as the average American.[84]

Americans generally support expansion of public transportation. A 2014 ABC News/Washington Post poll found that Americans preferred transit to road expansion as a tool for reducing congestion by a 54 percent to 41 percent margin, with adults under the age of 40 supporting transit over roads by 62 percent to 36 percent.[85] In a 2015 survey by the National Association of Realtors and Portland State University, more than half of respondents ranked expanding public transportation as a high priority, with young Americans again showing greater levels of support.[86]

Only 2.4 percent of street space in San Francisco was devoted to transit-only or bike-only lanes – this in a city in which private automobiles account for fewer than half of all trips.

Studies of public transit ridership in American metropolitan areas find that providing affordable, frequent and safe service, available over a broad swath of a given region, increases ridership.[87] In other words, in cities where transit service is good, people tend to ride more.

Transit use has been also been associated with increases in walking, as many transit trips begin with a walking trip to the stop or station. One study found that train commuters walk 30 percent more steps per day than car commuters.[88]

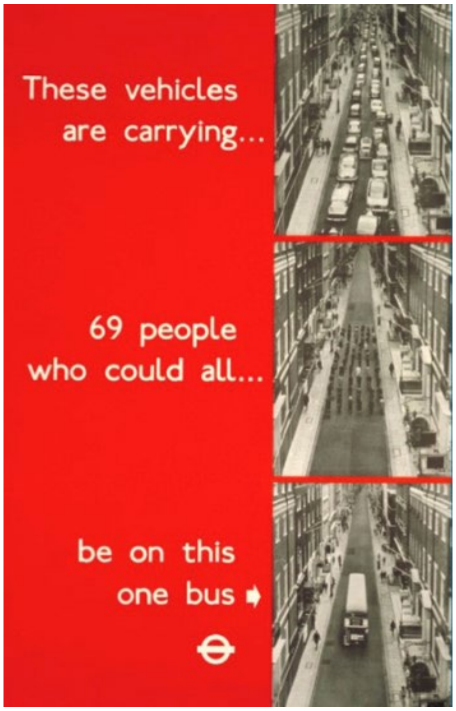
Reallocating Space

Streets account for a significant share of public space in cities, representing a quarter of the land area in Los Angeles and Washington D.C., and about a fifth of the area of Phoenix.[89] In most cities, that space is dedicated largely to moving private motor vehicles – many of them carrying only a single passenger – and storing them when not in use.

A 2014 study found that only 2.4 percent of street space in San Francisco was devoted to transit-only or bike-only lanes – this in a city in which private automobiles account for fewer than half of all trips.[90] Reallocating space from inefficient and high-carbon modes of travel to sustainable and low-carbon modes can encourage the use of those modes, reducing greenhouse gas emissions.

In recent years, leading cities have begun to reimagine streets to support a wide range of users and encourage travel by low-carbon modes of transportation. Cities that have invested in "complete streets" – streets that are designed for all users – have seen increases in walking and biking. After the Federal Highway Administration undertook a "Non-motorized Transportation Pilot Program" and invested in pedestrian and cyclist infrastructure in four cities, pedestrian trips in those communities increased 23 percent while the number of cycling trips increased 48 percent.[91]

This 1960s ad for London's transit system shows the space efficiency of transit versus private cars. © TfL from the London Transport Museum collection



Cities in the United States and worldwide that have reallocated space to low-carbon forms of transportation have experienced dramatic results.

- In U.S. communities with good bicycle infrastructure, bike commuting rates are nearly double the national average.[92]
- Melbourne, Australia, nearly doubled the space allocated to pedestrians over the course of a decade. In that time period, pedestrian volume on the improved streets rose 50 percent.[93]
- In Seville, building a network of two-way dedicated bike lanes drove an increase in bicycling levels from practically zero to 7 percent of all trips.[94]
- Cities around the world that have dedicated roadway space for bus lanes or bus rapid transit systems have experienced large boosts in transit ridership, often drawing travelers away from private cars.[95]

Access to curb space and off-street parking are also integral to the success of shared mobility modes such as shuttles, demand-responsive "microtransit" services, carsharing and bikesharing.[96] (See "Shared Mobility," page 29.) Curbside electric vehicle charging – such as that provided by Indianapolis' BlueIndy electric carsharing program – can also help expand the market for electric vehicles to urban centers where off-street charging is more difficult and costly to provide.

Smart Pricing

Free access to the roads, low gas taxes and free parking are considered a birthright by many American drivers. They are, however, extremely costly to provide. Gas taxes and other fees on vehicle use cover only about half the cost of building and maintaining roads, with the share decreasing over time, meaning that general taxpayers actively and lavishly subsidize individuals' decisions to drive.[97] Meanwhile, driving creates congestion, pollutes the environment, creates noise, and imposes a variety of other "external" costs on society. Studies have estimated the cost of these external impacts to be as high as $2.10 per gallon of gasoline.[98]

Vehicle sharing programs, such as Indianapolis' BlueIndy electric carsharing service, require access to space on public curbs to make their services available to the public.

Free access to roads and parking doesn't even serve drivers well much of the time. Simple economics suggests that giving away a good or service for free leads more people to demand it, resulting in overuse and congestion. Similarly, parking – even on streets owned and maintained with public tax dollars – is often provided to drivers free of charge, leading to shortages that make it difficult to find a place to park during peak times.

As proceeds from the gasoline tax have stagnated in recent years, tolling has made a comeback as a source of revenue to pay for roads. A few states and cities have also explored the congestion-reducing potential of smart pricing through variably tolled express lanes and demand-responsive parking pricing.

Figure 2. Gasoline Tax[99] (per Gallon)

Advances in technology make it more possible than ever to use smart pricing as a tool to improve the workings of the transportation system and curb emissions. Technology now makes it possible to vary the price of travel by time of day, level of congestion, type of vehicle and even the number of occupants, allowing transportation agencies to charge prices that reflect a driver's impact on the system and maximize the efficiency of traffic flow.[100]

Smart pricing can reduce greenhouse gas pollution in several ways:

» It can encourage people to shift from high-carbon single-occupancy car travel to less carbon-intensive modes such as shared rides or public transportation.

» It can increase the efficiency of the transportation system, reducing carbon emissions caused by traffic congestion or "cruising" for parking.

» It can generate revenue to support lower-carbon modes of transportation, such as transit service.

» Preferential pricing of, or access to, tolled lanes can encourage individuals to purchase lower-carbon vehicles such as electric cars.

Cities around the world have adopted congestion pricing systems that put a price on travel on specific roads or access to urban core areas. The International Council on Clean Transportation (ICCT) surveyed several successful programs and found congestion reductions of 13 to 30 percent, with greenhouse gas emissions reductions of up to 20 percent.[101]

In 2003, London started charging vehicles entering the city core during weekdays, reducing vehicle traffic by 20 percent.[102] Ten years after the program went into effect, the city's transit agency reported that bus ridership reached a 50-year high, bike trips had increased nearly 80 percent, and vehicle-miles traveled had fallen by 10 percent, all despite growth in population and jobs.[103] Stockholm has had similar results. In the first three years after introducing a tax to enter the city center, traffic dropped 18 percent, public transit ridership rose nearly 5 percent and carbon emissions dropped up to 18 percent.[104]

In 2003, London started charging vehicles entering the city core during weekdays, reducing vehicle traffic by 20 percent. Ten years after the program went into effect, the city's transit agency reported that bus ridership reached a 50-year high, bike trips had increased nearly 80 percent, and vehicle-miles traveled had fallen by 10 percent, all despite growth in population and jobs.

Pricing will likely also be a key feature of future systems of automated, shared vehicles. A 2015 study found that, under some scenarios, a per-mile fee on driving worked synergistically with dynamic ridesharing to deliver modest additional reductions in driving.[105]

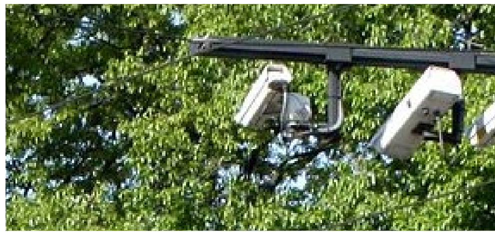
There are several ways in which pricing can be used to reduce carbon emissions.

Pricing vehicle mileage: Taxes or fees that charge drivers by the mile have emerged as a possible substitute for the gas tax. One review by the Rocky Mountain Institute found that a tax on vehicle-miles traveled (VMT) could reduce driving by 12 to 15 percent below a business-as-usual scenario.[106]

Pricing pollution: In January 2015, California became the first state to include transportation fuels in its carbon cap-and-trade system. The carbon charge is assessed as a tax on fossil fuel distributors, not a per-gallon charge to drivers, and the revenue from the assessment is channeled largely to investments in low-carbon forms of transportation.[107]

Pricing insurance: Automobile insurance can be a major cost associated with driving. Yet, most consumers pay annual auto insurance bills that vary little based on the number of miles driven. This creates an inherent economic incentive for individuals to "get their money's worth" from those upfront payments by using their cars for all or most of their transportation needs. Pay-as-you-drive insurance would incentivize car owners to drive less, potentially resulting in an estimated 8 percent decline in vehicle-miles traveled nationwide.[108]

Pricing parking: The availability of cheap, abundant parking in urban centers has been shown to result in increased vehicle travel (and, by extension, carbon emissions).[109] Increasing parking charges, or varying them based on demand, can encourage the use of sustainable modes of travel and discourage inefficient use of private vehicles. Charging variable prices for curb parking spaces – as occurs in San Francisco and an increasing number of cities in America and worldwide – reduces the amount of energy wasted in “cruising” for parking, providing a modest reduction in carbon dioxide pollution and discouraging private vehicle travel during peak periods.[110] Eliminating public subsidies for parking and mandatory parking minimums changes the economics of individuals’ trip-making decisions and allocates costs more fairly among drivers and non-drivers. The Rocky Mountain Institute has estimated that parking pricing could reduce VMT up to 3 percent below a business-as-usual scenario.[111]




Milan’s “Area C” congestion pricing system reduced car traffic to the city’s urban core by 14.5 percent.[116] *Photo credit: Wikimedia user Ita140188, CC BY-SA 3.0*

Transportation pricing measures are often politically a tough sell. A 2015 meta-analysis of polling on mileage-based user fees (VMT fees) found that the fees were supported on average by only about a quarter of the public.[112] Support for increasing the gas tax is similarly low, with less than a third of Americans expressing support for a 10-cent gas tax increase (when the purpose of the tax is not specified).[113]

However, there is evidence from polling that Americans are more likely to support road prices or taxes when they understand the reasons for the pricing and how the revenue will be used. For example, in the Mineta Transportation Institute’s polling on the gas tax, support for a 10-cent increase jumps to as much as 71 percent when the revenue is clearly dedicated to the maintenance of streets and highways.[114] In addition, experience around the world shows that congestion charges gain popularity as their benefits become apparent; in London and Stockholm, for example, congestion pricing gained acceptance only after it succeeded in reducing traffic in the core areas of those cities.[115]

Smart pricing reform is not likely to happen overnight. But careful, conscientious introduction of pricing can promote efficient use of the transportation system and build public support over time.

Active Transportation

Active transportation – biking and walking – is a zero-carbon alternative to motorized travel. Federal studies have found that half of all trips taken with private vehicles are less than 3 miles long, a distance that can be biked in 20 minutes. More than a quarter of all car trips are under a mile, which could be walked within 20 minutes.[117]

Walking and bicycling are becoming increasingly important modes of transportation in many cities. According to the Census Bureau, the number of people walking or biking to work increased more than 60 percent between 2000 and 2012, a greater increase than any other commuting mode.[118] Growth in bicycling has been particularly rapid, with the share of commuting done by bicycle increasing by 62 percent between 2000 and 2013 and bike commuting in "bicycle-friendly communities" with good biking infrastructure more than doubling over that same period.[119]

Walking and cycling reduce greenhouse gas emissions by substituting for motorized travel, and by enabling compact land uses that reduce the need to travel long distances by car. Bicycling and walking are extremely space-efficient ways to move people around cities, enabling cities to support more compact housing and commercial development without corresponding increases in car traffic. Individual sidewalks along some streets in Midtown Manhattan, for example, carry as many as 30,000 people during the three-hour evening rush.[120] Biking and walking also support local businesses that are needed to sustain successful cities; data from several U.S. cities that have installed protected bike infrastructure suggest that businesses near protected lanes see an increase in sales after their installation.[121]

Pedestrians and bicyclists in Austin, Texas. Active transportation is a zero-carbon alternative to motorized travel.
Photo credit: City of Austin

By improving infrastructure for cyclists and pedestrians and creating programs to encourage people-powered transportation, millions more Americans could replace car trips with zero-carbon travel. According to the National Household Transportation Survey, car trips under a mile account for 10 billion miles of travel every year. The EPA has found that if Americans made half as many one-mile trips by vehicle, we could reduce greenhouse gas emissions by 2 million metric tons annually, the equivalent of removing 400,000 cars from the road.[122] Globally, the Institute for Transportation and Development Policy (ITDP) estimated that bicycling could reduce urban transportation emissions by 11 percent worldwide by 2050, while saving society $24 trillion over that time.[123]

Smartphones are powerful transportation tools because they are portable, Internet-connected and location-aware, enabling people to plan, book and pay for transportation services easily, wherever they happen to be, and without the need for advance planning.

In some U.S. cities, bicycling and walking are already major transportation modes. When it comes to traveling to work, about 6 percent of all commuters in large cities biked or walked to their place of employment in 2012 – a figure that is far higher in compact, transit-oriented cities such as Boston (14 percent), Washington, D.C. (13 percent), San Francisco and New York City (11 percent each).[124]

Recent polling suggests that walking is the favorite mode of transportation for all but the oldest Americans, with the availability of safe, pleasant places to walk being among the most important factors people take into account when choosing a place to live.[125]

Information Technology

The mass commercialization of the smartphone, which came with the introduction of the iPhone in 2007, was one of the most disruptive events in transportation in years. Smartphones are powerful transportation tools because they are portable, Internet-connected and location-aware, enabling people to plan, book and pay for transportation services easily, wherever they happen to be, and without the need for advance planning.

The innovations unleashed by the smartphone are among a broader range of technology-driven changes that are transforming transportation systems around the world. Information technology and open data are enabling users to make smarter travel choices, helping transportation systems to operate more efficiently, and encouraging shifts toward lower carbon travel options. As one study by Deloitte University Press said, "there is no aspect of travel that is not being transformed by IT [Information Technology]."[126]

Information technology can address global warming by helping individuals to travel more efficiently and by making it easier to use less carbon-intensive modes of travel.

The automobile has long held an advantage over low-carbon modes of travel when it comes to ease of use. Drivers choose their time of departure, have GPS and traffic reports on television and radio to help them determine their route and plan for delays, and can adapt their travel plans to changing conditions or new needs (e.g., the desire to take a side trip) on the fly.

By contrast, traveling via transit – much less renting a car or borrowing a neighbor's bike – has historically been a hassle. Transit riders have had to conform their travel plans to fixed schedules, read complicated timetables and confusing maps to figure out how to use the system, and carry exact change or a special fare card in order to ride, and were often left in the dark about delays or service disruptions.

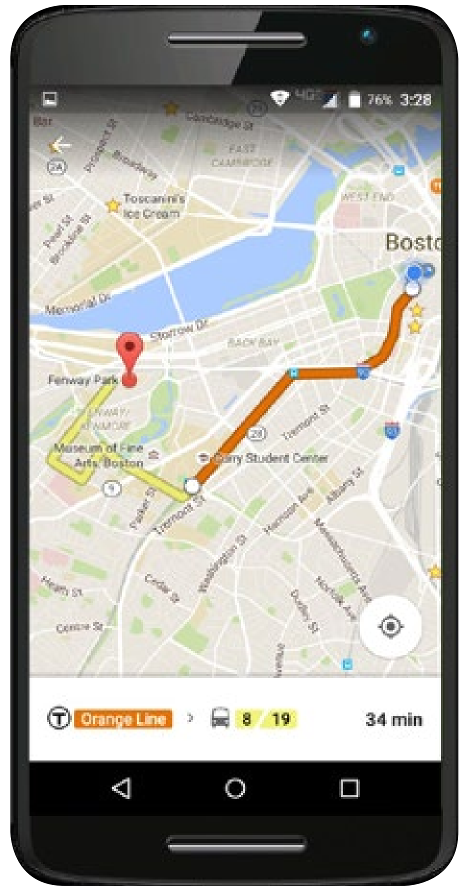
Information technology is leveling the playing field, making it easier for people to use and pay for low-carbon modes of travel. Moreover, by combining data about a variety of modes in integrated, multi-modal apps, travelers have an ever-expanding range of options for completing a particular trip, and more information about the implications of those choices for their schedules and pocketbooks.

Among the important information technology advances of recent years are the following:

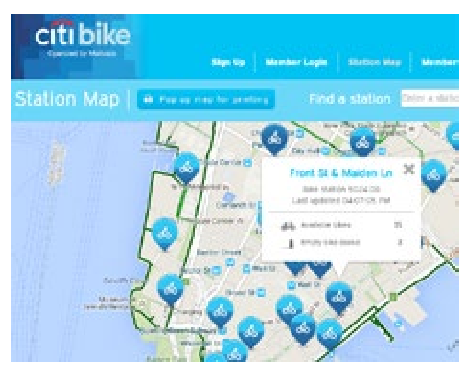
Real-time information: Real-time information apps let riders know when the next bus or train will arrive, whether a bikeshare station has a bike available, or which means of travel will be the quickest, cheapest or even healthiest based on current travel conditions. Knowing when the next bus will arrive reduces the amount of time riders perceive that they must wait, increasing their satisfaction with riding transit. Overall, ridership in Tampa increased an average of 2.2 percent on weekday transit routes as a result of real-time information,[127] while implementation of real-time information for buses in New York City led to a ridership increase of 2.3 percent on each route, with a substantial impact network-wide.[128]

Electronic payment: New payment technologies are making it easier for travelers to use public transportation or other shared-use modes of travel. In November 2015, Chicago upgraded its contactless card system to an app, allowing transit riders using any of the Chicago-area transit systems to purchase tickets online, eliminating the need to stand in line at a station. The app also allows transit users to plan their trip and receive real-time information.[129]

Multimodal trip planning: New apps are being developed that knit the entire transportation experience together – helping people get from door-to-door in the fastest, cheapest, most convenient way possible, regardless of the mode. Instead of deciding how one will travel and then considering the best timing and route, a full array of options is displayed side by side along with their timing and routes. Multimodal apps can help users evaluate different routes based on price, traffic,



The availability of smartphone trip planning apps like Google Maps has made public transportation use easier. *Image Credit: screenshot of Google Maps*



Many bikeshare systems, including New York City's Citibike, makes use of information technology to allow users to locate available bicycles from their smartphone or computer. *Credit: Citibike* routes, schedules and even the opportunity to burn calories. This greatly expands the options available and facilitates transit, walking, biking and sharing vehicles.[130]

System efficiency: Technology is also enabling operators of transit and shared-use systems to become more efficient in their operations and to provide new service offerings to the public. With the arrival of the smartphone, bus and van services can shape their offerings to meet consumer demand in ways never before possible. Private shared-ride services such as Bridj and Via, currently operating in major American cities such as New York, Boston and Chicago, allow riders to customize their rides within certain service areas, while San Francisco-based service Chariot uses crowdfunding principles to design routes around the specific expressed needs of a group of commuters.

Smart parking: Smart parking technology can help drivers can find open parking spaces – reducing the need to circle the block looking for empty spaces – while enabling parking managers to vary the price of parking to reflect market demand.[131]

Self-Driving Vehicles

The advent of automated and connected vehicles could revolutionize transportation in the United States, though it is unclear precisely how. Automakers and technology companies are currently in a race to bring the first driverless car to market, and automakers such as Tesla already beginning to integrate some self-driving capability into current-model vehicles.

The effect of automated and connected vehicles on greenhouse gas emissions depends critically on the answers to several key questions:[132]

- Will a system of autonomous and connected vehicles be optimized for energy-efficient travel – making use of energy-saving measures such as efficient braking and platooning?
- Will the system be safe enough to enable vehicles to be made of lighter materials, improving vehicle energy efficiency?
- Will policy incentives and economic forces encourage autonomous vehicles to be used as part of shared fleets or be privately owned?

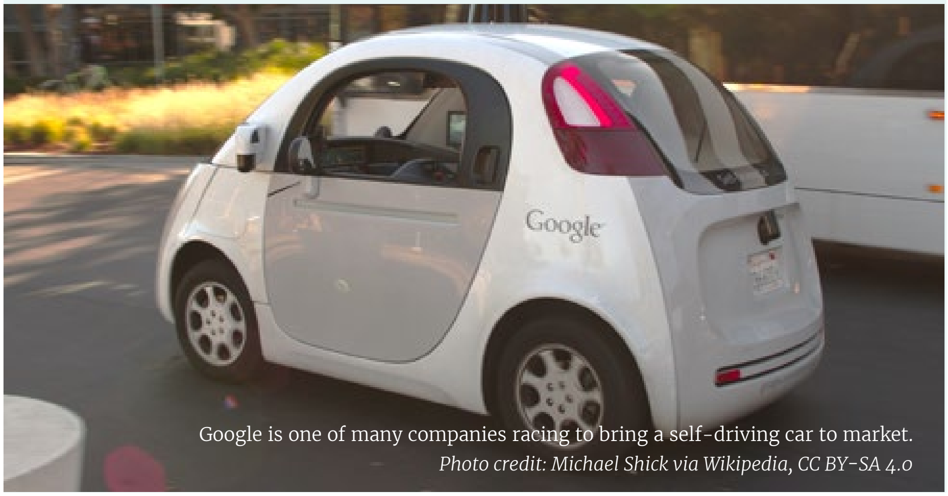
» Will autonomous vehicles give priority to the safety of pedestrians and bicyclists – enabling those modes to be used more safely in cities?

» Will autonomous vehicles be available and affordable to all segments of society or limited to a few?[133]

The answers to these and other questions will determine the effect of automated vehicles on travel demand, land use and greenhouse gas emissions. Early studies of automated vehicles have postulated impacts on energy use and greenhouse gas emissions ranging from dramatic increases to dramatic decreases, though there is slightly greater consensus that automated vehicles would lead to an increase in vehicle travel.[134]

Automated and connected cars can be a vehicle for implementing and magnifying the benefits that can be delivered by the other emission reduction tools described in this section – hastening the repowering of the vehicle fleet, providing mobility-as-a-service through integration into shared-use services, making cities safer for bicyclists and pedestrians, and reducing parking demand so as to enable more compact and walkable land uses in cities and suburbs. Public policy will ultimately help to decide whether automated cars achieve these goals or stand as an obstacle to climate progress.

While we do not address automated and connected cars as a distinct strategy for decarbonization, several of the transformation narratives (see page 45) later in this report incorporate aspects of vehicle automation in their vision of the future.



Google is one of many companies racing to bring a self-driving car to market.
Photo credit: Michael Shick via Wikipedia, CC BY-SA 4.0

Envisioning a New Way Forward

American metropolitan areas have distinct histories, "mobility cultures," and present-day needs that might lead to different strategies for decarbonization.

A wide and growing array of tools exist that can help move America toward a carbon-free transportation system. Political, cultural and technological hurdles must be overcome, however, if transformation is to happen at the speed and scale needed to prevent the worst impacts of global warming.

No single tool in the toolbox can carry the full load. It may be possible to simply swap today's inefficient, fossil fuel-fired internal combustion engine cars for a new generation of efficient electric cars, and a transition to electric vehicles is an indispensable part of any decarbonization strategy. A strategy focused solely on vehicles and fuels, however, may prove to be a more costly and less beneficial route to zero-carbon transportation than an integrated strategy that also addresses the many fundamental problems of our auto-oriented transportation system: the financial burden it places on households and taxpayers; traffic congestion, deaths and injuries on the roads; and the system's failure to adequately serve the poor, the young, the elderly and the disabled.

Nor is the same pathway likely to be the optimal solution for every city or metropolitan area. American metropolitan areas have distinct histories, "mobility cultures," and present-day needs that might lead to different strategies for decarbonization.[135]

How might various regions choose to use these tools to move toward a zero-carbon transportation system? Below, we explore the various ways in which transformation might play itself out – illuminating key opportunities for policy action to support the transition.

Four Narratives of Transformation

In this section, we present narratives representing four pathways by which urban areas might decarbonize their transportation systems, applied to four recognizable types of U.S. urban areas. The following narratives are intended to tell plausible, internally consistent stories for how urban areas might pursue decarbonization. They *do not* purport to represent what *will* happen – setting a decarbonization strategy for cities, regions, states and the nation will require collaboration among a variety of stakeholders and action on many policy fronts over the course of decades.

The purpose of this exercise, rather, is to reinforce the fact that pathways for decarbonizing transportation exist in *every* type of urban area and to spark renewed discussion of how to bring a zero-carbon transportation system closer to reality.

The narratives contain the following elements:

- A **backstory** that describes how the city came to where it is today.
- A **crisis** that serves as a "critical juncture," creating an opportunity for transformative change.
- A **policy response** that includes the use of one or more tools in the transportation toolbox.

The narratives were informed by popular and academic literature (including many works cited in the endnotes that begin on page 106), as well as conversations with more than 70 planners, advocates, experts and stakeholders from more than 20 urban areas across the country from the fall of 2015 to the spring of 2016. While the narratives are informal in nature, they are in the tradition of scenario analyses that have found increasing favor in recent years as a tool to explore the implications of alternative futures for transportation. (See "Notable Transportation Scenario Analyses.")

Notable Transportation Scenario Analyses

In the last five years, there have been several notable efforts to use scenario analysis to envision the implications of various futures and policy pathways for transportation.

- **Global Transport Scenarios** (2011). The World Energy Council evaluated two scenarios – a "freeway" scenario in which the future of world transportation was driven by market forces leading to unfettered global competition, and a "tollway" scenario in which governments attempted to shape transportation for common good. The analysis found that the "tollway" scenario would result in a 16 percent increase in transportation carbon dioxide emissions worldwide by 2050 compared with a 79 percent increase in the "freeway" scenario.[136]
- **Future of Mobility** (2013). RAND Corporation and the Institute for Mobility Research evaluated two scenarios – "no free lunch," which assumed, among other changes, strong government action to address climate change, and "fueled and freewheeling," which assumed cheap oil and no change in U.S. energy policy. The "no free lunch" scenario produced a 0.3 percent annual increase in travel across all modes between 2010 and 2030, with nearly all of that growth in transit and air travel, one-third the annual rate of growth of the "fueled and freewheeling" scenario.[137]
- **Re-Programming Mobility** (2014). Anthony Townsend of the NYU Rudin Center on Transportation devised four scenarios, applied to four U.S. metropolitan areas, in which technological changes in transportation were evaluated according to the traditional storylines of scenario analysis: growth, collapse, constraint and transformation.[138]
- **The Effects of Socio-Demographics on Future Travel Demand** (2014). Produced as part of the National Cooperative Highway Research Program, this study evaluated four future transportation scenarios for five U.S. metropolitan areas. The analysis envisioned per-capita vehicle travel changes ranging from declines of 61 to 67 percent under a "gentle footprint" scenario of pro-environment policy to increases of as much as 6 percent under a "tech triumphs" scenario of vigorous, tech-driven economic growth.[139]

The four transformation storylines are:

» **Building Up:** A future of intense urbanization, facilitated in part by expanded, high-quality public transportation. Jobs, housing and amenities are concentrated close to one another in dense urban corridors and nodes, reducing demand for motorized travel, with walking, bicycling and travel in shared, low-speed vehicles accounting for a large and growing share of travel needs.

» **Fixing Up:** A future of fiscal and other constraints that drive communities to prioritize the efficient use of resources and infrastructure. Subsidies for highways and sprawl are ended, replaced with more modest investments in high-return urban revitalization. Technological tools support grassroots sharing of community resources. Underutilized infrastructure is used to support low-carbon/low-cost forms of transportation.

» **Linking Up:** A future of continued metropolitan growth on a trajectory similar to that of the late 20th century, but built instead around an expanded transit network and transit-oriented development. Suburbanization and private vehicle use continue, but with their effects moderated through efficient road pricing and vehicle electrification.

» **Syncing Up:** A future characterized by rapid technological advances, optimized for societal benefit by a nimble, coordinated and active public sector. Automated, shared electric vehicles, traveling on an intelligently managed road network, supplant privately owned vehicles as the dominant mode of personal transportation.

Each of the storylines above could be applied to any urban area in the United States. Practically speaking, however, certain strategies for decarbonization are likely to be more feasible, cost-effective and culturally compatible in some cities than in others. To indicate how the scenarios might be applied to real-life cities, we apply the storylines above to hypothetical cities that correspond with common categories of U.S. urban areas.

The hypothetical urban areas are not perfectly representative of any given city – in fact, residents of many cities may see their story partly reflected in two or more of the narratives. (In Chicago, for example, residents of the city's North and South sides may have very different views on which narrative best represents their neighborhood).

The cities are:

Centerville

Centerville is a global leader in business, government, technology and/or culture. Centerville experienced an exodus of people and investment to its suburbs during the second half of the 20th century, but has experienced a renaissance during the first decades of the 21st century. It is relatively dense and ranks low on indicators of sprawl. It has relatively few miles of freeway per capita and high transit ridership.

Good fits: *New York City, San Francisco, Boston, Washington, D.C.*

Possibly relevant: *Los Angeles, Miami, Chicago, Seattle.*

Beltania

Beltania is a former industrial powerhouse that has lost much of its population since the 1950s as major industries closed down or moved abroad. It ranks relatively high in transit ridership per capita and low in sprawl, befitting a city that was largely developed before the automobile era. But it also has relatively high freeway capacity per capita, befitting a city that built its key infrastructure to accommodate a much larger population than currently resides there.

Good fits: *Cleveland, Pittsburgh, Buffalo, Detroit*

Possibly relevant: *Philadelphia, Baltimore, Milwaukee, Chicago, Cincinnati.*

Westlandia

Westlandia has experienced nearly continuous population growth since the 1950s, developing largely, if not exclusively, around the needs of the car. Concerns about automobile dependence and sprawl have periodically been salient political issues locally, driving the city to embark on major investments in public transportation infrastructure. It falls toward the middle of the scale among large urban areas on measures such as vehicle travel and transit ridership per capita, even though it is characterized by extensive suburban sprawl.

Good fits: *Denver, Phoenix, Minneapolis, Seattle, Salt Lake City*

Possibly relevant: *Los Angeles, Portland, Dallas, Charlotte, Indianapolis.*

Sun City

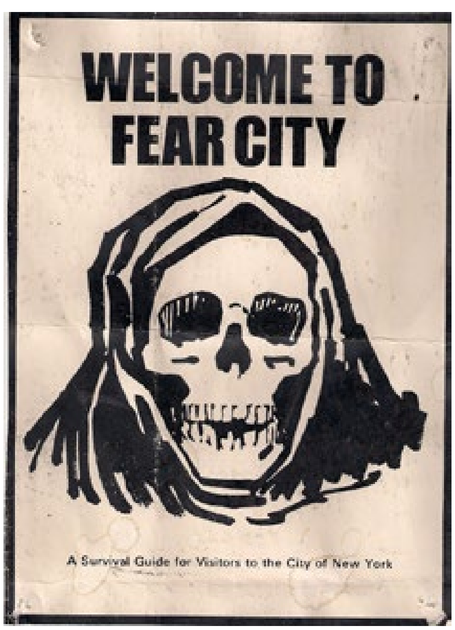
Like Westlandia, Sun City has experienced continuous, often rapid population growth since the mid-20th century. Unlike Westlandia, the city has made only passing efforts to expand transit or limit sprawl. It ranks high for vehicle travel per capita and high on metrics of sprawl, falling in the middle of major cities for highway lane-miles and transit ridership per capita.

Good fits: *Atlanta, Houston, Charlotte, Columbus.*

Possibly relevant: *Indianapolis, Dallas, Tampa, Orlando, Phoenix.*

Building Up in Centerville

In the mid-1970s, disgruntled New York City police officers distributed pamphlets (pictured below) to visitors urging them to "stay away from New York City if you possibly can," but cheerfully noting that, despite rising crime rates, "some New Yorkers do manage to survive and even to keep their property intact" by following the included advice, such as staying off the streets after 6 p.m.



The Backstory

Just a few decades earlier, Centerville seemed like it might "drop dead."

Nearly all the news was bad: rising crime, growing disinvestment and decay, fiscal strain, societal turmoil. As the city's downward spiral gained speed, some wondered what it would look like in 20 or 30 years. Would it even survive?

Decades later, however, things couldn't be more different. The young, the well-educated and the well-off – along with the businesses that hoped to hire them – were flooding back into the city, with those new residents leading less car-dependent lifestyles, often in smaller housing units, than their predecessors in previous generations who flocked to auto-oriented suburbs. The appetite for new housing, especially near the urban core, seemed insatiable and more cranes could be seen dotting the skyline than at any other time in recent memory.

Centerville's resurgence was impressive. But many residents who had stuck it out in the city during hard times wondered if they'd be able to stick around to enjoy it.

The Crisis

Talk of gentrification began even amid Centerville's worst hours in the 1960s and 1970s, but it was limited to only a few enclaves – a drop in the bucket amid the city's overall decline. But the pace of neighborhood change had accelerated dramatically since 2000.

Neighborhoods that had once been labeled "troubled" by outsiders – but that housed communities with deep social ties and who needed the access to transit, jobs and services that living in the city could provide – were now labeled "up and coming" in real estate advertisements and even rechristened with hip new names. Entire neighborhoods changed in character, seemingly in the blink of an eye, with housing and businesses catering to a new wave of residents with disposable income. As housing prices rose, working- and middle-class people increasingly found themselves pushed into outlying city neighborhoods or suburbs that, whatever their other benefits, lacked access to public transportation and many other amenities.

By the mid-2010s, the rapid changes in the city led to tensions between rich and poor, long-time residents and newcomers – tensions that were on the verge of boiling over.

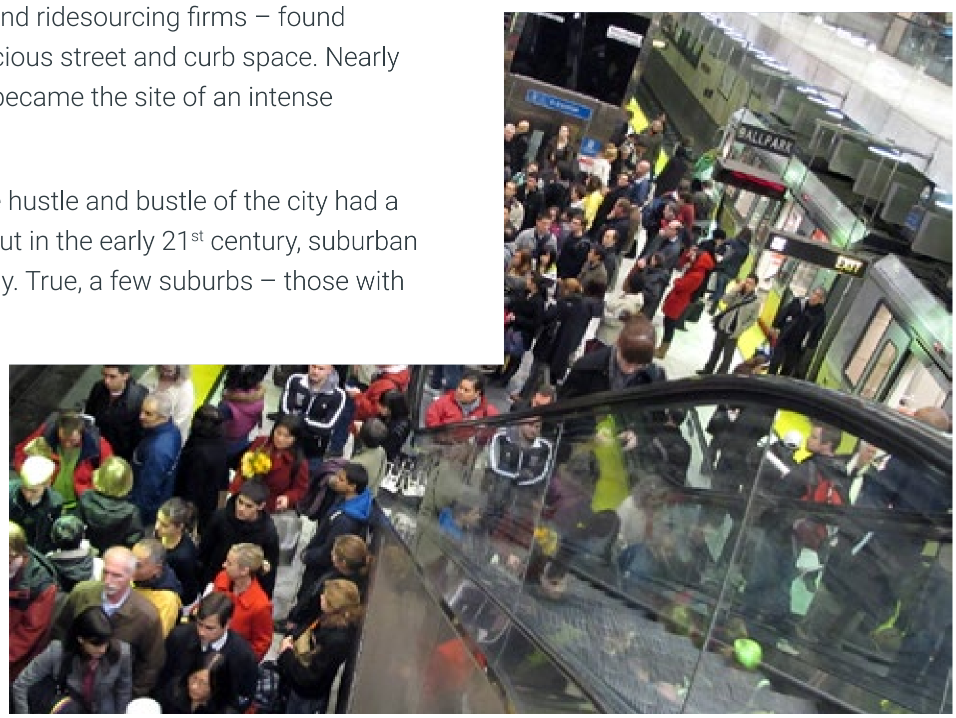
Nowhere were those tensions as palpable as on the city's subways and buses at rush hour. Decades before, Centerville had been ahead of the curve in not only keeping its pre-war transit networks, but reinvesting in them, extending service to new areas and rebuilding decaying systems to deliver improved service. Many believed that those investments in transit had helped to lay the groundwork for Centerville's current boom.

Now, however, those systems were failing. Rising ridership – especially on core rail lines – added strain to a system that was already buckling under the burden of years of deferred maintenance. The cost to fix, much less expand, the transit network grew to unfathomable heights. Centerville needed transit more than ever, but had a harder time than ever delivering it.

On the streets, meanwhile, an array of new users – including bicyclists, carsharing operators, employee shuttles and ridesourcing firms – found themselves jockeying for increasingly precious street and curb space. Nearly every major street and corner, it seemed, became the site of an intense turf battle.

In generations past, those who tired of the hustle and bustle of the city had a simple alternative: move to the suburbs. But in the early 21st century, suburban life was a much less viable option for many. True, a few suburbs – those with walkable downtowns, transit access, excellent schools, and/or a history of catering to the wealthy – thrived as never before. Those suburbs, however, were unaffordable to most people and weren't exactly growing, in part due to restrictive zoning rules. Some older "inner ring" suburbs suffered from many of the same ills that Centerville itself had once faced – declining tax

Transit systems in large cities are increasingly strained by growing ridership, producing scenes like this one at rush hour in San Francisco. *Credit: Flickr user Anita Hart, CC BY-SA 2.0*



base, crumbling infrastructure and aging housing stock. And the auto-oriented exurbs that had sprung up at the far fringes of the metropolitan area in the 1990s and 2000s? Homeowners there had lost their shirts in the housing crisis and many still hadn't recovered, even years later. A new generation of homebuyers was unwilling to repeat the mistake – especially if the reward for doing so was a soul-crushing car commute of an hour or more each way to work.

By the late 2010s, Centerville's skyrocketing real estate prices and collapsing transit network posed a dual threat to its continued growth and prosperity.

The Response

Urbanization and Smart Growth

Centerville leaders came to recognize the city's core challenge: more people wanted to live and do business there than could afford to do so. But with political pressures limiting housing growth for years, how could Centerville provide "more city"?

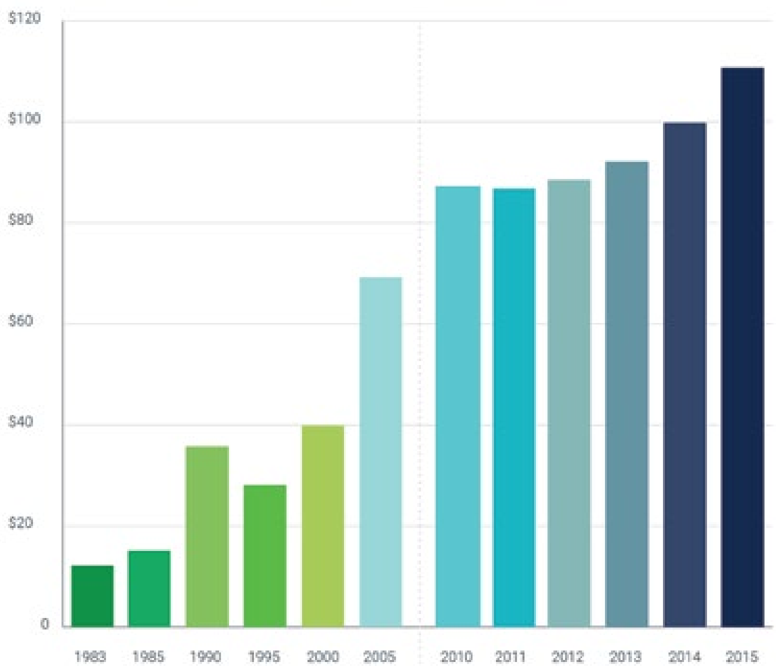
Centerville's leaders began by naming the affordable housing problem as a crisis, setting an ambitious target for housing growth within the city, and challenging neighboring jurisdictions to follow suit. The city then began to identify and target areas for new development – focusing initially on those areas most open to change. Looking at the city's prospects, leaders and residents saw several options, modeled on examples from elsewhere in the country:

- Encourage construction in the urban core, by supporting a new wave of skyscrapers and infill developments in and near the city's central business district.
- Convert formerly industrial land within the city to compact residential and commercial uses.
- Encourage the revitalization of smaller, formerly industrial cities on Centerville's periphery – cities that had once thrived as manufacturing hubs but now craved reinvestment.
- Create dense corridors of development along new and existing transit lines.

Centerville-area leaders worked to ensure through zoning and other policies that these new developments included a diverse range of housing types targeted at a range of income levels – developing a strategy that could win the support of developers, local officials in inner-ring suburbs, and advocates for affordable housing. Within several years, enough new housing units had come online to slow the torrid rise in housing costs. At the same time, new development eased the gentrification pressures facing existing neighborhoods, and the creation of new urban centers and corridors brought urban amenities within a manageable walk, bike or car ride of residents of the region's existing suburbs.

More people – urbanites and suburbanites alike – found themselves able to live desirable low-carbon lifestyles that were less dependent on the personal car.

Figure 3. City of Boston Assessed Property Value[140] (Billions)



Public Transportation

The creation of new, dense nodes of development within the area raised a challenge: to be viable, they would need to have access to public transportation. Yet, these newly built areas tended to be underserved by Centerville's legacy transit network, which was built to serve the development patterns of an earlier era.

To address its affordable housing problem, Centerville needed to address its transit problem. The immediate priority was keeping the existing transit system running – a task that required sustained investment to address the backlog of deferred maintenance. But new transit connections were also needed to reach emerging centers of commercial and residential development adjacent to downtown and to satellite cities.

Paying for that investment at a time of fiscal austerity was challenging, and required local leaders to assemble a diverse package of funding: state and federal money, revenue from local-option taxes, revenue from value capture, revenue from congestion pricing and carbon cap-and-trade, and revenue from development of transit stations, along with local general tax revenue. It took years of diligent work by local leaders and close collaboration with neighboring governments and various parts of the public to put the plan into motion.

It also took diligent attention to costs. The region's transit agency – as part of the collaborative effort – sought to develop transit services that made the most of existing infrastructure. Commuter rail came to take on many of the characteristics of rapid transit service, with frequent, bidirectional service. Bus rapid transit and signal priority for conventional bus routes became important features of the transit network.

The expanded, improved transit network gave more Centerville-area residents greater access to more of what the region had to offer, and, when coupled with the upsurge in new development, it enabled Centerville to accommodate nearly all regional growth in compact, low-carbon urban centers.

New York extended its subway system in 2015 to serve new development on the West Side of Manhattan. *Photo credit: Photo: Metropolitan Transportation Authority / Patrick Cashin*

Repurposing Space

As development intensified in Centerville's core, conflicts between users of the streets became more intense, leading, over time, to a renegotiation of the bargain between the city and the automobile.

First, a wave of crashes, followed by intense advocacy by public health officials and the growing legions of cyclists and pedestrians, led to the creation of protected bike lanes and widened sidewalks in the urban core, along with increasingly stringent regulations on vehicle speeds. Next, the city reorganized management of its curb space, regulating the timing of freight deliveries, establishing variably priced parking, and dedicating curb space in urban cores to shared mobility modes. Finally, the city adopted a cordon toll, charging all private vehicles entering the densest urban nodes a substantial fee.

All of these moves were controversial, especially among drivers, but with the growth of cycling, transit use, and use of shared modes, drivers of private vehicles found themselves increasingly in the minority. Business leaders in the core were also coming to realize the benefits of a diverse transportation system, and were willing to consider the next step: banning private cars from parts of the urban core for much of the day.

The ban on private car traffic wasn't a ban on all traffic – indeed, Centerville's streets continued to hum with an array of vehicles: robot delivery vehicles little bigger than the packages they carried; small vehicles transporting people with mobility limitations; demand-responsive minivans; various types of bicycles and more. The one thing all of these vehicles shared was that they traveled slowly –

no faster than the speed of a bike – enabling all users to share the streets safely. During off-hours, the prohibition on private vehicles was relaxed, with certain streets opened to delivery vehicles and to a limited number of on-demand shared cars.

As private vehicle traffic in the downtown declined, city leaders reallocated some of the space that was no longer needed to move or store vehicles for other civic purposes – creating linear parks, performance spaces and places for neighbors to sit and talk. Over time, adjacent neighborhoods – and even some satellite urban areas linked via public transportation – lobbied to join the zones, with a network of bike lanes eventually connecting the nodes together in a seamless network stretching out dozens of miles from the city's core.

By 2050, the majority of Centerville-area residents lived a walk, bike, or short car ride from most of the places they visited on a daily basis and had access to an extensive, high-quality transit system to take them to other parts of the region and beyond. Those who chose to remain in auto-oriented suburbs spent increasing amounts of their time in walkable suburban and second-city hubs, getting there via shared electric vehicles or their own private, electric cars. The region's transportation and land use strategy enabled Centerville to meet the challenges of the 21st century in a way that served all its residents and could absorb new growth without resurgence of carbon-intensive sprawl.

Fixing Up in Beltania

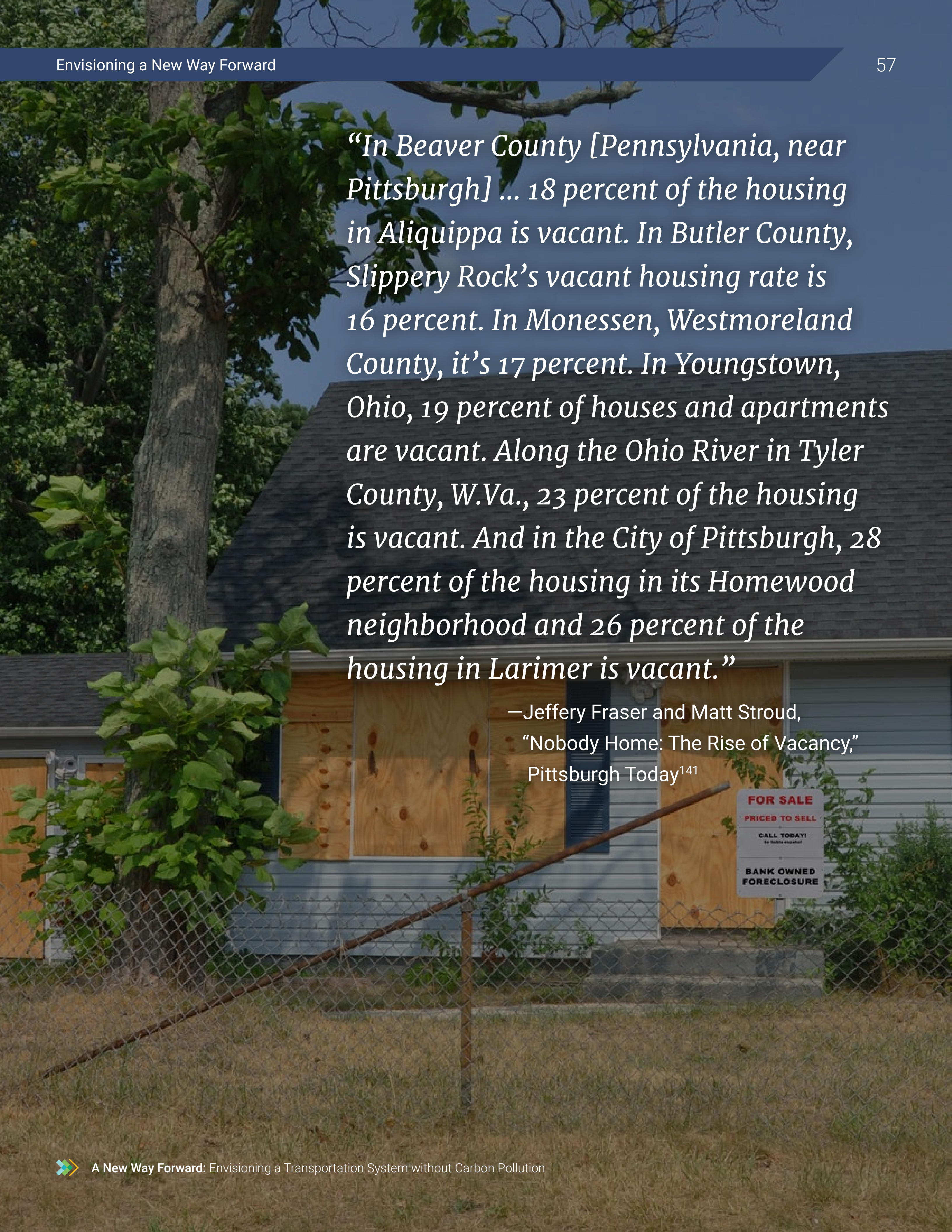
The Backstory

"You should have seen this place when the mills were running," old timers would recall, pointing to the main street in the industrial heart of Beltania. Mill Street, legend had it, once hopped with people day and night – millworkers catching a beer or a bite to eat after a shift, families shopping at the neighborhood stores, children running off to school or church. On special occasions, those families might take the streetcar that ran right down the center of Mill Street to an amusement park, a ball game, or a day of shopping at downtown Beltania's spectacular department stores.

Few people remained alive, however, who could recall those days of prosperity. Suburbanization, and then urban renewal, had sucked much of the vitality out of Beltania's downtown and neighborhood commercial centers by the 1950s and 1960s. Then came the collapse of the industrial economy, eroding the local tax base and putting working-class people by the tens of thousands out of work. Decay followed a predictable course, with neighborhoods tipping over time into disrepair and abandonment. The loss of population triggered further drain on the tax base, leading to further cuts in city services that only contributed to the next round of decline.

By the early 21st century, there weren't just fewer people in Beltania who could recall the "good old days" – there were fewer people, period. Between 1950 and 2010, the population of the city of Beltania was cut in half. Many of those who remained were those who didn't have a choice but to stay – the aged, the poor, and those with limited economic prospects.

Beltania's suburbs, by contrast, prospered in the second half of the 20th century, sprawling seemingly endlessly into the countryside. Private investment flowed into the suburbs from Beltania's center along new Interstate highways, into new



"In Beaver County [Pennsylvania, near Pittsburgh] ... 18 percent of the housing in Aliquippa is vacant. In Butler County, Slippery Rock's vacant housing rate is 16 percent. In Monessen, Westmoreland County, it's 17 percent. In Youngstown, Ohio, 19 percent of houses and apartments are vacant. Along the Ohio River in Tyler County, W.Va., 23 percent of the housing is vacant. And in the City of Pittsburgh, 28 percent of the housing in its Homewood neighborhood and 26 percent of the housing in Larimer is vacant."

—Jeffery Fraser and Matt Stroud, "Nobody Home: The Rise of Vacancy," Pittsburgh Today[141] housing developments underwritten with low-interest government loans. These communities were designed and zoned in such a way as to require the use of a car for nearly all the daily tasks of living – and often to deliberately exclude people of certain races and classes.

The abandoned Packard automobile factory in Detroit. *Photo credit: Wikimedia user Albert duce, CC BY-SA 3.0*

As the 21st century dawned, however, there were signs of hope for the city. One was the economic activity generated by the city's universities, hospitals and cultural institutions – institutions that had stayed in the city when just about everything and everyone else seemed to be leaving. Those institutions gave the Beltania region a fighting chance in the post-industrial economy, drawing talented people from a variety of fields and many places into the city's orbit.

The depressed cost of real estate – especially compared to big coastal cities – was another resource Beltania could tap. Not only was housing cheap, but so was industrial and commercial space, meaning that the barriers to entry for entrepreneurs – from immigrant families to fresh-faced college grads – were relatively low. Anyone, it seemed, could try just about any crazy idea without fear of falling too far in the event of failure. Many of these enterprises also benefited from a local culture, left over from the city's industrial past, that prized resourcefulness, technical skill and hard work.

"The presence of foreign-born residents of the city of Buffalo has increased by 95 percent" since 2006.
–Buffalo Mayor Byron Brown, as quoted by National Public Radio[142]

Meanwhile, history, which once seemed to be passing Beltania by, had stopped for a second look. Neighborhoods that had been built to enable millworkers and their families to walk to work, church or shopping, it turned out, could be made walkable again in the 21st century. The city's public transportation network – which residents had continued to rely on in large numbers (where it remained available) – was a vital, if degraded, resource. The decaying factories, lightly trafficked streets, and long-dormant business districts represented spaces where new ideas could take root.

Walkable before walkable was cool, with strong universities, striking architecture and ample housing stock – Beltania, for all its troubles, had a lot going for it. Might it become prosperous again in the 21st century, supporting regional growth in a less auto-dependent way? Might it even, some wags began to wonder, become the next Brooklyn?

"We do have pretty good bones. If we can get more people living in the city, zone a little differently, allow mixed-use … it wouldn't necessarily be a matter of people living without cars here, but people would use them much less."

–Jason Segedy, Director of Planning and Urban Development, City of Akron, Ohio

The Crisis

Beltania had a fundamental problem, though: it was broke.

As people and businesses fled in the late 20th century, the city was left with more schools, bridges, roads and sidewalks than it could possibly afford to maintain – along with massive pension obligations to previous generations of municipal workers. A declining tax base left the city with fewer resources to provide even the basics to its population, let alone the improved public services that might attract new residents. Ironically, given the low quality of city services, those who remained in the city paid property taxes at rates well exceeding those of surrounding suburbs or other, more prosperous, cities. (See Table 1.)

Table 1. Highest and Lowest Homestead Taxes Among the 50 Largest U.S. Cities for $150,000 and $300,000 Valued Homes, Payable 2013[143]

Rank (of 50)	$150,000 Location	$150,000 Tax	$300,000 Location	$300,000 Tax
1	Detroit, MI	$4,988	Detroit, MI	$9,976
2	Philadelphia, PA	$4,437	Philadelphia, PA	$8,874
3	Milwaukee, WI	$4,113	Milwaukee, WI	$8,419
4	Cleveland, OH	$4,024	San Antonio, TX	$8,111
5	San Antonio, TX	$3,953	Cleveland, OH	$8,047
46	New York, NY	$1,087	Mesa, AZ	$2,289
47	Denver, CO	$1,005	Denver, CO	$2,010
48	Colorado Springs, CO	$706	Washington, DC	$1,909
49	Washington, DC	$661	Boston, MA	$1,784
50	Boston, MA	$175	Colorado Springs, CO	$1,412

Neighboring suburbs, which saw Beltania's fall from grace as partly its own doing, provided only limited financial support. And many of the new arrivals to the city – including those priced out of more expensive coastal cities – weren't awash in capital either.

Tapping the promise of Beltania – the necessary centerpiece of building a less auto-dependent (and less carbon-intensive) region – was going to take time. And with the city's financial woes, it was going to have to happen on a shoestring.

The Response

Repurposing Space

Beltania had more infrastructure than it needed, or would likely ever need again, with much of it in poor shape. With limited resources, city leaders were forced to make tough decisions: Which pieces of infrastructure were worthy of reinvestment? Which had to be abandoned? And which could – through creativity and judicious use of public, private and philanthropic resources – be converted into the kinds of infrastructure that would support the city's resurgence in the 21st century?

City officials undertook a detailed inventory of their infrastructure and determined which assets might be reused. Abandoned railroad beds and bridges were eyed for conversion into mixed-use paths for bicyclists and walkers. Old mill buildings, shuttered schools and city-owned lots were repurposed for community amenities like parks, neighborhood gardens, arts spaces and innovation centers – or else for housing for seniors and low-income residents.

Abandoned industrial spaces offer the opportunity of repurposing, including the creation of housing (like these apartments in former Heinz Company buildings in Pittsburgh), office space, bike trails and public spaces. *Credit: Flickr user Brook Ward, CC BY-NC 2.0*

Even the city's streets – many of which were wider than they needed to be and falling into disrepair – were re-envisioned as "complete streets" with improved facilities for bicyclists and pedestrians. Some were designated as corridors for express bus or bus rapid transit services.

Not every bit of the past could be rebuilt, recycled or reclaimed – especially given Beltania's limited resources. Some buildings and bridges were simply too far gone. Debates frequently arose about where to target resources – were Beltania's limited funds being invested equitably to benefit the entire community? Those debates were not new – they had been happening in the city for decades – but city leaders' emphasis on public engagement and participation helped to develop trust among various constituencies within the community, and to solicit bold new ideas.

Slowly, the city began to build a track record of success, to learn from its mistakes, and to lure people and investment that provided a stronger tax base and more resources that could be invested elsewhere in the community. The

Pittsburgh's Hot Metal Bridge, which once carried molten steel across the Monongahela River, has been converted to a bike trail, with an adjoining railroad bridge converted to carry car traffic. *Photo credit: City of Pittsburgh*

city's long population decline, which had once seemed like a terminal condition, stopped, and slowly began to reverse. And the creative reconstruction of transportation infrastructure led to changes as well, as the share of people traveling by bicycle doubled, then doubled again, and transit ridership began to tick up again as the transit network was stabilized following decades of debilitating cuts.

Smart Pricing (And Spending)

The suburban expansion that sucked the economic life from Beltania was driven in large part by government policy. The construction and expansion of Interstate highways, mortgage redlining, and subsidies for public infrastructure and economic development in the suburbs gave those areas a leg up – especially in the 1950s, 1960s and 1970s when the flight of capital out of Beltania was most intense.

By the early 21st century, though, many of Beltania's inner ring suburbs were faced with declining housing stock, growing needs for infrastructure repair and replacement, and rising numbers of poor residents. The shiny new shopping centers of an earlier day were increasingly abandoned, their occupants having decamped to the newest rings of outer suburbs years earlier – suburbs that owed their growth to the same kind of publicly funded highway expansions and developer subsidies that had benefited the inner ring decades earlier.

"This is the wrong thing to do with our tax dollars. More concrete, more freeways — this is crazy. We're going to pay for people to drive past Royal Oak?"

–Royal Oak, MI, City Commissioner Kyle DuBuc, regarding plans to widen Interstate 75 in suburban Detroit, as quoted in the *Detroit Free Press*[144]

The Beltania region faced a choice: continue to expand outward – at great public expense – or refocus new growth in the region's core and inner suburbs. A key flashpoint in that debate: highways.

As was the case in many cities, freeway construction carved the heart out of urban neighborhoods in Beltania during the 1950s and 1960s. Incredibly, however, state highway officials entered the 21st century eager to compound the error – proposing a massive expansion/reconstruction project for the main freeway bisecting downtown Beltania. Beltania residents questioned the logic – hadn't the area's population been stagnating for years? – but especially chafed at the cost: hundreds of millions of dollars that could otherwise have been used to fix the region's potholed streets or restore lost transit service.

Coalitions of community groups mobilized to challenge those projects, taking a page from the book of earlier generations of highway revolts. This time, however, they had allies in environmentalists concerned about global warming and in fiscal conservatives aghast at the waste of public resources. The new "odd bedfellows" coalition didn't agree on everything, but it was formidable enough to begin rolling back subsidies and policies that had once benefitted Beltania's suburbs to the exclusion of everyone else.

And soon, Beltania discovered that in a fair fight, it could actually hold its own in the battle for investment with distant greenfield suburbs, and that by finding common cause with inner ring suburbs facing similar challenges, it could drive a rethinking of regional governance and development strategy. True regional cooperation and governance – something that had once seemed unthinkable – became a live possibility. Priorities guiding the investment of public dollars began to shift.

Major highway expansion projects have drawn opposition from community groups in their path seeking a shift in priorities toward local needs. Here, opponents of expansion of I-94 in Milwaukee call for a shift in funding toward public transportation. *Credit: Screenshot from Fox6News Milwaukee TV broadcast*

Slowly, the downward spiral that had pulled at Beltania for decades began to reverse. Suddenly – and paradoxically, following decades of residential disinvestment and decay – Beltania woke up to an urban affordable housing crisis, one that was only relieved with policy efforts aimed at rebuilding and redeveloping city neighborhoods whose housing stock had decayed beyond the point of repair.

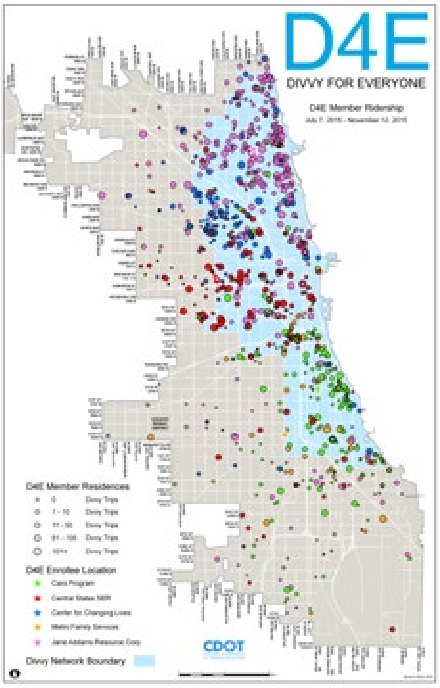
By 2050, Beltania was again attracting the majority of new development in the region. The city's population, bolstered by waves of new migrants looking for affordability and opportunity, had rebounded, enabling the city to approach its peak population level of a century earlier. The glory days of industrialization were long in the past, but Beltania was discovering that it had a future after all.

Shared Mobility

The "sharing economy" in Beltania long predated the smartphone. In the city's poor and working class neighborhoods, shared transportation was a key part of the informal economy, with illegal jitneys, gypsy cabs or "hack cabs" providing low-cost transportation beneath the (often knowing) gaze of law enforcement.

The emerging tech-enabled sharing economy services – ridesourcing, carsharing and bikesharing – held great potential to benefit Beltania's lower-income communities, providing new forms of affordable mobility and an additional layer of verification and safety for the kinds of shared rides local residents had relied on for decades.

But private-sector sharing economy companies did not always provide the same level of service in lower income neighborhoods as they did elsewhere, while lack of bank accounts, smartphones or English language proficiency made using these services difficult for many residents. Local government and the local transit agency – already struggling to continue to provide existing services – were reluctant to take up the slack.



Chicago's "Divvy for Everyone" program makes the city's Divvy bikeshare program available to low-income people for a one-time $5 membership fee, expanding access to shared bicycles to new constituencies.
Image credit: CDOT

Community leaders began to ask whether the same platforms used by for-profit firms to aggregate supply and demand could also be used by non-profits to serve community needs. Local community leaders, working with city government, local non-profits and philanthropists, developed nonprofit carsharing services and ridesharing platforms similar to the jitney services of old, while organizing politically to get publicly sponsored shared services such as bikesharing to establish an affordable presence in low-income neighborhoods.

These innovations revolutionized mobility in low-income communities, reducing the need for costly vehicle ownership while expanding mobility for many residents. At the same time, Beltania residents advocated for revitalization of public transportation service, which had experienced a seemingly never-ending cycle of service cuts that left the transit system all but unusable for most would-be riders. Given Beltania's fiscal problems, leaders joined with other cities around the state to lobby for increased funding to restore transit service.

Among city residents, transit and shared mobility began to slowly capture market share for mobility that had belonged to the car. Access to affordable, clean mobility proved to be an important amenity for people considering whether to settle in Beltania or its suburbs, furthering the "virtuous circle" that contributed to Beltania's revival.

As had been the case in Centerville decades before, renewed growth in Beltania brought its own challenges and conflicts. But the city had avoided yet another cycle of sprawl and auto-dependence, boosted its ability to compete with other cities for investment and talent, and put in place the foundation for a more sustainable future.

The Backstory

Westlandia took its pioneer heritage seriously. Civic lore extolled the virtues and courage of the settlers who had traveled vast distances to establish the fragile homesteads that grew into the trading post that emerged as a major railroad junction around which grew a vibrant, grand city.

Individuality, pioneer spirit and an appreciation for wide-open spaces had been hallmarks of Westlandians' worldview down through the generations. That spirit of adventure, combined with affordable land, a favorable climate, and massive public investments in highways, electricity and water, drew new migrants throughout the 20th century – especially after World War II.

Denver got its start as a Gold Rush town, but in the 20th and 21st centuries saw explosive, auto-oriented growth. *Photo credit: Library of Congress / William Henry Jackson*

The population of the Westlandia metropolitan area doubled between 1960 and 1980, then doubled again by 2010. Nearly the entire city, with the exception of a tiny, well-touristed core, was laid out around the automobile. As the decades went by, the wide open spaces around Westlandia filled with highways, parking lots, shopping centers and vast tracts of single-family housing. Public transportation service was limited at best, an afterthought at worst.

Following a brief blip during the Great Recession, by the mid-2010s, Westlandia was booming again – leaving many residents concerned about where and how future growth would take place.

The Crisis

Twentieth century sprawl had left Westlandia with major headaches, including traffic congestion that seemed to grow worse with every passing year. New arrivals kept coming – migrants from rural areas, immigrants from abroad, transplants from cities with skyrocketing housing prices. Where would they live? How would they get around? And how much would it cost to build enough highways to accommodate all the cars?

Salt Lake City experiences high levels of air pollution. *Photo credit: Flickr user TimeScience, CC BY-NC 2.0*

Continuing on the current trajectory seemed impossible. Air quality problems were severe and growing, with the city shrouded in a "brown cloud" on some days. Highway expansion projects costing hundreds of millions of dollars saw their additional lanes filled within a few years of their completion. Sprawl required massive public investments in transportation and water infrastructure; investments that were increasingly difficult to sustain with current sources of revenue.

At the same time, congestion and pollution undercut Westlandia's major selling point: its high quality of life. Rather than seeing the city as an exciting, growing place in the shadow of awesome natural beauty, a place to live a healthy lifestyle, visitors increasingly associated it with the worst of urban excess.

Westlandians wanted a future for their city and region that protected the environment, and that fostered authentic community, but that also accommodated future growth and reflected the region's values.

Table 2. Reasons for Living in West Ranked by Significant Factor, from Colorado College survey[145]

	A Factor	A Significant Factor
Clean air, clean water and environment	**57%**	**85%**
Healthy, outdoor lifestyle	**56%**	**88%**
Ability to live near, recreate on and enjoy public lands like national parks and forests	**49%**	**80%**
Cost of living	44%	80%
Economic opportunities	41%	78%
Quality of public schools	36%	63%
Quality of health care and hospitals	32%	66%
Level of traffic congestion	32%	64%

The Response

Public Transportation

Westlandia was built around the car, and many people liked it that way. But the dangers of building *only* around the car had become apparent decades earlier, leaving the city's leaders and its residents searching for other options.

Around the turn of the century, Westlandia voters approved an ambitious plan to bring rail transit to the region. Over the course of several decades, the city built out its network, adding light rail and commuter rail lines along several corridors. The service turned out to be popular, breaking original ridership projections. But in the context of addressing the region's overall transportation and traffic problems, it appeared to make barely a dent. In addition, not every aspect of the region's transit system received the same level of attention and care, with limited funding resulting in declines in bus service that undercut the benefits of rail.

Few regretted the decision to build rail transit, or could envision modern Westlandia without it, but it was clear that the city could get more out of its investment. For one thing, the system had initially been planned around the needs of daily commuters, with vast park-and-ride lots at key stations and with only limited service at off-hours. But regional leaders came to the conclusion that transit should do more – supporting a shift toward walkable development rather than just moving 9-to-5 workers. It was a decision that tracked well with residents' own priorities. So the city and its transit agency worked aggressively to promote transit-oriented development near transit stations, bringing more people, jobs and destinations within a quarter-mile walk or a mile-long bicycle ride from transit stations.

Denver is one of several Western cities to plan large-scale expansions of their transit networks in the hopes of supporting continued growth with a minimum of congestion and sprawl. *Photo Credit: Regional Transportation District, Denver*

The other major shift involved making the transit system useful for all trips – not just commuting. Westlandians who wanted to live a transit-centered or car-free lifestyle were often frustrated by the lack of transit service at mid-day, at night and on weekends. In order to capitalize on the increasing number of people and destinations locating near transit, Westlandia's transit authority increased the frequency of transit service – issuing a public guarantee that no one traveling on bus routes connecting major destinations throughout the city would have to wait more than 10 to 15 minutes for a bus or train. The proclamation – and the city's ability to deliver on it – gave the increasing number of residents living near transit the confidence that affordable transit service would be available when and where they needed it.

That confidence was bolstered by the city's third step – the integration of shared mobility tools as first mile/last mile connections with transit. The region's transit agency reached out to shared mobility providers to create a common payment platform that provided residents with access to a variety of mobility products. For a reasonable daily, monthly or annual charge, residents could have access to all of the region's transit and shared mobility options, in the same way that a transit passholder has access to all of a region's buses or trains.

Smooth connections between modes, shared facilities, and easy and economical transfers made using the transit/shared mobility service cost-effective and convenient. Westlandia officials negotiated contracts with shared mobility providers to ensure that they provided service that was equitable across the city and that met the needs of the disabled. In some cases, the transit agency pioneered or piloted new services itself when private entities proved unable or unwilling to do so.

Over time, as the partnerships between the public and private sector grew closer, the riding public became less able to distinguish between public and private transportation. Increasingly, those distinctions ceased to matter very much – the new system was simply how most people got around.

Smart Pricing

Population growth and sprawl continued to strain the Westlandia region's highway network, but highway expansion had proven itself to be a costly and ineffective strategy for relieving congestion.

Westlandia had some limited experience with modern toll roads and with the construction of high-occupancy/toll (HOT) lanes paralleling existing highways. But it was the region's decision to transition to a fully-priced network of regional highways, with tolls varying based on congestion levels, that finally began to make a dent in traffic congestion.

A growing number of cities are using high occupancy/toll lanes as a tool to manage congestion. *Photo credit: Federal Highway Administration*

The move was initially controversial, but the breakthrough came when regional leaders stopped viewing road pricing as a tool to raise money for highways and instead committed to making the system revenue neutral for a transitional period of several years. Area residents were issued a limited number of free rides on the system, with low-income residents, transit vehicles and high-occupancy vehicles traveling free all the time.

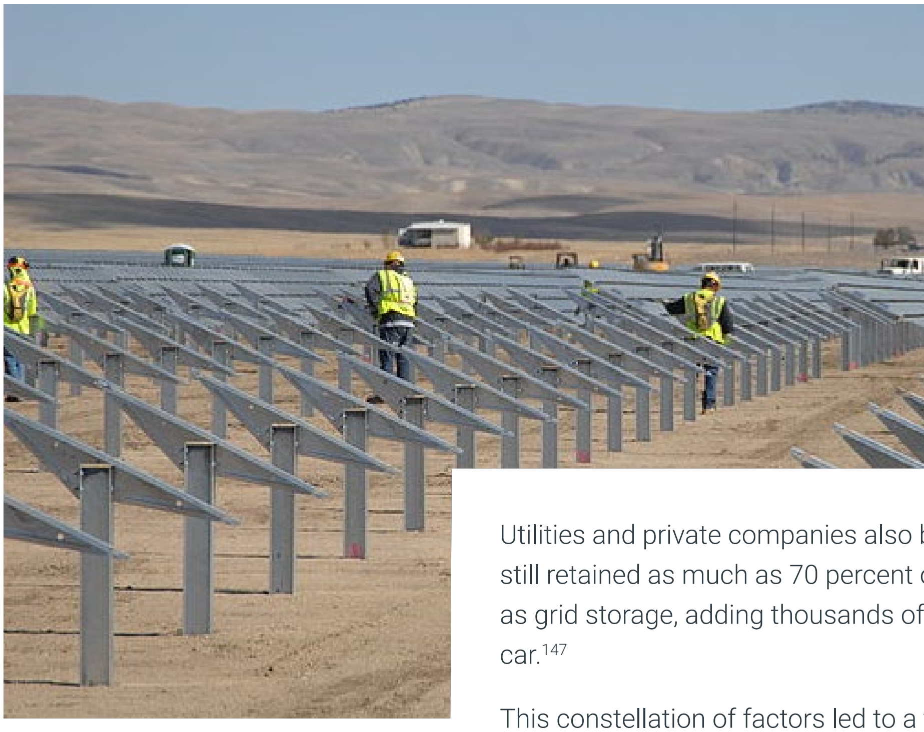
The newly priced network did its job. Rush hour auto commuters either paid a bit more for an uncongested commute or changed their behavior to avoid the charges – carpooling, taking transit, or leaving for work earlier or later in the day. The efficiency of the highway network was vastly improved, reducing carbon emissions and eliminating pressure for further costly expansion of highway capacity. And after initial the adjustment period, regional leaders began to shift tolling revenue to support public transportation and other low-carbon transportation options.

Westlandia used pricing as a tool in other areas as well. Free parking in Westlandia's city center and dense suburban nodes became increasingly rare, providing yet another financial incentive for people not to drive. And Westlandia benefited from statewide imposition of an economy-wide carbon pricing system – a measure that would have an important role in promoting electrification of the vehicle fleet.

Repowering

The region surrounding Westlandia was sometimes called the Saudi Arabia of renewable energy. Vast wind and solar energy resources existed just on Westlandia's outskirts. As renewable energy technologies came down in price, and as state and federal policies removed barriers to renewable energy growth, electrifying Westlandia's transportation system became a powerful tool to reduce greenhouse gas emissions.

Electric cars' dominance seemed to come all at once, but in reality, it was decades in the making. Continued technological advances brought the initial



Renewable sources of energy, such as solar power from this solar farm in California, can be harnessed to power transportation with minimal greenhouse gas emissions. In many cases electricity from utility scale solar installations in the American southwest is already cheaper than electricity from natural gas. *Credit: Sarah Swenty, USFWS*

price of electric vehicles down while performance improved. Solar power/ battery electric vehicle combinations became increasingly popular. Public policy measures, from changes in building codes to financial incentives for vehicle purchases and the installation of public charging equipment, began to gain traction. Utilities developed programs to incentivize EV owners to charge their cars at times when excess renewable capacity existed on the grid and to discharge power back to the grid at times of high demand. Utilities and private companies also began to buy up used EV batteries – which still retained as much as 70 percent of their original storage capacity[146] – for use as grid storage, adding thousands of dollars to the residual value of an electric car.[147]

This constellation of factors led to a tipping point in which electric vehicles came to dominate new car sales and become the vehicle of choice for the growing ranks of shared mobility providers. As the years went on, it became more and more difficult to find places to fuel or service a gasoline-powered vehicle. And by 2050, the few gasoline-powered cars remaining on the road were increasingly seen as relics of a bygone era.

People continued coming to Westlandia in search of high quality of life. With slowing sprawl, cleaner air, and a more connected region that was succeeding in reducing its impact on the climate, they often got what they were looking for.

Syncing Up in Sun City

The Backstory

For decades, people had come to Sun City for a shot at the American Dream. In the course of only a couple of generations, the creativity of private enterprise, along with the energy, hard work and pluck of its people, had built a city that could hold its own against any in the United States. Fortune 500 companies, world-class cultural institutions, professional sports teams, prominent leaders in industry, politics and culture – by any standard, Sun City had found its way "onto the map."

> *"Florida grew in a time when the car was king. We don't have bones to go back to like some cities."*
>
> - Darla Letourneau, BikeWalk Lee (Lee County, Fla.)

Sun City got there by rolling out the welcome mat for new businesses and new people. Government often offered a helping hand to companies seeking to build or locate there – providing tax incentives and infrastructure support to attract new jobs. Those workers needed places to live and they needed cars. Home construction – most of which took place in the ever-widening rings of new suburbs spreading outwards from the core – was an important driver of the local economy and a source of middle-class jobs. New towns required new schools, new churches and new stores, and new cars required filling stations, repair shops and roads on which to drive them – all of which needed to be built and operated, creating even more new jobs and economic opportunity.

Not everyone, of course, had access to the bounty. If you happened to live in the poorer neighborhoods of the city's center, or in one of the many inner suburbs experiencing rapid increases in poverty, life could be difficult and cruel. Public transportation was often not an option, leaving residents cut off from the economic opportunities available just a few miles away in the growing suburbs or increasingly hip downtown. Poor residents commuting to service jobs by bus often faced an hours-long ordeal just to get to work. Traveling on foot was often dangerous or impossible – even in those places where transit did exist, just getting to the bus often required taking one's life into one's hands. For as strong and vital as the private sector in Sun City might have been, the public sector was often correspondingly weak. What's more, because of the region's sprawl and economic segregation, the poor of Sun City seemed to the well-off to exist in a kind of shadow world – unseen and often misunderstood.

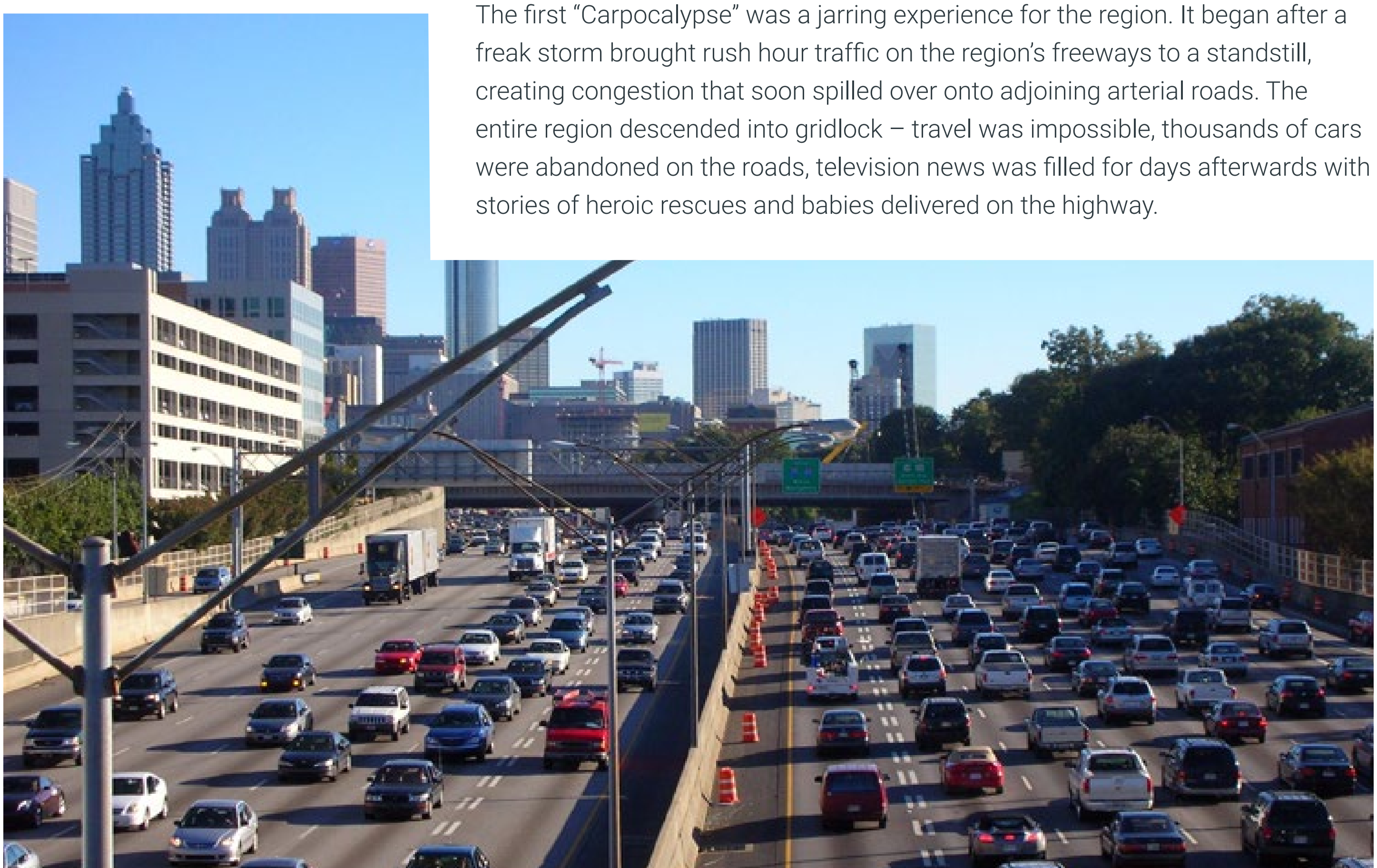
Life in the comfortable middle-class and well-to-do suburbs had its own challenges, with one rising above all others: traffic. Complaining about traffic congestion, like discussing the performance of the local football team or talking about the weather, was a sure-fire conversation-starter throughout the Sun City area. People swapped stories about traffic jams, comparing strategies for avoiding bottlenecks the way they discussed recipes for favorite meals. Parents got used to spending much of each weekend shuttling kids to and from sports and activities, and a large share of each morning and evening staring at the bumper of the car in front of them.

At the end of each day, however, most Sun City residents found themselves returning to comfortable homes that they could afford. And that meant a lot.

The Crisis

The first "Carpocalypse" was a jarring experience for the region. It began after a freak storm brought rush hour traffic on the region's freeways to a standstill, creating congestion that soon spilled over onto adjoining arterial roads. The entire region descended into gridlock – travel was impossible, thousands of cars were abandoned on the roads, television news was filled for days afterwards with stories of heroic rescues and babies delivered on the highway.

Traffic in downtown Atlanta. *Photo credit: Wikimedia user Atlantacitizen, CC BY-SA 3.0*

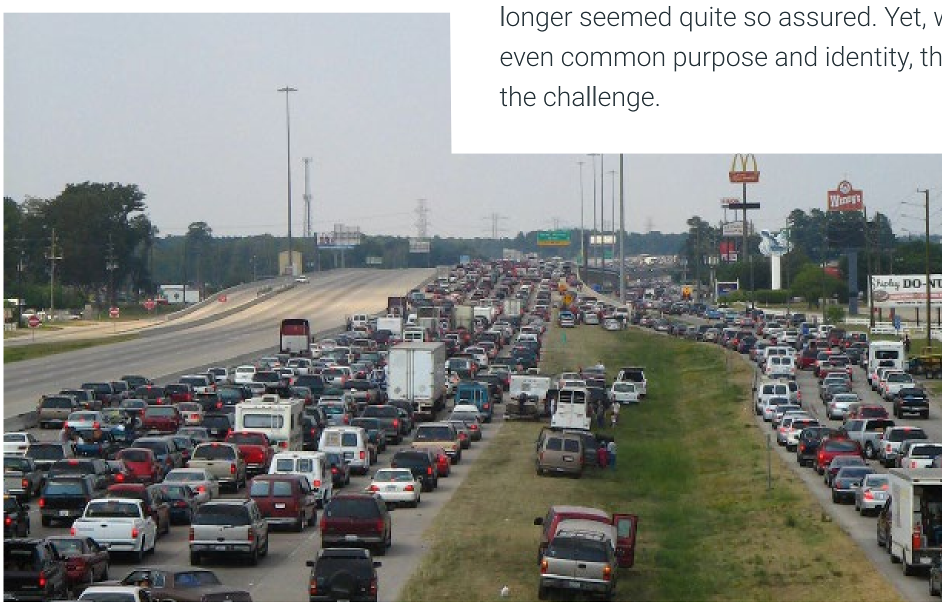


"There are signs the region wants to work together to solve its problems. Yet a slew of serious economic, government, business, political and environmental divisions threaten to strangle the region's growth, which lags that of several peer metro areas since the recession. Metro Atlanta, an amalgam of 150 cities spread across 29 counties, is something of a poster child for regional disharmony."
—*Atlanta Journal-Constitution*[148]

Carpocalypse wasn't the only example of near-total systemic failure of Sun City's infrastructure. As the early part of the 21st century progressed, Sun City faced increasing stress from population growth, climate change and the poor fiscal condition of its local governments. When drought came, or when major pieces of infrastructure failed, or when gridlock once again prevailed on the roads, as seemed to occur more and more frequently, the Sun City area seemed unable to put together a coherent response.

Lack of coordination extended to long-range issues as well. Historical economic and racial divisions in the region, a weak state government, and a tradition of bruising battles over resources led to an "every municipality for itself" strategy of economic development and planning. Cities in the region tried to outdo each other in the tax and regulatory incentives offered to lure business, knowing full well that the loss of a major employer or attraction could spell fiscal or economic doom. Transportation planners found themselves constantly playing catch-up to new demands, with their ambitious plans for a more balanced transportation system collecting dust on the shelf as political pressure built to add a lane to a highway here or reconfigure an intersection or interchange there to accommodate economic development.

Sun City's leaders – at least when asked off the record – recognized these problems. Sun City's frequent dysfunction was beginning to obscure its once-sunny optimism and faith in the future. Regional leaders began to fret that lack of regional coordination and a coherent approach to growth was causing them to be left behind by growing businesses of the 21st century that had a choice of where to locate. Rapid economic growth – which people in the region had come to take for granted and public officials to build into their revenue projections – no longer seemed quite so assured. Yet, with no real sense of regional coherence or even common purpose and identity, there was little they could do to address the challenge.



The evacuation of millions of people in Texas ahead of Hurricane Rita led to gridlock in severe heat, resulting in the deaths of more than 100 people. *Photo Credit: Flickr user clicksense, CC BY 2.0*

The Response

Technology

The initial rollout of driverless cars only made things worse.

At first, Sun City residents were hopeful about the driverless car revolution – finally, all the time previously wasted in traffic jams could be spent productively, or at least while being entertained. Breathless articles in local papers and sales pitches from automakers foretold of a future when driverless and connected cars would cut the amount of time spent commuting in half. Early experiments – such as the use of networks of fully autonomous vehicles on college campuses and in some of the region's planned communities – seemed promising.

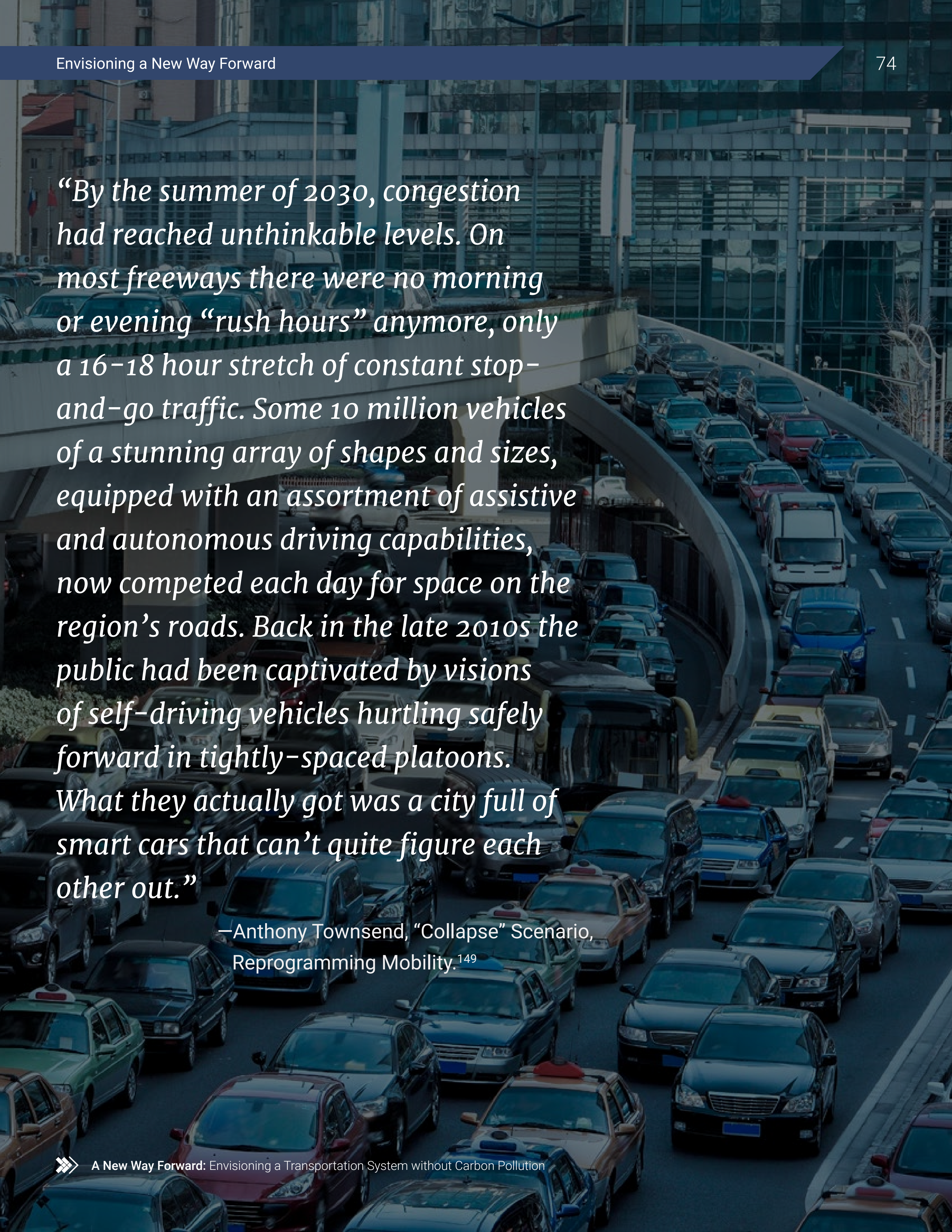
But as increasingly autonomous cars made their way onto the region's highway networks in greater numbers, the problems were quick in coming. For one thing, autonomous technology had advanced faster than the standards guiding it, leaving vehicles made by different manufacturers unable or unwilling to coordinate with one another. Rather than sell their autonomous vehicles as safe and economical, carmakers pitched them as bold and sexy, doing everything within the law (and, sometimes, in a concealed way, outside of it) to make their cars faster and give them advantages over other vehicles on the road.

Gaining comparative advantage over rivals came to be seen as far more important to carmakers than improving the efficiency of the transportation system – especially as carmakers fought to win the "early adopters" that could help them position their brand as the unquestioned leader in the brave new world of advanced cars.

The technological arms race extended to consumers as drivers of smaller or less-advanced cars found themselves compelled to purchase ever-more advanced cars and software – in self-defense if for no other reason. The result was great for auto manufacturers and tech companies, who pointed to surging demand for advanced vehicles as evidence of consumer enthusiasm. But it wasn't so great for everyone else.

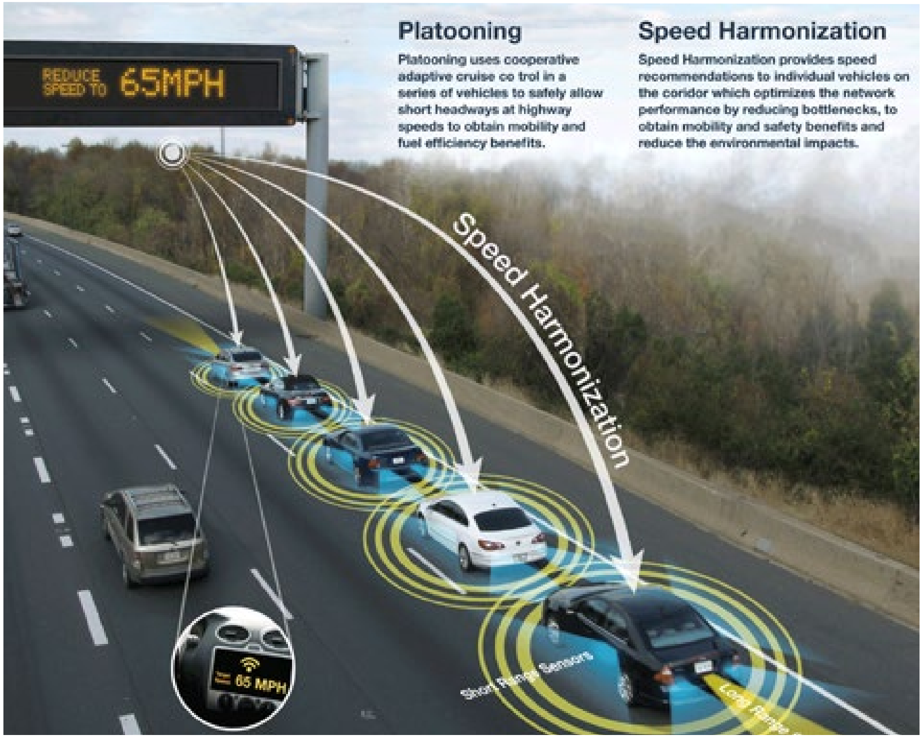
Sun City wasn't the only urban area to experience these problems, but, because of its automobile dependence and continued growth, it experienced them more acutely than most. Something had to be done.

Leaders of the Sun City region – along with metropolitan leaders across the country – petitioned federal decision-makers to force vehicle manufacturers to play nice with one another by developing a common set of standards and rules to manage communications between vehicles and between vehicles and road



"By the summer of 2030, congestion had reached unthinkable levels. On most freeways there were no morning or evening "rush hours" anymore, only a 16–18 hour stretch of constant stop-and-go traffic. Some 10 million vehicles of a stunning array of shapes and sizes, equipped with an assortment of assistive and autonomous driving capabilities, now competed each day for space on the region's roads. Back in the late 2010s the public had been captivated by visions of self-driving vehicles hurtling safely forward in tightly-spaced platoons. What they actually got was a city full of smart cars that can't quite figure each other out."

—Anthony Townsend, "Collapse" Scenario, Reprogramming Mobility.[149]



By "platooning" autonomous vehicles can save energy and better use roadway capacity. *Image credit: U.S. DOT*

infrastructure. But the Sun City region's leaders recognized that such steps wouldn't be enough to take advantage of the full potential for driverless cars to address the region's transportation challenges.

After a collaborative process that lasted several years, the region's leaders put in place a process to make the region's freeway network a comprehensively managed system. The regional consortium created to operate the highway system was given a clear set of directives to operate the system in a way that was efficient, clean, equitable and fiscally responsible, and it did so by establishing a set of rules:

» Platooning – operating vehicles in close proximity to one another in order to save energy and better use roadway capacity – became mandatory wherever possible.

» Speeds were required to be consistent and reasonable – another efficiency-gaining step – with violations automatically enforced.

» Priority passage was given to high-occupancy vehicles and transit, with zero-occupancy (empty) autonomous vehicles permitted on the roads only at periods of light traffic and only at high cost (see below).

Nationally, as use of collision avoidance technology in all cars became mandatory, automakers were able to remove much of the costly and weighty physical armor used to protect vehicle occupants, allowing cars to become much lighter and more fuel efficient.

The region's highways were used about as much as before, but in ways that were far more efficient and used significantly less energy.

Pricing and Shared Mobility

The creation of the managed highway network was preceded by a lengthy debate about what it would be managed *for.* Safety and congestion concerns had motivated the creation of the network, but concerns about equity, efficiency and access helped shape the design of the network's pioneering pricing system.

The calculations that determined how much a vehicle would pay to use the freeway system were complicated, but the concepts were simple. First, vehicles traveling on the most-travelled roads at the most congested times of day were charged more than vehicles traveling at off-hours. Second, travel was priced based on vehicle type and occupancy. Empty vehicles were charged a higher per-mile toll. For other vehicles, the price paid reflected the share of the vehicle's capacity in use –a five-seat car with five passengers would travel nearly free, as would one of the new, efficient, single-seat microcars increasingly found on the roads. Pricing also varied by vehicle weight – encouraging the purchase of more fuel-efficient cars and aligning prices with the damage vehicles inflicted on the roads.

A variety of multimodal apps – populated with real-time open public data from the road system – provided each traveler with a simple menu of options for daily travel decisions. Want to get to work as quickly as possible in your own vehicle, traveling by yourself? Prepare to pay more. But if you are willing to travel with others, or take a less desirable route, you might be able to save money. Where drivers had once woken up to listen to the traffic report while brushing their teeth, travelers now looked up their travel options on their smartphone.

The system sparked a proliferation of business models to take advantage of the savings provided by vehicle sharing and "rightsizing." Solo commuters owning automated SUVs were confronted each morning with the savings that could be had if they shared trips with neighbors, or allowed their vehicle to service other passengers while they were at work.

Along highly traveled routes, automated bus service remained the most cost-effective option for many travelers. The consortium of governments operating the transportation network did not leave the provision of transit to chance. A schedule of payments was established to incentivize the provision of bus capacity, both to move people during the morning and evening rush hours, and to assist with the mass movement of people during emergencies or special events.

The consortium took other actions to encourage area residents to use the system efficiently: adjusting pricing to achieve set targets for shared travel and transit use, providing money-saving tips to users on their monthly "mobility bills," and even establishing games, contests and rewards to encourage users who had fallen into a transportation rut to periodically rethink their choices.

The needs of lower-income residents were served by dedicating revenues from the pricing scheme to guarantee access to transit in low-income areas, and to provide residents free or reduced-price access to shared vehicles.

Electric and natural gas utilities often encourage energy efficiency and conservation by informing their customers how their energy performance compares with their neighbors. Providing individuals with a summary of their transportation behavior, along with yardsticks against which to measure it and tips for improvement, could encourage travelers to drive less and use more sustainable modes. *Image credit: Screenshot of Nurio energy monitoring product.*

Repurposing Space

Many early 21st century theorists saw the transition to driverless cars as an enabler of greater sprawl. If travelers could read, eat or play games in their cars on the way to work, wouldn't they want to drive everywhere?

Some certainly did – although the pricing system for regional highways created strong disincentives for doing so. Long-distance commuters racked up greater road tolls and were less likely to be able to find a timely rideshare match or transit bus heading their way.

But in many parts of the region where the shared/driverless vehicle revolution had left acres of vacant parking, a new wave of redevelopment took place, with asphalt replaced in many areas with housing, parks, biking and walking paths, and commercial spaces. The elimination of parking and congestion as real concerns reduced much of the political push-back to increased density, while cash-strapped local governments – many of them facing rising expenditures as infrastructure built in the 20th century came to the end of its useful life – were eager for any influx of new tax revenue.

Over time, nodes of walkable, mixed-use development cropped up – in downtown Sun City, in recently developed commercial strips in the suburbs, in reclaimed malls and big box "power centers," and in newly built multi-use centers at the metropolitan fringe, creating new "live/work/play" neighborhoods in which life's necessities were within easy reach on foot. Meanwhile, in pre-existing suburban neighborhoods, households that had opted to go car-free suddenly found themselves with a two-car garage worth of additional space in their homes. Garage conversions became big business for a time, with many former garages

Indianapolis' Cultural Trail repurposed space once used by cars for a bicycle and pedestrian trail linking key destinations across the city. *Photo credit: U.S. DOT*

used as auxiliary apartments for children or elders, recreation spaces, or spare rooms for rent.

By 2050, Sun City was still dependent on cars. Many people in the region looked forward to a day when that might not be the case. But through cooperation, smart leadership, community-wide goal setting and the creation of institutions capable of managing the transportation system for the common good, the region had managed to curb the environmental and societal impact of automobile use – unlocking possibilities for growth and carbon reductions that had previously seemed impossible.

Getting to Zero: Decarbonizing Transportation

The narratives above show that there are many pathways available for transforming transportation – from pathways built on a foundation of intense or renewed urbanization to those that focus on integrating new technologies into our existing, auto-oriented transportation system. How might those pathways affect the carbon intensity of our transportation system?

There are many pathways available for transforming transportation – from pathways built on a foundation of intense or renewed urbanization to those that focus on integrating new technologies into our existing, auto-oriented transportation system.

There are three ways by which technological or policy change might reduce transportation system emissions. It can:

» Reduce vehicle travel.

» Support conversion to zero-carbon vehicles and fuels.

» Improve the energy efficiency of vehicle travel.

In this section, we evaluate how changes in transportation behavior consistent with those described in the narratives might affect greenhouse gas emissions.

Reducing Vehicle Travel

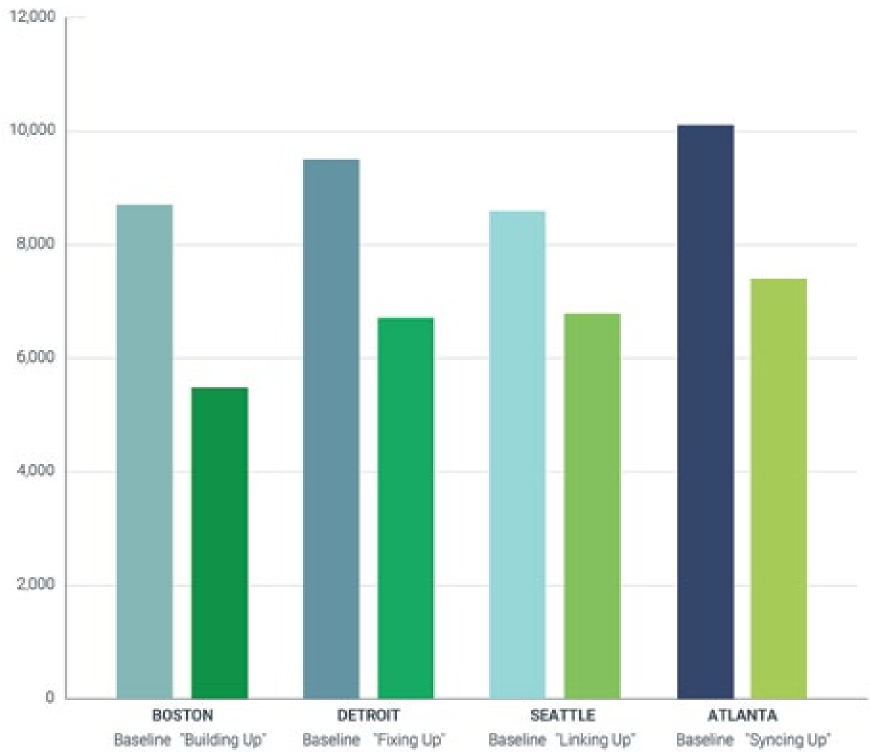
To explore the question of how changes such as those described in the narratives might affect vehicle travel, we used *Impacts 2050* – a scenario planning and evaluation tool developed as part of the National Cooperative Highway Research Program.[150] *Impacts 2050* is described as a "strategic model" that "illustrates a range of future scenarios that could occur in a given region under a range of different assumptions." The tool includes four scenarios applicable to five U.S. cities: Atlanta, Boston, Detroit, Houston and Seattle, and enables users to modify the scenarios and to input data from additional cities.

The *Impacts 2050* model, like all transportation models, uses assumptions based on demonstrated historical relationships among factors that influence transportation use, and so is limited in its ability to account for truly transformative change. For the purpose of this analysis, we modified the tool's "Momentum" scenario – which represents a "business-as-usual" case – consistent with the changes in land use and transportation policies and infrastructure described in the narratives above. We then evaluated the results for a single urban area and narrative: Boston ("Growing Up"), Detroit ("Fixing Up"); Seattle ("Linking Up"), and Atlanta ("Syncing Up"). Details on how the model was specified can be found in the Appendix A.

The *Impacts 2050* baseline ("Momentum" scenario) suggests a slow decline in per-capita vehicle travel in all areas between 2010 and 2050, with Seattle and Atlanta both experiencing an 8 percent decline. The scenarios evaluated here drive greater reductions in per-capita VMT – between 28 and 41 percent. In total, the estimated change in light-duty vehicle-miles traveled from 2010 to 2050 ranged from -10 percent to +8 percent by 2050.

The reduction in per-capita vehicle travel implied in these scenarios is consistent with the approximate 30 percent reduction needed in industrialized countries to remain on a 2° C pathway in a scenario that combines efforts to avoid vehicle travel, shift travel that does occur to more efficient modes, and improve vehicles to reduce per-mile greenhouse gas emissions.[151]

Figure 4. Vehicle-Miles Traveled per Capita in Scenarios, 2050



The reduction in per-capita vehicle travel implied in these scenarios is consistent with the approximate 30 percent reduction needed in industrialized countries to remain on a 2° C pathway in a scenario that combines efforts to avoid vehicle travel, shift travel that does occur to more efficient modes, and improve vehicles to reduce per-mile greenhouse gas emissions.

Switching to Zero-Carbon Vehicles and Fuels

Even with a large-scale reduction in per-capita vehicle travel, America's transportation system would remain highly energy-intensive. Switching to clean fuels – electricity, or perhaps hydrogen or some forms of sustainable biofuels – will be needed to provide motorized transportation while achieving decarbonization.

As noted above (see "Repowering Vehicles," page 26), switching to electric vehicles reduces greenhouse gas emissions in two ways: 1) it replaces highly inefficient internal combustion engines with efficient electric motors and 2) it enables transportation to be operated on zero-carbon renewable sources of energy.

Simply switching from gasoline cars to electric vehicles (based on projected 2040 vehicle characteristics from the U.S. Energy Information Administration[152]) reduces the tank-to-wheels energy demand of a vehicle by approximately two-thirds, making a strong contribution toward decarbonization.[153]

Improving Energy Efficiency of the Transportation System

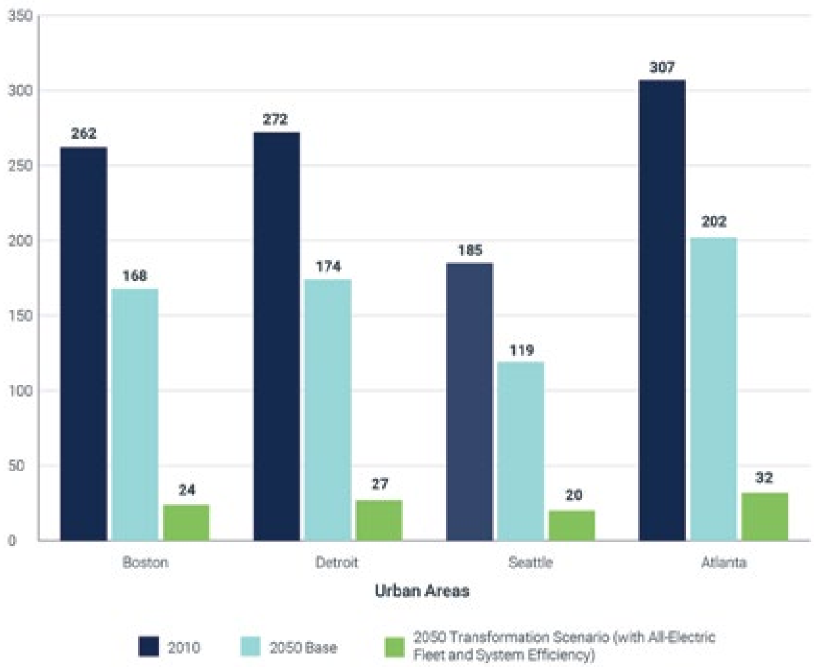
Technological and other shifts envisioned in the narratives also have the potential to alter the types of vehicles we use and the ways in which we use them. Automation of vehicle fleets and adoption of shared-use services create additional opportunities for energy savings:

- **Lightweighting:** The development of collision-proof systems of automated vehicles could allow for automakers to produce lighter vehicles without the protective armor of many of today's vehicles.
- **Rightsizing:** Systems of shared vehicles would enable vehicles to be matched to an individual's needs for a particular trip. A solo commute, for example, might be served by a single-passenger microcar while a family outing to the beach might be served by the equivalent of an SUV. Rightsizing of vehicles could reduce or eliminate the excess energy most drivers use to propel too-large vehicles that are occupied mostly by empty space.
- **Eco-driving:** Automated vehicle systems could be programmed to require driving behaviors that conserve energy, such as smooth acceleration, reasonable speeds, limited braking, and platooning. Eco-driving practices in conventional vehicles can reduce fuel consumption by at least 5 percent.[154]

The Rocky Mountain Institute, in its 2011 book, *Reinventing Fire*, estimated the energy efficiency potential of advanced vehicle designs.[155] Based on their "revoluationary" scenario for vehicle design, which includes lightweighting and other measures to improve vehicle efficiency, tank-to-wheels energy demand from vehicles would be reduced by about a third compared with the electric vehicles assumed to be on the road in 2050.[156] This estimate is likely conservative: recent research suggests rightsizing of passenger vehicles alone could reduce vehicle energy demand by as much as a factor of two.[157]

Systems of shared vehicles could enable "right-sizing," in which vehicles would be matched for an individual's needs for a particular trip. A short solo trip could be served by an ultralight microvehicle, like Renault's Twizy vehicle shown here. *Photo credit: Flickr user Jose Antonio Moreno Monge, CC BY-SA 2.0*

Figure 5. Light-Duty Vehicle Energy demand (trillion Btu)



Reductions in Annual, per Capita Vehicle Energy Consumption in Scenarios

Policy strategies that can facilitate all three shifts, therefore, have the potential to reduce energy demand from vehicles dramatically. In the four cities studied, these shifts could result in reductions in light-duty vehicle energy consumption of between 89 percent and 91 percent compared with 2010 levels. (See Figure 5.)

The overall conclusion is that a transition to a zero-carbon transportation system is possible, and that a variety of tools and strategies can be used to bring it into being.

This remaining energy demand is within the range of what can be supported by local renewable energy sources in many places. For example, a typical 6-kilowatt solar photovoltaic system in the Boston area produces approximately 7,900 kilowatt-hours of electricity per year. [158] Per capita light-duty vehicle energy consumption in a transformed transportation system in 2050 would amount to approximately 856 kilowatt-hours per year. Not every resident of Boston (or any other city) can host solar panels on his or her home, and solar power would need to be augmented by other sources of clean energy to supply energy for an electric vehicle over the course of a year. In addition, higher energy demand from public transportation (not evaluated in the *Impacts 2050* tool) would undercut some of the energy savings from light-duty vehicles evaluated here.

The overall conclusion, however, supported by numerous other studies of greenhouse gas emission reduction scenarios (see text box on page 83), is that a transition to a zero-carbon transportation system is possible, and that a variety of tools and strategies can be used to bring it into being.

Transforming transportation can also support low-carbon transitions in other sectors of the economy. Oil and natural gas production, transportation and processing account for about 4 percent of U.S. energy-related greenhouse gas emissions.[159] Eliminating the use of fossil fuels for urban transportation would reduce those "upstream" sources of pollution as well. Meanwhile, electric vehicles can provide a valuable source of energy storage that can help integrate large volumes of renewable energy and stabilize the grid – enhancing strategies for carbon reduction outside of transportation.

Studies Show that a Transition to Low-Carbon Transportation Is Possible

The conclusion of this paper – that strategies to transform transportation in the United States can lead to dramatic cuts in greenhouse gas emissions – is one that has been shared by other analyses, evaluating a variety of pathways to decarbonization. Among them:

» The **Institute for Transportation and Development Policy** estimated in 2014 that the United States could reduce urban passenger transportation emissions by nearly 60 percent below current levels by 2050 under a "high shift" scenario that includes expanded use of public transportation, bicycling and walking, as well as a reduction in growth of vehicle travel.[160]

» The **National Renewable Energy Laboratory** found that a combination of strategies – including improved vehicle economy, fuel switching and reductions in travel growth – could cut transportation-sector carbon dioxide emissions by 80 percent.[161]

» **The Rocky Mountain Institute** found that adopting advanced vehicles and using them more efficiently could reduce U.S. transportation energy use by two-thirds compared with forecast levels and eliminate oil consumption by 2050, even at increased levels of overall driving.[162]

» **Energy and Environmental Economics**, working with two U.S. national laboratories, evaluated four scenarios for deep reductions in U.S. greenhouse gas emissions, each of which yielded a 75 percent or greater reduction in transportation sector emissions. Emission reductions were achieved by improvements in vehicle fuel economy and fuel switching to electricity and hydrogen fuel.[163]

» The **Transportation and Climate Initiative** of the Georgetown Climate Center found in 2015 that a series of public policy initiatives in northeastern states, coupled with existing state and federal policies, could reduce transportation carbon dioxide emissions by up to 39 percent by 2030, consistent with a trajectory to achieve 80 percent emission reductions from transportation in the region by 2050.[164]

» A 2015 analysis by researchers at **Lawrence Berkeley National Laboratory** estimated that a transition to a network of shared autonomous taxis, powered by low-emission electricity, and rightsized to meet demand, could reduce per-vehicle greenhouse gas emissions by 87 to 94 percent by 2030 compared with conventional gasoline-powered cars.[165]

Each of these studies evaluated a different pathway for cutting transportation greenhouse gas emissions. Some relied on technological advances, others on changes in land-use and travel behavior. But the end conclusion is the same: America has the technical and policy know-how to achieve large-scale reductions in carbon dioxide emissions from transportation – and to do it within a time frame sufficient to make a difference.

Implications for Public Policy

In many places the prospect of achieving these "co-benefits" will be more immediately compelling to the public and decision-makers than addressing climate change.

New technologies and emerging social trends provide America with an unprecedented opportunity to build a 21st century transportation system with little impact on the global climate. Achieving a transformation to a zero-carbon transportation system – and doing so in a way that minimizes costs and maximizes benefits – will require us to challenge old assumptions, and to take a fresh look at the role of public policy.

It is beyond the scope of this report to propose a detailed set of policy steps to facilitate transformation – a subsequent report will address the relevant policy issues in greater depth. To follow, however, are a series of general observations on the shifts in public policy required to achieve transformation.

Make climate protection an explicit goal of transportation policy. The strategies for transformation described in this report can deliver broad benefits to society – improving public health and safety, saving money for taxpayers and consumers, eliminating environmental and national security concerns related to fossil fuel extraction and processing, and more.

In many places, the prospect of achieving these "co-benefits" will be more immediately compelling to the public and decision-makers than addressing climate change. Indeed, each of the four pathways in this report begins with urban areas employing transformative transportation tools to address a crisis unrelated to climate change – affordable housing, urban revitalization, air pollution or traffic congestion.

Nevertheless, establishing targets for greenhouse gas emission reductions from transportation – and elevating climate change as a central concern of transportation policy-making – is essential. The current circumstance in much of the country, in which the greenhouse gas emission impacts of transportation policies and investments are not rigorously evaluated and are unremarked upon in the public discourse, is clearly inconsistent with the goal of achieving a zero-carbon transportation system. Accurate carbon accounting for transportation projects and policies is needed, as is the establishment of emission reduction targets that can ensure that carbon reductions achieved through one set of transportation reforms are not canceled out by backsliding elsewhere.

The 2012 federal transportation reauthorization, MAP-21, created, for the first time, a system for performance-based evaluation of transportation infrastructure investments. In April 2016, the U.S. Department of Transportation announced its intention to establish greenhouse gas reporting and performance standards. Strong performance metrics can play an important role in driving states and regional bodies to integrate climate impacts into every transportation decision.

Shift from infrastructure expansion to system management. U.S. transportation agencies have traditionally focused on building infrastructure, not improving the efficiency of that infrastructure once created. The bias toward viewing infrastructure expansion as the solution to any transportation problem is strong: traffic congestion anticipated decades in the future is used to justify present-day highway-widening schemes, and federal funds are available to transit agencies for capital expenditures, but not (with a few exceptions) for transit operations.

As a result, transportation debates tend to focus on which types of infrastructure to build – and how to raise the often extraordinary amounts of money required to pay for their construction – rather than how to better *use* the infrastructure in which we have invested so much.

Advances in information technology are potentially transformative because they enable us to use our existing vehicles and roads far more efficiently. Shared mobility maximizes the use of otherwise idle vehicles and empty seats, while smart pricing aims to increase the efficiency of traffic movement and parking. However, the full potential of these tools can only be realized if policy-makers take steps to support shared mobility and eliminate explicit and implicit subsidies supporting single-occupancy vehicle travel and private vehicle ownership.

Elevating effective management of the transportation system – long the goal of transportation demand management (TDM) programs – to a place of central importance in transportation agencies will require a major culture shift. It may even require new institutions capable of managing regional transportation networks on a day-to-day basis on behalf of the public interest. The time to begin the process of institutional reform is now.

Of course, government's role in providing infrastructure will remain important – several of the narratives in this report require major expansions of public transportation systems, as well as continued maintenance, repair, reconstruction and repurposing of existing infrastructure. Aligning infrastructure decisions with climate goals – beginning with the rejection of new infrastructure projects likely to contribute to climate change – will remain critical.

Design for long-term emission reductions. Achieving cheap, fast, sure reductions in greenhouse gas emissions is essential to prevent climate "tipping points" from which recovery may be impossible. However, a different set of strategies may be needed to achieve the fastest, most beneficial transition to an *entirely* decarbonized transportation system.

Certain measures – such as incentives for electric vehicle purchases in areas of the country with coal-fired electric grids – may have limited to no greenhouse gas benefits in the short run, but yet may be essential to the ultimate creation of a zero-carbon transportation system. Similarly, small-scale changes – such as the construction of bike lanes in cities – may not have great short-term emission reduction potential, but may, through network effects and changes in land use and local mobility cultures, pave the way for greater changes in the future.

Similarly, as systems are established to support the transition to zero-carbon transportation, those systems must be designed with integrity from the very start. It is far easier to change prices on highways, increase emission reduction targets, or change the rules for accessing an HOV lane than it is to reform the structure of a public policy system or bureaucracy once it has been established. Taking the time to get institutional reform and new systems right is critical if such systems are to be durable and retain political support.

Emphasize win-win-wins. Ideally, the three changes necessary for decarbonization – a transition to low-carbon vehicles and fuels; reduced growth in vehicle travel; and improved system efficiency – will occur simultaneously, brought about by policies that forward all three objectives at once. Doing so will require care to minimize or address conflicts among the strategies. Policies that support electric vehicles, for example, may reduce per-mile carbon emissions and enable the creation of new, more flexible vehicle designs, but the lower running costs of electric vehicles may increase vehicle travel without concurrent policies to discourage overuse. Urban design decisions may support the creation of vibrant, compact settlements with lower travel demand and support shared mobility services, but may also make it more challenging for private electric vehicle owners to find places to charge their vehicles.

Policy-makers seeking to decarbonize the transportation system must integrate all strategies for decarbonization into their thinking, rather than treating them as separate and disconnected silos of effort. Ideal public policies would support the achievement of all three objectives at once.

A zero-carbon transportation system must provide zero-carbon transportation options to all Americans.

Serve everyone. The young, the old, low-income people and people with disabilities have long been disadvantaged in America's car-dependent transportation system. A zero-carbon transportation system must provide zero-carbon transportation options to all Americans.

New transportation technologies and tools create exciting new opportunities to overcome obstacles to transportation access. Policy-makers should ensure that the move to a zero-carbon transportation network includes solutions providing access to the unbanked, people with various levels of access to and facility with digital technology, people who primarily speak languages other than English, as well as the disabled, the elderly and the young.

Turbocharge innovation. Standards such as corporate average fuel economy (CAFE) standards and California's Clean Cars Program have helped to drive innovation in vehicles and fuels and ensure that technological advances in automobiles and fuels are applied for environmental and societal benefit. At the other end of the spectrum, recent years have seen cities across the country adopt new approaches to testing new ideas in transportation. Tactical urbanism, "pop-up" bike lanes, and shared mobility pilot programs all provide opportunities for the public to see and try out innovative concepts on a trial basis.

While the policy mechanisms are very different, the impact of both ambitious technology standards and local experimentation is to expand the realm of the possible, providing policy-makers with new tools with which to make transformation happen. These efforts have another important effect: they can help prepare the public for the dramatic transformations that await on the path to a zero-carbon transportation system.

Empower strong local leadership. Different regions of the United States have different histories, different present-day needs, and differing future aspirations. It only stands to reason that they may choose different paths toward a zero-carbon transportation system.

Cities and their adjoining regions are best positioned to plan and execute sensible strategies for decarbonization of metropolitan transportation.

However, America's federal structure largely empowers states – not cities or municipalities, or even metropolitan regions – to determine where transportation dollars will be spent and, in some cases (as with road design standards and speed limits) determine how the system will be used.

Cities and their adjoining regions are best positioned to plan and execute sensible strategies for decarbonization of metropolitan transportation. Federal and state policies should recognize this by empowering cities to have greater autonomy and take on greater leadership in meeting greenhouse gas emission targets, and to match that autonomy with funding.

Integrate transportation with other areas of public policy. Transportation and land use policy have long been seen as integrally related. As the nation transitions to a zero-carbon transportation system, however, the ties between transportation policy and other areas of policy – such as housing, economic development and management of the electric grid – become tighter, creating new challenges and new opportunities. The transition to electric vehicles and the transition to a renewable electric grid, for example, have the potential to be mutually reinforcing, with electric vehicles providing a source of storage to allow for the integration of more renewable energy to the grid. Transportation policy-makers must coordinate with policy-makers in other areas and devise win-win strategies to move more quickly toward the goal of a zero-carbon transportation system.

A zero-carbon transportation system will not happen on its own.

In addition, while this report focuses mainly on urban passenger transportation, smart policies will also be needed to achieve decarbonization in freight transportation, road transportation in rural areas, and in non-road modes of transportation.

Recognize and tally co-benefits. The same tools that can be used to transform transportation for the benefit of the climate can also be used to achieve an array of other important goals – saving taxpayers and consumers money; reducing air pollution, vehicle crashes and other public health and safety threats; ensuring fair and equitable access to transportation for low-income people, the young, the old and the disabled; and more. These benefits should be considered and taken into account as policy-makers consider steps toward transforming transportation. Transportation projects and policies should be evaluated based on their broad societal costs and benefits.

Conclusion

Transforming America's transportation system to one with little to no impact on the climate is possible. Technological and social change have provided the nation with a new suite of tools to improve the efficiency of our transportation system and serve Americans' travel needs, even as we work to eliminate greenhouse gas emissions from transportation and the broader economy.

A zero-carbon transportation system will not happen on its own. Taking full advantage of the potential of these new tools and strategies will require Americans to put aside old assumptions, reform hidebound institutions, and envision new ways of doing things.

None of that is easy. All of it is possible. The time to begin is now.

Appendices and Notes

Appendix A: Methodology

Data sources used in this report are cited throughout, with the following exceptions.

Carbon Dioxide Emissions from Road Transportation

Data on carbon dioxide emissions from road transportation by urban area were estimated through analysis of the Database of Road Transportation Emissions (DARTE), downloaded from the Oak Ridge National Laboratory Distributed Active Archive Center for Biogeochemical Dynamics at http://daac.ornl.gov/cgi-bin/dsviewer.pl?ds_id=1285 on 7 October 2015. The DARTE database provides estimates of road carbon dioxide emissions, with estimates based on the Federal Highway Administration's Highway Performance Monitoring System (HPMS) for individual years from 1980 to 2012, on a 1-km grid for the coterminous United States. ArcGIS software was used to join the DARTE data cells to their respective Census Bureau-defined urban areas (2010 boundaries), based on cartographic boundary files downloaded from the U.S. Census Bureau. The result was an estimate of road transportation emissions for each urban area in the United States. A table listing emissions for the largest U.S. urban areas can be found in Appendix B.

Storylines and City Archetypes

The four storylines for transformation and hypothetical cities were informed by empirical data and the authors' judgment, as well as conversations with planners, experts and advocates across the country. (For a full list of those consulted in the shaping of the narratives and content of this report, see Appendix C.) This approach is theoretically consistent with the notion that urban "mobility cultures" consist of both objective and subjective dimensions as described by Klinger, Kenworthy and Lanzendorf (2010).[166]

The data sources used to help match cities with urban archetypes were as follows:

- Daily vehicle-miles traveled per capita; freeway lane-miles per capita: Calculated from Federal Highway Administration, *Highway Statistics 2013*, Table HM-72, October 2014, and urban area population data from U.S. Census Bureau, American Community Survey 1-year data for 2013.
- Transit riders per capita: Calculated from urbanized area allocation from Federal Transit Administration, *National Transit Database 2013*, accessed at http://www.ntdprogram.gov/ntdprogram/data.htm; and urbanized area population data from U.S. Census Bureau, American Community Survey 1-year data for 2013.
- Sprawl index: Metropolitan area sprawl index from Reid Ewing and Shima Hamidi, *Measuring Sprawl 2014*, Smart Growth America, April 2014. Note: San Francisco MSA is used for San Francisco-Oakland Urban Area.
- Population density: Population data as cited above, compared with net land area for each urban area from Federal Highway Administration, *Highway Statistics 2013*, Table HM-72, October 2014.
- Bicycle and pedestrian commute mode share: Urbanized area population data from U.S. Census Bureau, American Community Survey 1-year data for 2014.
- Historical population data for central cities for 1950 and 1980, from the U.S. Census Bureau.

Estimated Impact of Transformation on Energy Use

The effect of the various shifts represented in the narratives on light-duty vehicle energy use was estimated as follows.

Vehicle-Miles Traveled

To simulate the effects of the changes consistent with the metropolitan narratives on light-duty vehicle travel, we used the *Impacts 2050* scenario analysis tool developed for the Transportation Research Board as part of National Cooperative Highway Research Program Report 750, Volume 6. The *Impacts 2050* tool is described as "a strategic model. Rather than produce detailed forecasts of travel behavior, it illustrates a range of future scenarios that could occur in a given region under a range of different assumptions." According to the user's guide, "As a tool for long-range planning, *Impacts 2050* emphasizes producing qualitatively accurate representations of how different variable relationships will evolve over time, rather than numerically accurate forecasts for one particular sector." The tool evaluates relationships among socio-demographic, travel behavior, employment, land use and transport supply factors.

Scenarios for this report are based off of the "Momentum" scenario in *Impacts 2050*, which represents the equivalent of "business-as-usual" assumptions about the future. Alternative scenarios are created by specifying rates of change from this core scenario – for example, a 50 percent increase in gasoline prices in a particular year relative to "business-as-usual" would be specified by entering "1.5" in the "gasoline price" input variable. *Impacts 2050* includes default baseline information for five U.S. cities – Atlanta, Boston, Detroit, Houston and Seattle.

The four scenarios evaluated in this report were specified as described in Table A-1 below and applied to specific cities to develop the estimates of light-duty VMT reductions presented in Figure 4 on page 80. Tables presenting the full outputs of the *Impacts 2050* model, including results for several transportation and land-use indicators, can be found in Tables A-2a through A-2d.

Table A-1: Impacts 2050 Specifications and Rationale for Four Scenarios

Scenario/Metro Area Evaluated Parameter	"Building Up"/ Centerville Boston	"Fixing Up"/ Beltania Detroit	"Linking Up"/ Westlandia Seattle	"Syncing Up"/Sun City Atlanta
High Income Effect on Space per Household	0.8: Increasing popularity of urban lifestyles among higher-income people reduces differential in housing size between higher- and lower-income households.	0.8: Increasing popularity of urban lifestyles among higher-income people reduces differential in housing size between higher- and lower-income households.	no change	no change
Gasoline price (used to simulate changes in vehicle operating costs and road pricing)	no change: The lower operating cost of electric vehicles is assumed to be fully counterbalanced by per-mile or other charges on vehicle use.	0.8: The lower operating cost of electric vehicles is assumed to be partially counterbalanced by per-mile or other charges on vehicle use.	no change: The lower operating cost of electric vehicles is assumed to be fully counterbalanced by per-mile or other charges on vehicle use.	1.25: Aggressive and pervasive pricing of vehicle use results in increase in per-mile costs, despite lower operating costs of electric vehicles.

Scenario/Metro Area Evaluated Parameter	"Building Up"/ Centerville Boston	"Fixing Up"/ Beltania Detroit	"Linking Up"/ Westlandia Seattle	"Syncing Up"/Sun City Atlanta
Shared car fraction	1.5: Shared mobility programs and services become more widespread.	1.5: Shared mobility programs and services become more widespread.	2: Shared mobility programs and services become much more widespread, supplanting some private vehicle ownership.	3: Shared mobility programs and services become pervasive, supplanting much private vehicle ownership.
Fraction of no-car households	2.0: Intense urbanization leads to greater share of residents living in dense, urban neighborhoods with lower rates of car ownership.	no change	1.25: Increase in transit-oriented development leads to modest increase in zero-car households.	no change: The shift to shared mobility is represented in "Shared Car Fraction" above.
Work trip and non-work trip rate	no change	no change	no change	0.9: As road pricing becomes more widespread, telecommuting and compressed work schedules gain favor.
Car passenger mode share	1.5: Vehicle occupancy increases with moderate uptake of ridesharing.	1.2: Vehicle occupancy increases with modest uptake of ridesharing.	1.75 Vehicle occupancy increases with aggressive uptake of ridesharing.	2.5: Vehicle occupancy increases dramatically with very aggressive uptake of ridesharing.
Transit mode share	1.5: Transit expansion and urbanization increase transit ridership (though transit mode share in these cities is already high).	1.5: Transit ridership increases as discontinued services are restored and the transit network experiences modest expansion, reflecting urban population growth.	2.5: Transit ridership increases dramatically with major investments in transit and transit-oriented development (compared with initial low transit mode share).	1.2: Transit ridership increases modestly with growth of compact, mixed-use centers.
Walk/bike mode share	1.5: Dense development and infrastructure improvements boost already high mode share.	2: Redevelopment and infrastructure improvements boost low mode share.	no change	1.25: New nodes of mixed-use development enable increase in walk/bike mode share.
Car trip distance	0.75: The average car trip becomes significantly shorter, as most new development is infill and intensely urban.	0.8: The average car trip becomes somewhat shorter as new growth takes place primarily in existing urban neighborhoods.	no change	1.1: The average car trip becomes somewhat longer as increased travel speed encourages additional sprawl/longer trips (counteracted to some degree by road pricing).
Residential/ non-residential space per household	0.8: Intense urbanization results in less residential and commercial space per capita.	0.9: Infill development results in less residential and commercial space per capita.	no change	no change

Scenario/Metro Area Evaluated Parameter	"Building Up"/ Centerville Boston	"Fixing Up"/ Beltania Detroit	"Linking Up"/ Westlandia Seattle	"Syncing Up"/Sun City Atlanta
Road capacity addition	0.25 (after 2015): Road capacity expansion is curtailed as the region focuses new investment on transit and non-motorized modes.	0.25 (after 2020): Road capacity expansion is curtailed due to fiscal constraints.	0.5 (after 2030): Road capacity expansion is curtailed due to fiscal constraints.	0.75 (after 2030): Road capacity expansion is reduced as improved system efficiency reduces demand for new capacity.
Transit capacity addition	1.5: Large-scale expansion of an already-mature transit system.	1.25: Restoration of previously eliminated service with mild expansion.	2.5: Large-scale expansion of a small initial transit system.	no change
Road capacity per lane	no change: Increased capacity from autonomous vehicles is counteracted by reallocation of road space away from cars.	no change: Increased capacity from automated vehicles is counteracted by reallocation of road space away from cars.	1.25: Large-scale adoption of autonomous vehicles allows for modest increase in capacity per lane.	1.5: Near-universal adoption of autonomous vehicles allows for significant increase in capacity per lane.
Transit passenger capacity per route	1.75: Service on existing routes is expanded dramatically, including through creation of new services on existing routes.	1.25: Service on existing and restored routes is provided with greater frequency.	1.25: Service on existing and new routes is provided with greater frequency.	no change

Tables A-2. Key Transportation Indicators from Impacts 2050 Simulation of Four Scenarios

Table A-2a. "Growing Up": Boston

Year	2010		2020		2030		2040		2050	
Scenario	"Momentum" (business-as-usual)	"Building Up"	"Momentum" (business-as-usual)	"Building Up"	"Momentum" (business-as-usual)	"Building Up"	"Momentum" (business-as-usual)	"Building Up"	"Momentum" (business-as-usual)	"Building Up"
Metro population (million)	5.39	5.39	6.16	6.17	6.80	6.90	7.33	7.58	7.78	8.24
Percent in workforce	47%	47%	43%	43%	41%	41%	40%	40%	39%	39%
Percent non-car-owning	4%	4%	5%	5%	5%	6%	5%	7%	5%	7%
Percent car-sharing	23%	23%	23%	24%	23%	25%	23%	27%	23%	28%
Avg. car-occupancy - Work	1.08	1.08	1.08	1.09	1.08	1.11	1.09	1.12	1.09	1.14
Transit mode share - Work	7.5%	7.5%	7.8%	8.4%	8.0%	9.5%	8.1%	10.5%	8.1%	11.3%
Walk/bike mode share - Work	4.8%	4.8%	5.0%	5.3%	5.0%	5.9%	5.0%	6.5%	5.0%	7.0%
Avg. car-occupancy - Non-work	1.84	1.84	1.83	1.88	1.83	1.97	1.83	2.06	1.84	2.16
Transit mode share - Non-work	2.2%	2.2%	2.3%	2.4%	2.3%	2.7%	2.3%	2.9%	2.3%	3.0%
Walk/bike mode share - Non-work	18.7%	18.7%	18.9%	19.5%	19.0%	20.7%	19.1%	21.7%	19.1%	22.6%
Work trips/capita per day	0.45	0.45	0.41	0.41	0.39	0.39	0.38	0.38	0.37	0.37
Other trips/capita per day	2.99	2.99	3.07	3.06	3.10	3.09	3.12	3.10	3.12	3.11
Auto VMT/capita per year	9,358	9,358	9,008	8,455	8,835	7,288	8,750	6,323	8,710	5,488

Table A-2b. "Fixing Up": Detroit

Year	2010		2020		2030		2040		2050	
Scenario	"Momentum" (business-as-usual)	"Fixing Up"	"Momentum" (business-as-usual)	"Fixing Up"	"Momentum" (business-as-usual)	"Fixing Up"	"Momentum" (business-as-usual)	"Fixing Up"	"Momentum" (business-as-usual)	"Fixing Up"
Metro population (million)	5.29	5.29	5.92	5.93	6.47	6.53	6.95	7.08	7.38	7.61
Percent in workforce	44%	44%	42%	42%	40%	40%	39%	39%	39%	39%
Percent non-car-owning	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%
Percent car-sharing	30%	30%	30%	32%	30%	34%	30%	36%	30%	37%
Avg. car-occupancy- Work	1.09	1.09	1.09	1.09	1.09	1.10	1.09	1.11	1.09	1.12
Transit mode share- Work	2.9%	2.9%	3.1%	3.3%	3.3%	3.7%	3.3%	4.1%	3.4%	4.5%
Walk/bike mode share - Work	6.2%	6.2%	6.5%	7.3%	6.7%	8.9%	6.8%	10.4%	6.9%	11.8%
Avg. car-occupancy- Non-work	1.79	1.79	1.78	1.79	1.77	1.81	1.77	1.84	1.77	1.87
Transit mode share- Non-work	0.6%	0.6%	0.7%	0.7%	0.7%	0.7%	0.7%	0.7%	0.7%	0.8%
Walk/bike mode share-Non-work	12.1%	12.1%	12.3%	13.5%	12.5%	15.9%	12.7%	17.9%	12.8%	19.7%
Work trips/capita per day	0.43	0.43	0.40	0.40	0.39	0.39	0.38	0.38	0.38	0.38
Other trips/capita per day	3.61	3.61	3.67	3.67	3.70	3.70	3.71	3.71	3.72	3.72
Auto VMT/capita per year	9,906	9,906	9,692	9,236	9,580	8,281	9,526	7,455	9,500	6,715

Table A-2c. "Linking Up": Seattle

Year	2010		2020		2030		2040		2050	
Scenario	"Momentum" (business-as-usual)	"Linking Up"	"Momentum" (business-as-usual)	"Linking Up"	"Momentum" (business-as-usual)	"Linking Up"	"Momentum" (business-as-usual)	"Linking Up"	"Momentum" (business-as-usual)	"Linking Up"
Metro population (million)	3.80	3.80	4.37	4.37	4.84	4.85	5.23	5.27	5.57	5.66
Percent in workforce	47%	47%	43%	43%	41%	41%	40%	40%	39%	39%
Percent non-car-owning	6%	6%	6%	6%	6%	6%	6%	6%	7%	6%
Percent car-sharing	17%	17%	17%	19%	17%	22%	17%	24%	17%	26%
Avg. car-occupancy- Work	1.09	1.09	1.09	1.10	1.09	1.12	1.09	1.14	1.09	1.17
Transit mode share- Work	12.0%	12.0%	12.8%	14.6%	13.2%	18.5%	13.5%	21.7%	13.7%	24.5%
Walk/bike mode share - Work	4.5%	4.5%	4.7%	4.8%	4.8%	5.2%	4.9%	5.4%	4.9%	5.7%
Avg. car-occupancy- Non-work	1.75	1.75	1.75	1.81	1.75	1.92	1.75	2.04	1.75	2.16
Transit mode share- Non-work	2.0%	2.0%	2.1%	2.4%	2.2%	3.1%	2.3%	3.6%	2.4%	4.1%
Walk/bike mode share-Non-work	21.8%	21.8%	22.1%	22.3%	22.4%	23.0%	22.5%	23.6%	22.7%	24.1%
Work trips/capita per day	0.52	0.52	0.48	0.48	0.45	0.45	0.44	0.44	0.43	0.43
Other trips/capita per day	2.68	2.68	2.75	2.74	2.78	2.77	2.79	2.79	2.80	2.79
Auto VMT/capita per year	9,364	9,364	8,964	8,642	8,760	7,872	8,653	7,278	8,593	6,789

Table A-2d. "Syncing Up": Atlanta

Year / Scenario	2010		2020		2030		2040		2050	
	"Momentum" (business-as-usual)	"Syncing Up"	"Momentum" (business-as-usual)	"Syncing Up"	"Momentum" (business-as-usual)	"Syncing Up"	"Momentum" (business-as-usual)	"Syncing Up"	"Momentum" (business-as-usual)	"Syncing Up"
Metro population (million)	5.38	5.38	6.22	6.22	6.92	6.95	7.52	7.60	8.04	8.23
Percent in workforce	47%	47%	43%	43%	41%	41%	40%	40%	39%	39%
Percent non-car-owning	2%	2%	3%	3%	3%	2%	3%	2%	3%	2%
Percent car-sharing	21%	21%	21%	25%	22%	31%	22%	36%	22%	40%
Avg. car-occupancy- Work	1.13	1.13	1.13	1.16	1.13	1.23	1.13	1.30	1.13	1.38
Transit mode share- Work	2.0%	2.0%	2.3%	2.4%	2.5%	2.7%	2.7%	2.9%	2.8%	3.1%
Walk/bike mode share - Work	5.8%	5.8%	6.2%	6.5%	6.5%	7.2%	6.7%	7.8%	6.8%	8.3%
Avg. car-occupancy- Non-work	1.80	1.80	1.79	1.90	1.78	2.11	1.77	2.33	1.77	2.56
Transit mode share- Non-work	1.7%	1.7%	1.8%	1.8%	2.0%	1.9%	2.1%	1.9%	2.3%	2.0%
Walk/bike mode share-Non-work	11.6%	11.6%	12.0%	11.6%	12.2%	11.3%	12.4%	11.2%	12.6%	11.2%
Work trips/capita per day	0.55	0.55	0.50	0.49	0.48	0.46	0.47	0.43	0.46	0.41
Other trips/capita per day	2.86	2.86	2.93	2.89	2.97	2.84	2.99	2.77	2.99	2.69
Auto VMT/capita per year	10,971	10,971	10,556	10,061	10,327	8,977	10,193	8,116	10,107	7,397

Electrification and System Efficiency

The "business-as-usual" and scenario outputs from *Impacts 2050* were combined with assumptions about per-mile vehicle energy consumption to arrive at an estimate of energy demand from light-duty vehicles in 2050.

The effect of electrification on energy consumption was based on assumptions about the fuel economy of future vehicles from the Energy Information Administration's *Annual Energy Outlook 2015* projections.[167] Conventional vehicle fuel economy (in miles per gasoline gallon equivalent) in 2050 was estimated based on continuation of the 2 percent annual rate of increase from 2013 to 2040 in the fuel economy of the light-duty vehicle stock in the *Annual Energy Outlook*. Electric vehicle energy efficiency (in miles per gasoline gallon equivalent) in 2050 was based on continuation of the annual rate of increase in efficiency of cars and light trucks with 200-mile all-electric range from 2013 to 2040 in the case of cars and 2018 to 2040 in the case of light trucks. The average efficiency of the light-duty electric fleet was estimated by assuming a 50-50 split in the number of vehicle-miles traveled by cars and light trucks. The use of energy efficiency data for new, as opposed to stock average, electric vehicles likely results in a slight overestimation of the energy savings resulting from electrification, although the slow rate of efficiency improvement for electric vehicles assumed in the *Annual Energy Outlook* means that any divergence between the average fuel efficiency of new and stock average electric vehicles in 2050 is likely to be minor.

In all cases, gasoline gallons equivalent was converted to British Thermal Units using a conversion ratio of 111,800 Btu per gasoline gallon equivalent from the state of California.[168]

Reduction in energy demand resulting from "lightweighting," "rightsizing" and other improvements in system efficiency were derived from the "revolutionary" vehicle scenario in the Rocky Mountain Institute's 2011 report, *Reinventing Fire*.[169] Miles per gasoline gallon equivalent estimates for cars and light trucks from the RMI report were averaged, assuming a 50-50 split in car/light truck vehicle-miles traveled.

Appendix B. Supplemental Data

Table B-1. Road transportation carbon dioxide emissions (metric tons) by U.S. urban area, top 100 areas.

Rank	Urban Area (2010 Boundaries)	Road Transportation Carbon Dioxide Emissions, 2012 (metric tons)
1	New York--Newark, NY--NJ--CT Urbanized Area	52,910,568
2	Los Angeles--Long Beach--Anaheim, CA Urbanized Area	46,083,549
3	Chicago, IL--IN Urbanized Area	32,112,674
4	Dallas--Fort Worth--Arlington, TX Urbanized Area	25,880,358
5	Philadelphia, PA--NJ--DE--MD Urbanized Area	22,946,736
6	Miami, FL Urbanized Area	22,754,863
7	Houston, TX Urbanized Area	22,659,697
8	Atlanta, GA Urbanized Area	20,595,344
9	Washington, DC--VA--MD Urbanized Area	20,372,790
10	Boston, MA--NH--RI Urbanized Area	18,245,154
11	Detroit, MI Urbanized Area	17,477,577
12	Phoenix--Mesa, AZ Urbanized Area	14,310,687
13	Minneapolis--St. Paul, MN--WI Urbanized Area	13,952,485
14	San Francisco--Oakland, CA Urbanized Area	13,686,893
15	Seattle, WA Urbanized Area	13,245,638
16	San Diego, CA Urbanized Area	11,956,429
17	Baltimore, MD Urbanized Area	11,624,342
18	St. Louis, MO--IL Urbanized Area	10,593,093
19	Denver--Aurora, CO Urbanized Area	10,401,670
20	Indianapolis, IN Urbanized Area	10,196,657
21	San Antonio, TX Urbanized Area	9,195,830
22	Orlando, FL Urbanized Area	8,670,366
23	Tampa--St. Petersburg, FL Urbanized Area	8,543,555
24	Riverside--San Bernardino, CA Urbanized Area	8,005,177
25	Kansas City, MO--KS Urbanized Area	7,948,830
26	Cleveland, OH Urbanized Area	7,804,330
27	Cincinnati, OH--KY--IN Urbanized Area	7,481,481
28	Las Vegas--Henderson, NV Urbanized Area	7,474,283
29	Austin, TX Urbanized Area	7,403,429
30	San Jose, CA Urbanized Area	6,912,611
31	Portland, OR--WA Urbanized Area	6,689,226
32	Charlotte, NC--SC Urbanized Area	6,496,827
33	Pittsburgh, PA Urbanized Area	6,457,940
34	Sacramento, CA Urbanized Area	6,106,631
35	Columbus, OH Urbanized Area	6,032,885

Rank	Urban Area (2010 Boundaries)	Road Transportation Carbon Dioxide Emissions, 2012 (metric tons)
36	Virginia Beach, VA Urbanized Area	6,031,684
37	Jacksonville, FL Urbanized Area	5,674,234
38	Nashville-Davidson, TN Urbanized Area	5,637,017
39	Milwaukee, WI Urbanized Area	5,565,585
40	Louisville/Jefferson County, KY--IN Urbanized Area	5,332,708
41	Providence, RI--MA Urbanized Area	5,306,105
42	Richmond, VA Urbanized Area	5,067,482
43	Memphis, TN--MS--AR Urbanized Area	4,944,766
44	Birmingham, AL Urbanized Area	4,872,147
45	Raleigh, NC Urbanized Area	4,762,070
46	Oklahoma City, OK Urbanized Area	4,520,228
47	Hartford, CT Urbanized Area	4,438,316
48	Salt Lake City--West Valley City, UT Urbanized Area	4,192,431
49	Bridgeport--Stamford, CT--NY Urbanized Area	4,059,088
50	Mission Viejo--Lake Forest--San Clemente, CA Urbanized Area	3,708,727
51	Columbia, SC Urbanized Area	3,699,068
52	Worcester, MA--CT Urbanized Area	3,466,454
53	New Orleans, LA Urbanized Area	3,433,507
54	Buffalo, NY Urbanized Area	3,363,310
55	Allentown, PA--NJ Urbanized Area	3,291,962
56	Baton Rouge, LA Urbanized Area	3,266,568
57	Harrisburg, PA Urbanized Area	3,253,350
58	Tulsa, OK Urbanized Area	3,231,291
59	Dayton, OH Urbanized Area	3,229,134
60	Knoxville, TN Urbanized Area	3,199,277
61	New Haven, CT Urbanized Area	3,184,445
62	Little Rock, AR Urbanized Area	3,164,691
63	Tucson, AZ Urbanized Area	3,119,951
64	Jackson, MS Urbanized Area	3,088,631
65	Albuquerque, NM Urbanized Area	3,076,919
66	Concord, CA Urbanized Area	3,034,316
67	Omaha, NE--IA Urbanized Area	2,964,197
68	El Paso, TX--NM Urbanized Area	2,943,294
69	Charleston--North Charleston, SC Urbanized Area	2,931,917
70	Springfield, MA--CT Urbanized Area	2,822,665
71	Grand Rapids, MI Urbanized Area	2,804,493
72	Albany--Schenectady, NY Urbanized Area	2,738,666
73	Rochester, NY Urbanized Area	2,695,705
74	Sarasota--Bradenton, FL Urbanized Area	2,634,248

Rank	Urban Area (2010 Boundaries)	Road Transportation Carbon Dioxide Emissions, 2012 (metric tons)
75	McAllen, TX Urbanized Area	2,575,209
76	Wichita, KS Urbanized Area	2,523,441
77	Greensboro, NC Urbanized Area	2,511,537
78	Denton--Lewisville, TX Urbanized Area	2,445,576
79	Greenville, SC Urbanized Area	2,379,476
80	Poughkeepsie--Newburgh, NY--NJ Urbanized Area	2,378,423
81	Palm Bay--Melbourne, FL Urbanized Area	2,287,014
82	Des Moines, IA Urbanized Area	2,230,658
83	Akron, OH Urbanized Area	2,148,270
84	Durham, NC Urbanized Area	2,081,178
85	Mobile, AL Urbanized Area	2,047,502
86	Murrieta--Temecula--Menifee, CA Urbanized Area	2,026,437
87	Ogden--Layton, UT Urbanized Area	2,012,617
88	Chattanooga, TN--GA Urbanized Area	1,986,546
89	Flint, MI Urbanized Area	1,970,521
90	Shreveport, LA Urbanized Area	1,945,935
91	Toledo, OH--MI Urbanized Area	1,944,892
92	Port St. Lucie, FL Urbanized Area	1,940,651
93	Colorado Springs, CO Urbanized Area	1,938,678
94	Asheville, NC Urbanized Area	1,920,477
95	Bonita Springs, FL Urbanized Area	1,908,011
96	Montgomery, AL Urbanized Area	1,865,738
97	Cape Coral, FL Urbanized Area	1,853,635
98	Barnstable Town, MA Urbanized Area	1,841,901
99	Lancaster, PA Urbanized Area	1,809,064
100	Fresno, CA Urbanized Area	1,790,220

Appendix C: Engagement Efforts

The narratives and policy insights in this document were informed by individual and group conversations with more than 80 experts, advocates and transportation system stakeholders in cities across the country. The engagement effort included the following:

» Structured interviews with local stakeholders and experts during the fall of 2015.

» A policy forum with leading national advocates and experts on transportation and climate change, which occurred in Washington, D.C., in January 2016.

» A series of regional webinars with local stakeholders and experts in March and April 2016.

We are extremely grateful for the willingness of the following individuals to share their thoughts with us in one or more of these settings. (Participation does not imply endorsement of the project or its recommendations.)

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