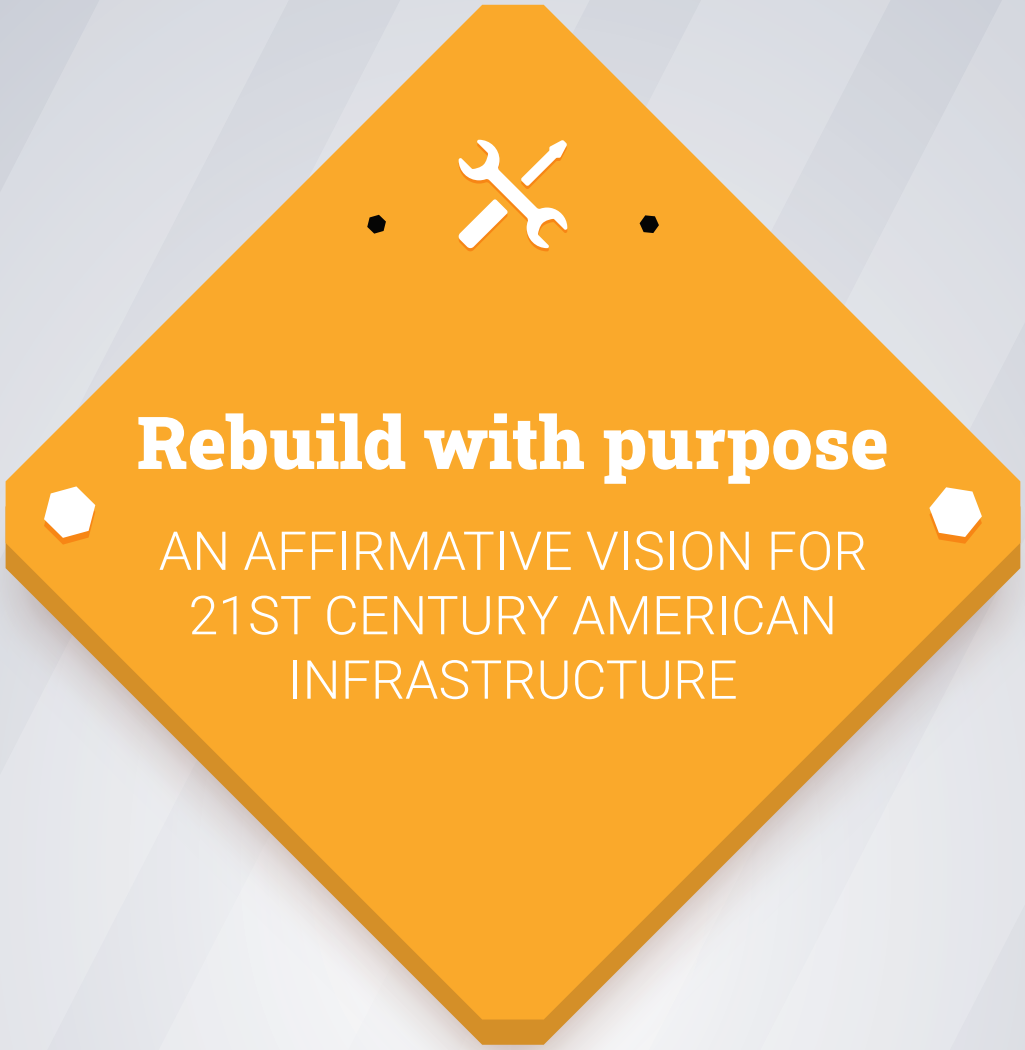

Rebuild with purpose

AN AFFIRMATIVE VISION FOR 21ST CENTURY AMERICAN INFRASTRUCTURE

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B | Metropolitan Policy Program at BROOKINGS

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Executive summary

Policymakers, practitioners, and the general public increasingly agree that our infrastructure systems are under pressure. Extreme weather impacts such as storm surges and chronic issues such as coastal flooding continue to wreak havoc on our cities and towns. A lack of world-leading digital infrastructure has made it harder for manufacturers, farms, and other businesses to compete in the global information economy. Outdated pipes and streets impact the health and safety of too many people.

Yet these mounting challenges also build the case for a forceful response. Simply repairing our outmoded infrastructure systems with the same traditional policies, technologies, and designs is not enough. Americans are ready for a grand reimagining of and reinvestment in our infrastructure to revitalize the transportation, water, energy, and broadband systems that power our economy.

This moment is not a historical anomaly. Every few decades, Americans have called for a new infrastructure vision to meet new generational needs—often in moments of crisis or structural transition. And for more than two centuries, the federal government has responded by forging partnerships with states, local governments, and private industry to rebuild the country's infrastructure in an attempt to better serve more people and places.

Today, we are living with the legacies of the last great federal infrastructure vision and the challenges federal leaders sought to address in the mid-20th century: the deep-water ports and airports connecting people and delivering goods worldwide; the highways swooping through our communities; the water pipes and power lines reaching most homes; and the cleaner rivers and air passing through our neighborhoods.

But we are also living with that vision's flaws. Disproportionate spending on highways stretched distances between people and businesses, divided neighborhoods, harmed our environment, and made transportation a burdensome expense. Constructing in flood plains and sensitive coastal areas exposed us to higher risks and costs from daily events or superstorms such as Hurricanes Katrina, Sandy, and Harvey. Limited direct investment in water utilities contributed to public health crises such as the one in Flint, Mich. A hands-off approach to broadband left students and workers digitally disconnected when the COVID-19 pandemic took hold.

Without high-performing infrastructure, our economy will fail. There is a strategic interrelationship between public investment in infrastructure and a dynamic, equitable market.

Our current moment provides an opportunity for action. Many past reports—in academia, government, business, and elsewhere—have designed solutions strictly around transportation, water, energy, and telecommunications needs, often in isolated siloes. That is not this report. Ideally, infrastructure's role is to deliver shared, sustainable prosperity across all types of projects, across all types of places, and for all types of people—and that requires a fundamental reimagining of how we talk about and frame our infrastructure needs.

Crafting a more integrated, coordinated vision must address two emerging and durable forces that impact all of our infrastructure systems:

- **The planet's worsening climate crisis requires a resilient built environment to protect communities and enable them to thrive.** Adapting to acute and chronic climate shocks, mitigating environmental impacts, and conserving natural resources demand significant changes. Fossil fuels are the source of 60% of the country's electricity and represent an even larger share of the country's transportation services. The U.S. may lose access to one-third of its freshwater supply in the next 50 years due to poor infrastructure quality, unchecked land development, and agricultural pollutants.
- **The digital economy is transforming how people and businesses connect, demanding new skills to succeed and upending data security.** Connectivity gaps, limited digital skills, and lack of affordable options have left at least 16 million households without a broadband subscription of any kind. Precision agriculture and small-town manufacturers frequently can't access broadband connectivity, including the 72% of farms without high-speed wireline. Meanwhile, rising cybersecurity attacks introduce a new kind of uncertainty for essential infrastructure operations.

Evolving challenges around climate and technology are not only impacting how our infrastructure systems perform, but also calling into question our capacity to manage and respond to these impacts. Providing safe, reliable, affordable, and accessible infrastructure requires leaders to harness two other forces of change:

- **Infrastructure industries need a range of skilled workers to design, build, and operate the country's critical networks.** Decades of rising income inequality, continued automation, and loss of unionized jobs have put American workers at a disadvantage—especially women, people of color, and those without advanced degrees. Infrastructure occupations can offer better pay and opportunity, but recruitment issues, inflexible training, and insufficient retention have dried up our talent pipeline. More than 25% of the current infrastructure workforce will need to be replaced over the next decade (and more than 10% in some occupations will need to be replaced each year) due to retirements and other employment shifts.
- **The country cannot modernize infrastructure systems if state and local governments do not have the fiscal resources they need.** Even though state and local governments cover 77% of public spending on transportation and water resources, they struggle to operate modern asset management systems and faced 25% inflation in construction costs over the past decade. Meanwhile, regional fragmentation often leads to diseconomies of scale, while state politics can lead to excessive construction in slow-growth places.

These generational challenges also create generational opportunities. Transitioning to renewable energy sources, limiting development in vulnerable locations, and adopting more resilient building standards can help us avoid the worst environmental impacts while still adapting to an evolving climate. Expanding broadband connectivity, skills programming, and sensor deployments can deliver economic efficiency and equity in the digital age. Creating new sector partnerships, expanding work-based learning programs, and leading more visible outreach for disadvantaged and underrepresented workers can ensure infrastructure industries serve as a growing source of economic prosperity. States and localities with more stable fiscal footing can boost net infrastructure investment and experiment with new data, designs, and projects.

These opportunities should serve as the foundation for a new affirmative federal vision. Instead of stubbornly attempting to spend more within traditional programs and expecting different results, congressional leaders and their executive branch partners should design policy to solve 21st century challenges and break free from decades of path dependencies.

To solve today's challenges and capture future opportunities, we recommend Congress and federal agencies use a three-part framework to guide their strategic direction:

- **The federal government should update how agencies measure infrastructure needs and connect that information to shared goals.** We need to better track the condition, performance, and use of different infrastructure assets. That means expanding how we manage assets (both natural and humanmade) and better assessing environmental impacts on communities. It also means better understanding infrastructure costs and barriers facing workers, private households, and small businesses. A new Federal Data Reserve can manage standards for data privacy, cybersecurity, data sharing, and even data storage.
- **Based on outputs from retooled measurement systems, the federal government should modernize physical assets and better serve user needs.** New design standards can improve digital capability and resiliency. Direct spending can upgrade physical networks across transportation, water, energy, and telecommunications systems. New equity-focused programming—including affordability programs—can help all households and businesses access those systems. And new fiscal instruments can help states and localities more flexibly and proactively execute new types of plans and projects.
- **The federal government should commit more resources to experiment with physical technologies, fiscal practices, training systems, and applied management practices.** The federal government can promote testing of new technologies, from the trillion-dollar autonomous vehicle industry to small-scale materials pilots. New data approaches such as an encrypted universal identification card for individuals and an artificial intelligence ethics laboratory can remake how we move through the world. Commitment to digital skills development can empower American workers for decades to come.

Remaking capital-intensive systems like infrastructure takes a generation. But that is not an excuse to ignore legislative opportunities—like the palpable urgency in 2021—to test what's possible and evaluate progress along the way. We need to use this moment to initiate short-term actions in support of longer-term structural changes. America has the trillions of dollars necessary to adopt a new vision, but we cannot afford to waste money or time on the wrong projects, policies, and actions.

Investing in infrastructure is always an optimistic choice. It reflects a collective belief that we, the people, can pool our resources together to grow our businesses, improve our quality of life, and protect our environment for the generations to follow. The United States was built for optimistic choices. It's time to rebuild.

Figure 1. Theory of change: how to rebuild with purpose

Challenges			
Climate Resilience	**Digitalization**	**Workforce**	**Fiscal Health**
Acute, costly disasters	Unequal access to emerging technologies	Changing nature of work	Aging assets, high project costs and capacity constraints
Chronic flooding, heat, and air pollution	Data privacy and cybersecurity concerns	Lack of diverse pathways	Regional fragmentation and state politics, emerging trends and volatility of demand
Recommendations			
	Measure	**Modernize**	**Experiment**
	Asset inventories	Physical standards	Technology testing
	Environmental impact analysis	Physical network upgrades	Data systems
	Benchmarking prosperity	Equitable access	Future of work
	Federal Data Reserve	Fiscal capacity building	State and local fiscal laboratories
Opportunities & Outcomes			
Climate Resilience	**Digitalization**	**Workforce**	**Fiscal Health**
Mitigating and adapting to a more uncertain climate	Supporting greater efficiency and equity through digital technologies	Creating visible and flexible infrastructure career pathways	Maintaining and upgrading infrastructure in more fiscally sustainable ways

Source: Brookings Institution

Introduction

Context: Fundamental changes facing infrastructure and American competitiveness

Infrastructure has always supported America's economic competitiveness. Canals, railroads, and telegraph lines opened the country's hinterland to global trade partners, brought money back to our shores, and attracted immigrants to chase their own opportunities. The engineering around paved roads, mass transit, telephone lines, managed water, and electricity systems allowed our cities and towns to flourish as new types of housing, factories, and offices grew around these physical systems. From rural farms to busy urban neighborhoods, infrastructure is our economic foundation.

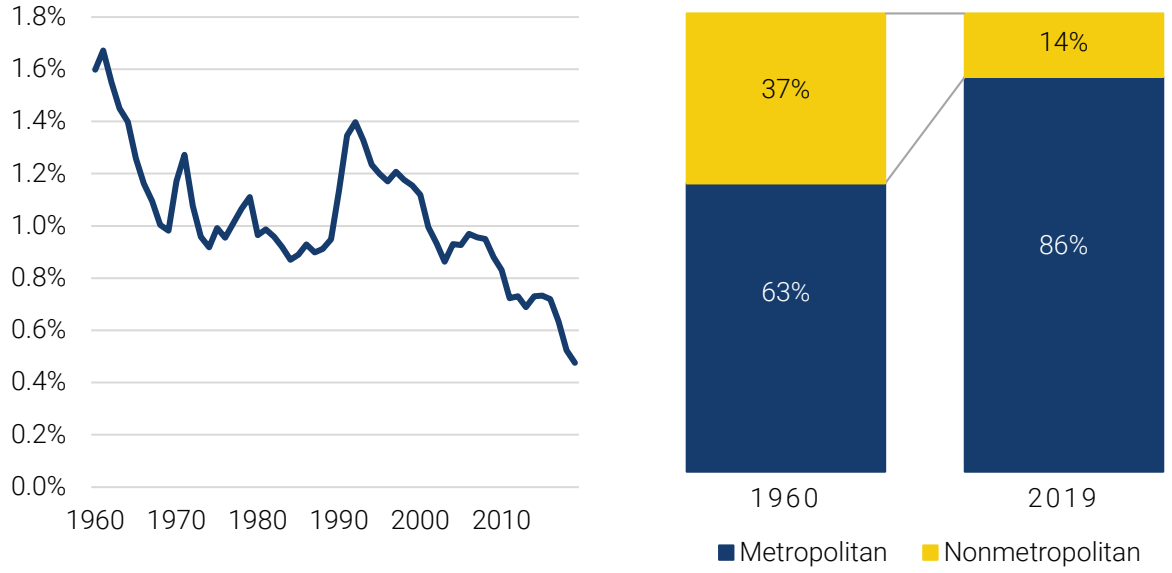
Yet infrastructure design and construction do not move at the same pace all the time. Across each generation, public and private leaders make decisions about how infrastructure can best connect households to opportunity, grow our industries, or work with our natural environment—and they do so through the lens of their current reality and the country they imagine.

The country's last great vision was designed, adopted, and executed over the middle of the 20th century. The national population was growing fast, income inequality was falling, analog technology was still ascendant, and the environment was more predictable. The federal government—working with state, local, and private sector partners—adopted a series of landmark bills to build around these fundamental concepts.

Decades later, the country has changed—and it's leaving our infrastructure outmoded.

For one, population composition is different. U.S. population growth has slowed for two straight decades, and the 2010-to-2020 decade could be

Figure 2. US population growth rate and metropolitan population share, 1960-2019



Source: Brookings analysis of U.S. Census Bureau data

the lowest growth in any decade since 1790. Yet where population growth is occurring, it's likely in metropolitan areas. These clusters of cities and suburbs housed 286 million people in 2019 (a 23% increase since 1990), while the rural population share has been steadily falling for decades. We need infrastructure systems that better serve a more metropolitan population experiencing different growth patterns.

Our economic conditions are also different. The changing American populace now confronts an urgent crisis around income and wealth inequality. Median wage growth has effectively stalled since 2000 even as average incomes rose, reflecting the shrinking of the American middle class. In turn, the top 10% to 20% of households now control more wealth than during the Gilded Age over a century ago. We need infrastructure systems that are affordable for all and help connect all people to opportunity.

As our population and economy transformed, so did our technological capacity. Our heavy investment in higher education, commitment to research and development funding, and access to venture capital continues to make the U.S. a global hub in knowledge-intensive industries, which attracts some of the brightest minds and significant foreign direct investment. We need infrastructure systems that promote both the acquisition of digital skills and ongoing industrial innovation.

Finally, improving environmental science exposed just how unsustainable our development practices are, from where we build our homes to the fuel we use for our vehicles. The rise of more frequent and destructive storms, droughts, wildfires, and other acute shocks has amounted to over $1.8 trillion in economic costs since 1980.1 Chronic, day-to-day challenges are also mounting, from stormwater overflows to urban heat island effects. We need infrastructure systems that protect all people while stewarding the natural environment for generations to come.

As the country fast approaches its 250th anniversary, the United States has a fresh opportunity to renew its commitment to cutting-edge transportation, water, energy, and telecommunications systems to boost national competitiveness. We can build a vision that matches our times—but it will require reforms.

In some instances, that means strategically reinforcing many of the same shared goals that infrastructure systems have pursued for decades. It's still important that transportation networks promote domestic and global trade, connect people to jobs, and keep people safe in the process. We still must keep our rivers and streams clean. Delivering reliable electricity is still the lifeblood of a modern economy.

But a new vision also requires an honest interrogation of what past priorities do not respond to the challenges of today. Now that metropolitan areas and rural areas are connected, the data is clear that highway investments no longer deliver industrial growth—but they do induce unending congestion and unsustainable pollution. American public policy did not prioritize maintenance of municipal water systems, especially in slow-growth communities, and the tragedies in Flint and Toledo, Ohio demonstrate this failure of omission. The same can be said for telecommunications, as the COVID-19 pandemic illuminated the deep societal effects of the digital divide. Electrical grid fragility in California and Texas only increased the devastation from more extreme climate events.

What the country needs, then, is a renewed sense of purpose around a forward-looking set of national policy priorities. Infrastructure can boost long-term competitiveness, but it will require designing, building, and maintaining systems for this century's demands. **The purpose of this report is to recommend shared priorities for a forward-looking national vision, justify them with rigorous research, and use those priorities to craft high-level strategies to inform policy change.**

Infrastructure will always be a fundamental part of how the country operates. But today's transportation, water, telecommunications, and energy systems will not magically lead us to shared prosperity, thriving industries, or a safer natural environment. Achieving these outcomes requires a national willingness to evaluate where current physical systems fall short and build consensus around how the country should look and operate in the future. In a time of great demographic, technological, and environmental change, it's time for a new infrastructure vision.

How this report works

This report outlines how infrastructure can continue to build long-term American competitiveness. It is not tied to current political cycles, legislative calendars, or which elected officials fill the country's legislative chambers and executive mansions. It is intended to be a more durable document. Federal policymakers, administration officials, and the broad range of federal advocates and practitioners should view the research framing and findings as a long-term resource.

One of the challenges of a sweeping report like this is simply defining infrastructure. Even within the federal government, entities such as the Bureau of Economic Analysis and the Congressional Budget Office use competing definitions of the sector. For the purposes of this report, we define infrastructure as transportation, water resources, energy, and digital telecommunications systems. This specifically excludes social capital assets such as hospitals, schools, and public housing. Our definition focuses on four physical systems that help things move—whether that's people, goods, or data.

The middle section of this report is oriented around **four cross-cutting forces: climate resilience, digitalization, workforce, and fiscal health**. We define these forces as economy-shaping patterns, each of which interrelate to one another and will directly impact infrastructure networks and operational systems for decades to come. Each section introduces the broader context around the cross-cutting force, the challenges it presents to today's infrastructure systems, and how a future-looking vision could transform each force into a source of opportunity.

The geography of our analysis is national—how we contextualize the forces themselves, the challenges they pose, and the opportunities they present. However, we recognize that each force does not impact the population, industries, and infrastructure in every geographic region equally. The four middle sections reference such local variety throughout and select distinct examples whenever possible.

The final section of the report introduces a series of categorical recommendations. Since the cross-cutting forces are interrelated, we do not organize the recommendations under each force. Instead, we bundle distinct recommendations under common themes: measure, modernize, and experiment. The intention is to show policymakers and their colleagues how specific recommendations can respond to multiple cross-cutting forces at once. While the recommendations are primarily intended for a federal audience, many will easily apply to state and local policy environments too.

To develop this report, we interviewed over 40 industry leaders, researchers, and policymakers to understand where they felt current infrastructure networks restrict American competitiveness—and what technological innovations and policy reforms could establish a more prosperous path forward.

Definitions box

KEY TERMS

Shared values and goals refer to fundamental, underlying objectives that guide our infrastructure policies, plans, and investments. These represent enduring principles that improve our economic, social, and environmental outcomes.

Cross-cutting forces refer to economy-shaping patterns, each of which interrelates to one another and will directly impact infrastructure networks and operational systems for decades to come. They include environmental resilience, digitalization, workforce development, and fiscal health.

Challenges refer to difficulties in design, construction, and operation related to the cross-cutting forces described above. These are the larger structural problems currently facing federal, state, local, and private leaders in addressing our infrastructure needs.

Opportunities refer to policies, collaborations, and other tools to address our current and emerging challenges. These represent potential pathways to improve our infrastructure systems for decades to come.

INFRASTRUCTURE SYSTEMS

Transportation includes roads and bridges; public transit; bicycle/pedestrian infrastructure; passenger and freight rail; airports; inland waterways; and other related facilities.

Water includes clean/drinking water, stormwater, wastewater, sewage/water treatment facilities, and "green" infrastructure critical to conserving related natural resources.

Energy includes the generation, transmission, and distribution of energy from natural gas (pipelines), facilities responsible for electricity (nuclear, hydroelectric, and solar/wind), and other utilities.

Telecommunications includes broadband and transmission infrastructure (wired, wireless, and satellite) concentrated in facilities outside radio and television broadcasting, and the software and hardware to collect and manage data.

Climate resilience

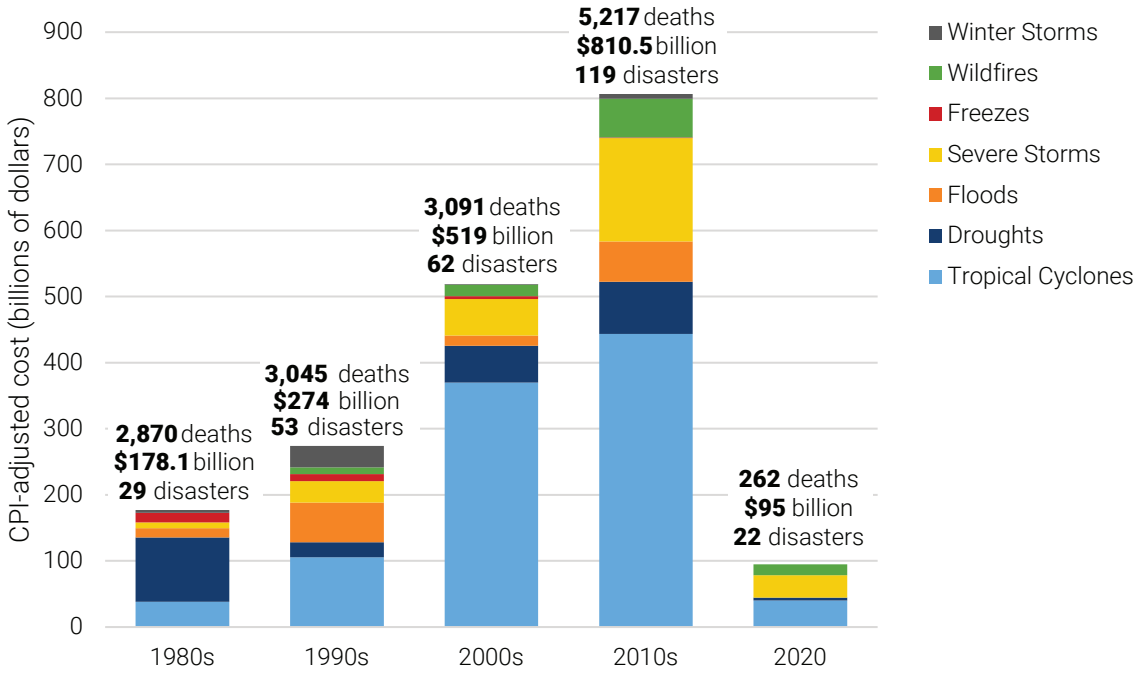
Context

An increasingly extreme climate is costing America more each passing year. Major storms and other acute climate shocks are hitting households and businesses with greater frequency and intensity, but it is our chronic climate challenges—rising emissions, floods, and other persistent environmental risks—that pose perhaps the most destructive threat to our future. Mitigating and adapting to these pressures will require more resilient infrastructure systems.

Extreme storms and other major events are the most visible manifestation of our climate challenges. Massive storms and flood events such as Hurricane Katrina, the California forest fires, and the 2021 Texas freeze are overwhelming events—and very expensive. The U.S. has endured 285 climate disasters of at least $1 billion each since 1980, amounting to a total of over $1.8 trillion. These climate disasters are also happening more frequently: In the 1980s there were an average of 2.9 such disasters per year, with average annual costs of $17.8 billion. The 2010s saw an average of 11.9 such disasters per year, with average annual costs rising to $81.1 billion.[2]

Over the past four decades, hurricanes have been 8% more likely to reach Category 3 (major storm) classification, causing increased damage and costs.[3] Among 50 major U.S. cities, the heat

Figure 3. Rising costs of U.S. climate disasters, 1980-2020



Source: Brookings analysis of NOAA National Centers for Environmental Information (NCEI) data
Note: Climate disasters refer to droughts, floods, freezes, winter storms, severe storms, tropical cyclones, and wildfires costing at least $1 billion each

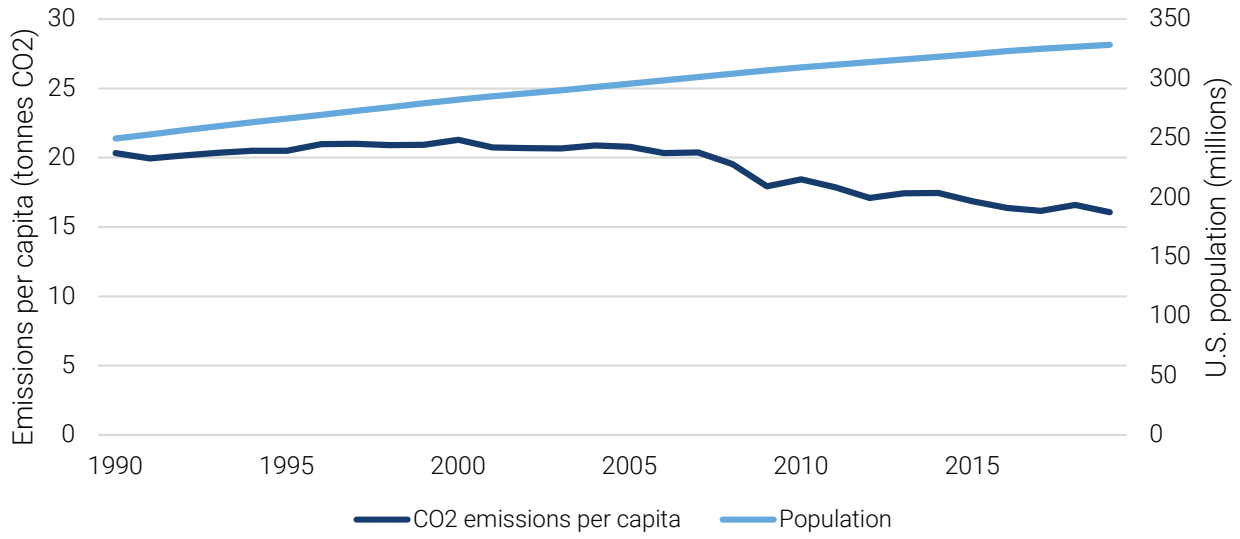
wave season is an average of 47 days longer, and includes about four more heat waves annually than in the 1960s.[4] Wildfires have made headlines in recent years as they've become increasingly intense and damaging. Annual acreage burned by wildfires has been increasing since the 1980s.[5] Between 2009 and 2018, the annual direct loss from fires increased 90.6%, to a total of $25.6 billion.[6]

These acute climate shocks are no accident; they are the result of decades (if not centuries) of a mismanaged natural and built environment—setting the stage for our current climate crisis.

Since the Industrial Revolution, Americans have developed more land, consumed more natural resources, and created more pollution—leading to more persistent and chronic climate challenges. Greenhouse gas (GHG) emissions have increased exponentially with industrialization and urbanization, while deforestation and other greenspace-limiting land uses have decreased our country's (and planet's) resilience.[7] Although emissions have fluctuated year to year, the population continues to grow and per capita emissions continue to remain elevated at more than 15 tons per person each year. The result is a changing climate with increasingly extreme weather patterns, resource scarcity, and more frequent and catastrophic disasters.

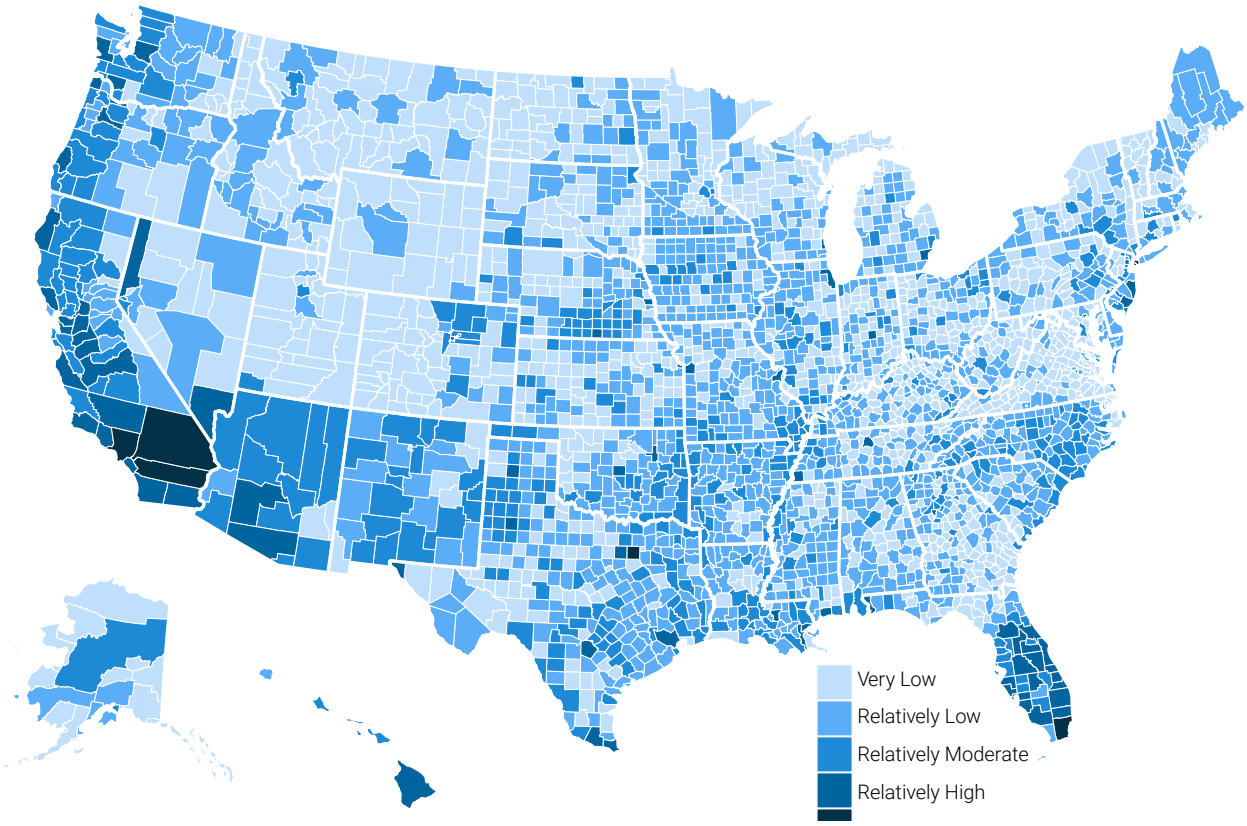
While our chronic climate challenges are widespread and varied, more frequent flooding has emerged as one of the most significant threats. By 2050, the number of high-tide flooding days that occur nationally each year will increase up to 15 fold—or around 75 days.[8] While high-tide flooding will hit coastal communities hardest, increased precipitation also causes more inland flooding and has accounted for more than one-third of U.S. flood damage over the last few decades.[9] And while sea levels have risen up to 9 inches since 1880, 3.4 inches of that change occurred between 1993 and 2019.[10] Together, rising sea levels, intensifying precipitation and storms, and changes in land use,

Figure 4. CO2 emissions per capita and U.S. population, 1990 to 2018



Source: Brookings analysis of World Bank and Global Carbon Project data

Figure 5. Natural risks at the county level, 2020



Source: FEMA National Risk Index, 2020
Note: The FEMA National Risk Index measures expected annual loss (likelihood and consequence) against social vulnerabilities (consequence enhancing) and community resilience (consequence reduction).

land cover, and water management all contribute to increasingly frequent and damaging floods.

Poor planning and development decisions have resulted in a variety of other chronic climate challenges for different communities. For instance, a lack of greenspace compounds the risk of intense heat for neighborhoods historically impacted by redlining—creating deadly risks for residents and raising serious environmental justice concerns.[11] While landmark environmental legislation such as the Clean Air Act and Clean Water Act led to improvements in air[12] and water[13] quality, these improvements have not reached all communities equitably. The counties receiving failing grades for all three major air quality measures (ozone, short-term, and year-round particulate pollution) are home to over 14 million people of color and 3 million people experiencing poverty.[14] While our natural risks are especially severe in communities hard-hit by droughts and floods—including those in California and Florida, respectively—these risks are widespread across the country.

These chronic climate challenges and inequities—rooted in legacy infrastructure planning and development decisions across all types of systems—need to be the focus of future federal efforts to support a more climate resilient future for all Americans.[15] Communities across the country face unequal natural hazards, unequal levels of social risk and vulnerability, and unequal economic impacts—all of which limit their ability to survive and thrive in an increasingly unpredictable and destructive environment. The following section explores these challenges in greater depth and identifies opportunities to better mitigate and adapt to our climate needs.

Challenges

Electricity

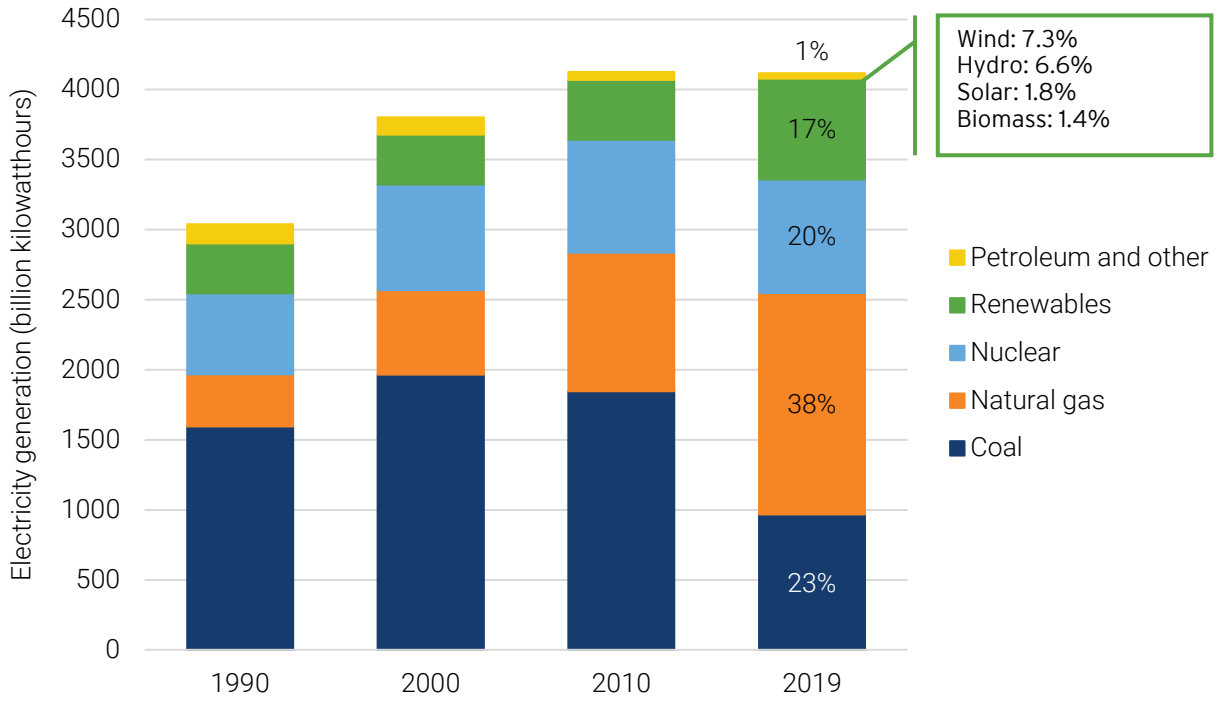
Many of our chronic climate challenges are a consequence of emissions, particularly from the production and consumption of energy. Our energy industry—and the infrastructure it depends on—is expansive, ranging from mining facilities to power plants to transmission and distribution systems. In addition to emissions, our energy infrastructure perpetuates inequitable and unsustainable use of natural resources. Our continued reliance on fossil fuels and our need for more widespread renewable energy production such as solar and wind remain outstanding challenges across the U.S.

One of the core functions of this complex energy infrastructure system is to deliver electricity. The specific portion of this system that is responsible for the delivery of electricity is known as the "grid." And the electricity sector is directly responsible for 27% of the country's GHG emissions.[16] Beyond the source of energy used, efficiency challenges in energy production continue to be a contributing factor to aggregate electric-related emissions. In total, 65% of the energy inputs to the electric power sector are forgone due to conversion loss at electric power plants.[17] These losses are compounded with an estimated 5% of transmitted and distributed energy that is simply lost along the way.[18]

In terms of the actual sources used, fossil fuels remain dominant. Coal and natural gas, for instance, account for 61% of national electricity production—on par with global averages.[19] The relative convenience and low cost of these fuels makes them hard to quit, in addition to political barriers for considering alternatives. Still, aggregate emissions have been falling in recent years. One major reason is the adoption of renewable energy sources—including wind, solar, hydroelectric, biomass, and geothermal—which now account for 17% of electricity generation.[20]

Scaling up adoption of renewable energy sources will require embracing several of the operational advantages that fossil fuels currently offer. Fossil fuels are compact, dense forms of energy that allow for easy, cost-effective storage and transportation.[21] Creating more distributed electricity systems—

Figure 6. Total electricity generation by energy source, 1990-2019



Source: U.S. Energy Information Administration data

which rely on a more diverse set of generation activities that are closer to the end user, as well as more efficient and agile energy use and storage—could address one of the inefficiencies in renewables.[22] However, renewable energy generation and management still struggle with variability and gaps in the timing of supply and demand, leading to intermittency concerns.[23]

Large- and small-scale battery storage can address this limitation by acting as an "energy holding tank" to be used when the sun is not shining or the wind is not blowing. Significant progress is already being made toward addressing this challenge: Between 2015 and 2018, the cost of utility-scale battery storage in the U.S. dropped by nearly 70%, and annual capacity additions are growing.[24] U.S. battery power and energy capacity increased nearly 15 fold and 59 fold, respectively, between 2010 and 2018.[25] Renewables (most notably solar and wind) have the potential to match these qualities through more innovative technologies and policies, including the development of hybrid systems. But the country still has a long way to go to scale these renewable approaches.

Transportation and urban land

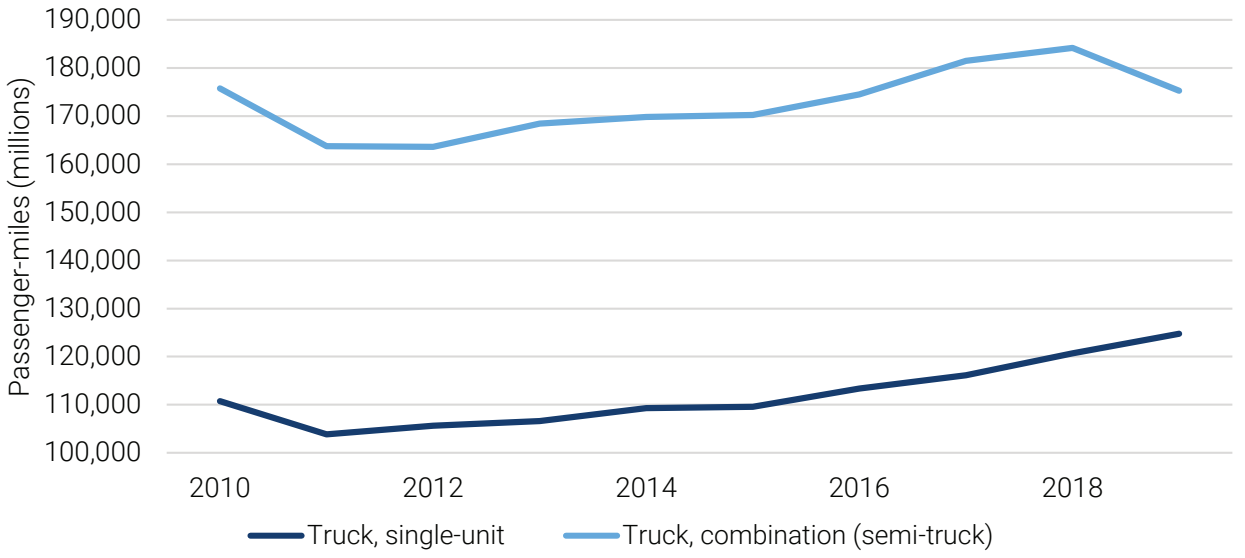
Transportation and real estate development work hand in hand to connect people, move goods, and build our communities. But while past investments in transportation and buildings have unlocked a range of industrial growth and household prosperity, their very design and operation have often come at the expense of environmental health and human-centric environmental justice. The country's overreliance on fossil-fuel-powered vehicles and sprawling land development patterns have generated pollution, drained natural resources, and exposed communities to environmental threats. Transportation is now the largest single GHG-emitting sector, accounting for 28% of national emissions.[26] Commercial and residential buildings are now responsible for 12% and 16% of national energy consumption, respectively.[27]

Driving is often a necessity to reach increasingly distant workplaces, stores, and other services. This not only perpetuates our economic costs, but also our environmental costs.[28] The public continues to use gas-powered automobiles for the vast majority of trips, including the 46% of household vehicle trips that are 3 miles or less in total distance.[29] Long-distance trip rates are growing faster than population too; in 2018, passenger cars and light-duty trucks travelled 46% more miles than in 1990.[30] It's little wonder that light-duty vehicles—which include the cars most of us drive every day—are responsible for 58% of carbon dioxide emissions in the transportation sector.[31] Although electric vehicle technologies and more sustainable fuels can offset some of these mounting threats, driving continues to imperil our environment.

It's not just household transportation that matters; our freight activity is also contributing to emissions challenges. For example, vehicle miles traveled by medium- and heavy-duty trucks increased 113% from 1990 to 2018—a growth rate three times faster than overall population growth.[32] Projected reductions in light-duty vehicle energy use are nearly all offset by projected increases in medium- and heavy-duty truck energy use.[33] Steps to reduce these emissions hold promise—including the use of co-combustion diesel/hydrogen technologies—but these challenges are still significant.[34]

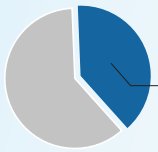
Our continued use of fossil-fuel-powered vehicles accompanies our inequitable and inefficient patterns of land use, with our environmental and associated public health dangers only increasing. We fail to accurately price or internalize the negative externalities of this activity, which leads to significant and uneven costs. Spending significant time around traffic pollution has negative health impacts,[35] and traffic collisions remain a safety challenge.[36] Highways carry a legacy of intentional fragmentation and destruction of communities of color, yet driving is often the only option for many Americans to access their basic needs.[37] The development of low-density communities further increases driving demand and congestion, which in turn incents places to invest in more highways and parking lots and again pushes houses and businesses further apart. Atlanta is a prime example of this pattern: Between 1990 and 2010, its core urban area grew 133% (from 1,137 to 2,645 square miles), ranking the region among the least pedestrian-friendly in the country and most congested in the world.[38]

Figure 7. Passenger-miles travelled by trucks, 2010-2019



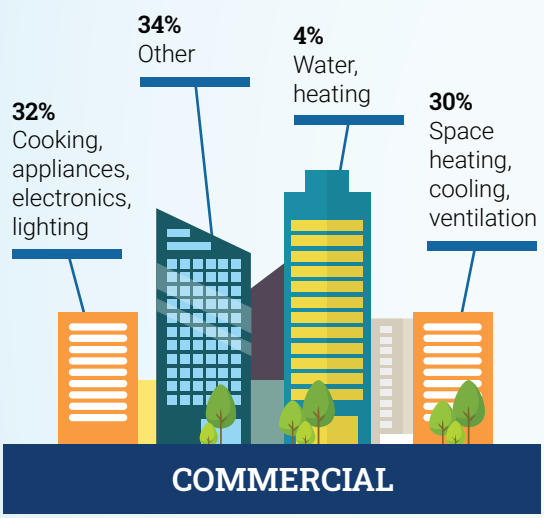
Source: Brookings analysis of Bureau of Transportation Statistics data

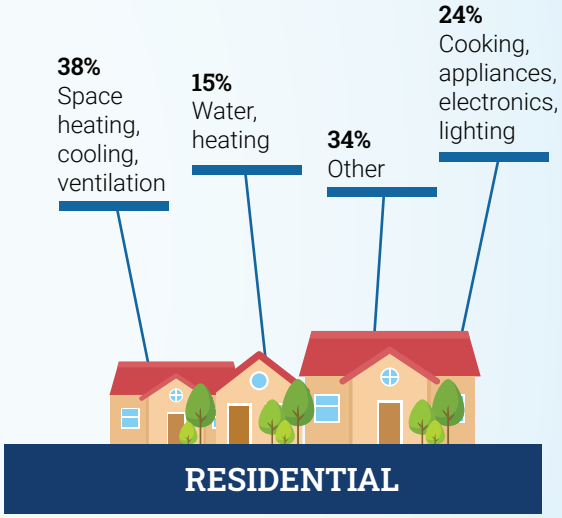
Figure 8. Building emissions



Building emissions are 39% of global emissions

Operational emissions: 28%





Embodied emissions: 11%

Including GHG emissions associated with building materials and construction

CONSTRUCTION

Source: UN Environment, International Energy Agency, and U.S. Energy Information Administration data

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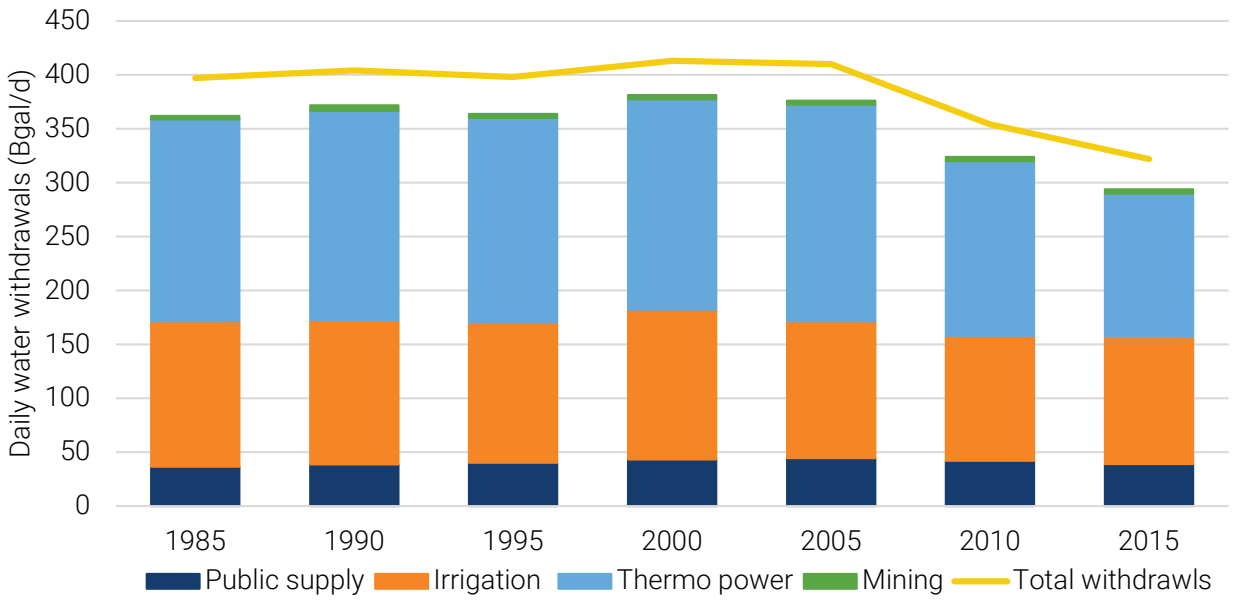
Regardless of location, buildings and roads themselves consume large amounts of energy, generate pollution, and use emissions-intensive materials in their construction and operation. While buildings vary in their design, management, and oversight—going beyond our core infrastructure sectors defined above—they are still an integral part of our larger built environment and drive many of our climate concerns. Increasingly, buildings are even becoming real energy resources through flexible management of energy, storage (thermal and battery), and onsite generation.[39] During their use phase, buildings produce *direct* emissions (those from onsite fossil fuel combustion and leaked from refrigeration and air conditioning) and *indirect* emissions (those from the offsite generation of electricity required to power the building).[40] Yet buildings also are responsible for emissions upfront and at the end of their lifecycle, including the *embodied* emissions that come with materials used and wasted during construction and deconstruction.[41] To lower these emissions, entire supply chains will have to decarbonize, and the processes by which industries manufacture and transport materials will also need to transform—a process that will take many years. The cement industry, for instance, generates about 25% of all industrial carbon dioxide emissions, and the technology to decarbonize the industry is still in its infancy.[42]

Water

Our water infrastructure—including drinking water, wastewater, and stormwater systems—contributes to many of our chronic climate challenges. Water scarcity, especially in the West, demonstrates our enormous resource constraints, while water quality and polluted runoff remain concerns in many regions with outdated treatment plants, inefficient pipes, and other aging facilities.

Models suggest the U.S. may lose access to one-third of its freshwater supply in the next 50 years, with nearly half of the country's freshwater basins unable to meet demand by 2071.[43] Although total water use has declined in recent years due to improved technologies and other conservation strategies, the U.S. still used 322 billion gallons per day in 2015, with thermoelectric power plants using 41%, irrigation 37%, and public supply 12%.[44] Per capita water use—at about 82 gallons per day per person nationally—is expected to continue its current downward trend, yet these decreases will

Figure 9. Total daily water withdrawals, by sector, 1985 to 2015



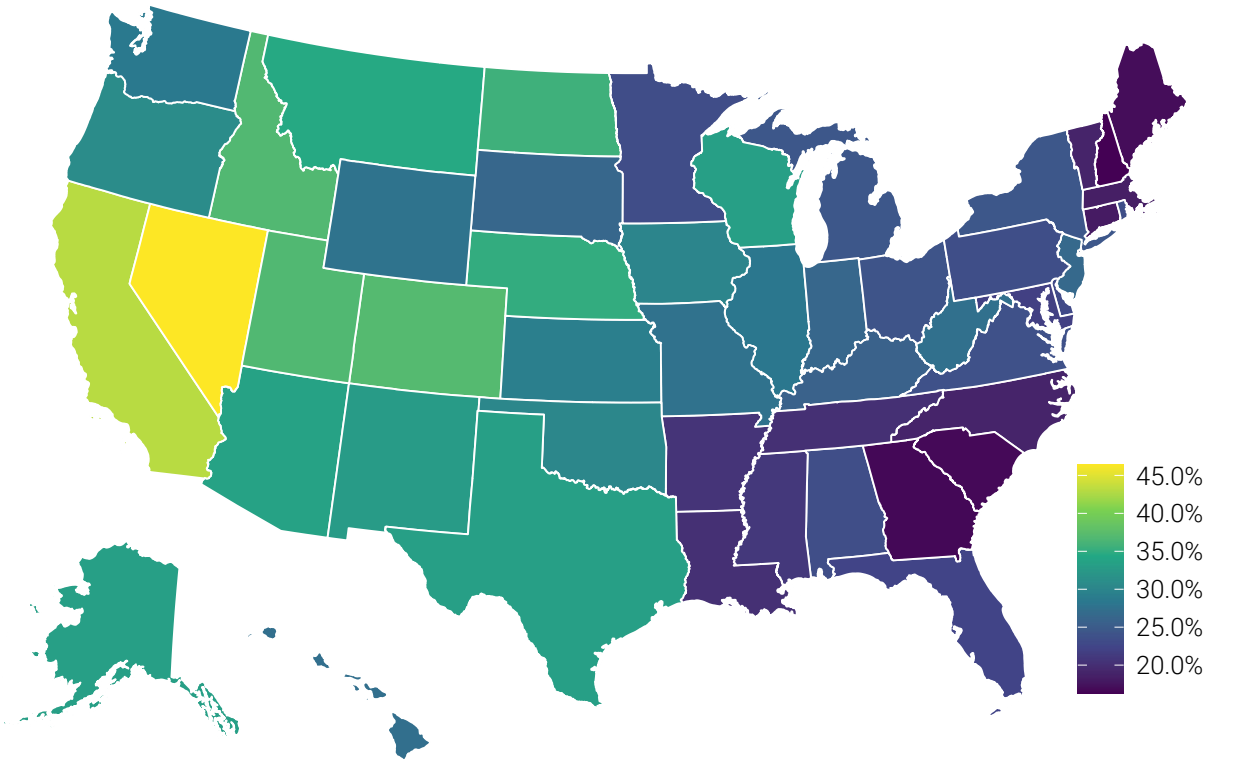
Source: Brookings analysis of U.S. Geological Survey data

be outpaced by population growth and increasing demand for electricity.[45] Additionally, leaking pipes lose up to 18% (2.1 trillion gallons) of treated water each year.[46] This is no surprise, as our nation's water pipes are 45 years old on average.[47] Regions face increasingly unpredictable and changing water needs—in watersheds that often cross multiple political jurisdictions and infrastructure service boundaries—that require more coordinated water management strategies.[48]

Each year, nearly 8% of community water systems (utilities) have at least one health-based drinking water quality violation, and these violations tend to repeat and cluster in hotspots.[49] One of the most persistent drinking water safety threats is lead; the U.S. still has approximately 10 million lead service lines, which corrode and leach lead into water as they age.[50] The lead water crisis in Flint made national headlines, and communities across the country continue to face these challenges today. Communities of color and low-income communities are more likely to face drinking water quality violations.[51]

Beyond shifting water use concerns, the quality of our water resources—including the environmental health of our rivers, lakes, and larger watersheds—is also increasingly under threat. Agriculture, which accounts for 37% of national water use, is the primary pollution source for the country's streams and rivers, the secondary pollution source for wetlands, and the third most significant pollution source for lakes.[52] Agricultural runoff carries fertilizer, pesticides, and animal waste into the water system, with a host of ecological and health consequences.[53] Meanwhile, groundwater use—including the excessive and sustained pumping of water underground—has led to land subsidence, water contamination, and other challenges.[54]

Figure 10. Impervious surface cover share of urban land area in the United States, by state



Source: U.S. Forest Service data organized by Nowak and Greenfield (2018)
Note: Based on estimated 2014 shares

Stormwater runoff also poses a growing challenge in our nation's urban areas, where nearly 27% of surfaces are impervious, and further development (especially along the urban fringe) continues to add more impervious surfaces despite more frequent, extreme precipitation.[55] Unable to naturally absorb into the ground as a result, stormwater runoff carries a variety of chemical pollutants and debris and can contribute to flash flooding or overwhelm wastewater treatment systems.[56] Approximately 860 municipalities across the country still manage excess rainwater runoff, domestic sewage, and industrial wastewater through combined sewer systems, which discharge untreated wastewater (or overflows) directly into nearby bodies of water when overwhelmed.[57] And despite the significant environmental, health, and safety risks, population growth and development continue to flourish in flood-prone regions.[58] Distributed green infrastructure systems—including rain gardens and permeable pavement—hold promise in addressing these issues, but they lack widespread implementation and investment in many regions.[59]

Opportunities

Despite numerous climate challenges across our energy, transportation, land use, and water systems, there are opportunities for reform and action in the coming decades. As an evolving area of concern across multiple infrastructure systems and geographies, our climate challenges demand more integrated thinking, planning, and actions that break down existing policy and programmatic siloes. To do so, our future federal plans not only need to address climate mitigation to avoid the worst climate impacts, but also climate adaptation to improve our ability to respond to evolving climate impacts.

Mitigation

Mitigating climate change would help limit GHG emissions while providing the opportunity to redesign communities and economies with resource efficiency, equity, and access at the forefront. The first step toward mitigation is a clean energy transition. There are significant opportunities to produce, distribute, and consume electricity that relies more on renewable energy sources such as solar and wind. Renewable energy production is already rising[60] and is, in many cases, more cost-effective,[61] which will help accelerate decarbonization efforts. Based on rooftop suitability and generation potential measurements for photovoltaic energy production, U.S. buildings alone could provide an estimated 39% of national electricity sales annually.[62] When coupled with other innovative technologies and policies such as distributed, onsite energy generation and storage and grid-interactive efficient energy management, our buildings can not only reduce their own energy consumption and emissions, but also eliminate stress from the grid. Highly efficient buildings, including those with their own onsite generation capabilities, can also perform better when outages occur, whether due to storms, freezes, or other climate events. Ultimately, the opportunity for resilience in the electricity and broader energy industry depend on the country's technical and political capacity to address issues of demand response and encourage performance-based regulation.[63]

Transportation has a significant opportunity to reduce GHG emissions by transitioning to electric vehicles or away from driving altogether. Private, single-occupancy vehicles will likely remain our primary transportation mode in the near future, and simply increasing fuel efficiency in existing gas-powered vehicles will not end our dependence on them; electrifying vehicles is an essential step toward emissions reduction and reducing dependency on fossil fuels. Publicly owned fleets and bus systems present another clear pathway for scaling electric vehicles.[64] And while electrifying heavier-duty transport and freight trucking poses more of a challenge, it also comes with potential for future cost savings as the country relies more on e-commerce and frequent deliveries.[65] However, electrified vehicle fleets will require sophisticated charging infrastructure,[66] which will need to be developed in tandem with transitions toward a more robust electricity grid. Active transportation—walking or biking for shorter trips—presents the most significant opportunity for reducing transportation energy consumption and related emissions. Some estimates note that half of all trips

taken in the U.S. could be completed in a short bike ride and one-quarter of all trips could be completed in a short walk.[67]

Our shifts in transportation—and the associated climate impacts—are inextricably tied to our land use patterns. The opportunity to promote denser development—including proximate housing and work locations, mixed-use structures, and human-scaled designs—can help people travel shorter distances.[68] Reducing auto-centric sprawl requires a fundamental rethinking of how we measure the performance of our transportation and land use systems together—focusing less on congestion reduction and more on the importance of physical proximity.[69] We need to internalize the negative externalities of our current built environment, improve how we price proximity, and reduce sprawl. Doing so can greater emphasize placemaking and the chance to create more economically dynamic and inclusive regions, which can also conserve green space, redevelop brownfields, and improve environmental outcomes.[70] While many of the planning and investment measures needed to make this possible exist at a state and local level—including urban growth boundaries, land value taxes, and the elimination of single-family zoning—there is a national opportunity to provide greater incentives, standards, and technical and financial capacity behind these efforts.

Improvements to our water systems can also lessen energy demands, reduce waste, and lead to several other operational efficiencies with lasting environmental benefits. Incorporating new technologies such as more efficient household appliances has already reduced our water footprint, but upgrades that lower water withdrawals for thermoelectric power and irrigation also remain important, including closed-loop cooling systems and drip irrigation.[71] Improved leak detection and other water reuse technologies can make a difference as well. For instance, biosolid digester facilities can reduce energy and recover resources at water treatment plants, while new desalination upgrades can diversify and recycle water supplies.[72] In addition, simply addressing deferred maintenance issues and other less visible but important projects (such as lead service line replacements) can support environmental equity and performance.

The path to water innovation starts with more coordinated regional and national leadership on these improvements by providing stronger financial incentives, flexible regulatory frameworks, and opportunities for experimentation.[73]

Adaptation

While mitigating the worst impacts is important, the country must also adapt to the extreme climate that is already here. That means ensuring our infrastructure systems have the physical flexibility and capacity to respond to increasing risks and costs. Doing so can lead to improved management, cost-effectiveness, and better performance of new and existing infrastructure systems.

Adapting to a more extreme climate requires new ways to measure, plan, and invest in infrastructure nationally. Rather than relying on the same types of construction projects, procurement processes, and maintenance approaches, policymakers and planners have an opportunity to reevaluate the vulnerabilities of our existing transportation, water, energy, telecommunications, and other systems.[74] That means rethinking the costs and benefits of different systems to include climate considerations and accounting for mounting risks over time, which many private sector companies are already doing.[75] Comprehensive plans, programmatic priorities, and capital budgets also need to highlight climate adaptation as a central consideration to explore in future projects, instead of an abstract engineering exercise.[76] For instance, capital planning budgets can consider all investment though a climate lens. Investments that are more proactive and flexible—including the emergence of new green bonds and public-private collaborations—can help us overcome our current investment approach, which tends to be reactive, inflexible, and costly.[77]

How we design our built environment matters as well. For example, increased floods and heat waves leave more destruction and costs in areas with extensive paved and impervious surfaces; the country can install and maintain more widespread green infrastructure to counter these environmental threats. That's especially the case in disadvantaged urban neighborhoods that have suffered the economic and environmental effects of redlining;

reversing decades of disinvestment with more proactive planning, community outreach, and forward-looking green investments can transform these communities.[78] Planting trees, building parks, and installing green rooftops not only lessen our environmental risks, but also connect communities to nature and improved public health outcomes—especially when maintaining affordability and avoiding gentrification.[79] Likewise, protecting and conserving existing green infrastructure such as wetlands and vegetated buffers can address our mounting flooding concerns. Scaling and expanding rain gardens and other distributed water projects can lead to greater resource protections and alternatives as well.[80]

Several technological upgrades can make a difference too. Smart metering technologies—combined with predictive modelling and maintenance monitoring, along with improved control and management by a utility responding to customer demands—can conserve water and energy, reduce costs, and more accurately identify future needs.[81] Similarly, grid hardening adaptations such as burying wires, properly maintaining power lines, and installing sensors can identify and isolate dangerous threats, including wildfires.[82] Cybersecurity remains crucial to protect these systems from privacy concerns and technological threats. Meanwhile, seawalls, natural buffers, and early warning monitoring systems can protect households, businesses, and other assets in coastal communities.[83]

Even the materials we use in our built environment can be adapted for better resilience to climate risks. Permeable pavement—including pervious asphalt and concrete, as well as interlocking and plastic grid pavers—not only reduces storm runoff, but filters pollutants and allows stormwater to infiltrate back into local groundwater, often at a lower cost than conventional pavement systems.[84] When it comes to transportation, reflective (or lighter-colored) paving and building materials can reduce the risks of hot and melting materials.[85]

Digitalization

Context

Digitalization—the diffusion of digital technologies in homes and businesses across the country—touches nearly every activity Americans do and how they do it.[86] From computers and smartphones to new transportation and manufacturing equipment, digital technologies have transformed the economy and everyday life, shifting how we communicate, travel, and create. Businesses have realized gains in productivity and efficiency as households have benefited from greater convenience and time savings. But digitalization has not improved outcomes for everyone, including those who lack access, affordability, or skills to take full advantage of emerging technologies. Federal policymakers need to ensure digital technologies benefit more people, businesses, and places in coming decades.

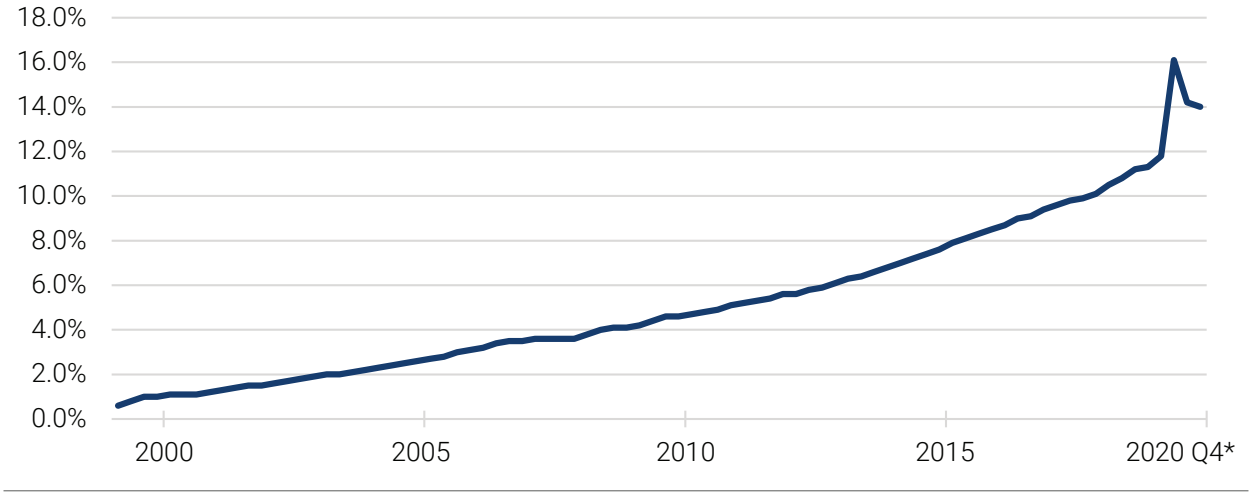
Households have been adopting digital services for decades, and COVID-19 only accelerated the broader trend. Over the past 20 years, for instance, e-commerce grew from 1% of national retail sales to more than 16%. The COVID-19 pandemic exponentially increased this trend: e-commerce doubled to 32% of all retail sales in Q2 2020, and current e-commerce sales are still above 2019 levels.[87] Essential services such as health care moved to a digital format; the first quarter of 2020 saw 50% more telehealth visits than Q1 2019.[88] The COVID-19 pandemic also pushed 44% more of all retail banking customers to engage through mobile apps, illustrating the accelerated digitalization of personal financial activities.[89] Work and school also shifted online, with over 50% of workers clocking in from home in April 2020. By fall 2020, two-thirds of those working from home reported they would like to continue to do so.[90] Even if some trends return to pre-pandemic levels, the pre-vaccination COVID-19 economy and society give us a glimpse of a more connected future.

Technology is also revolutionizing American manufacturing, logistics, and agricultural industries. Manufacturing accounts for 70% of the country's private sector R&D spending,[91] and the diffusion of disruptive technologies—from advanced robotics to 3D printing to the Internet of Things and big data—has already increased productivity for many firms.[92] Large logistics firms have automated processes and implemented data-driven changes, creating best practices that firms with smaller profit margins can now replicate.[93] Agriculture—most notably industrial row-crop farming—now regularly uses digital sensors and drones to enable precise and responsive crop management.[94] The digitalization of these sectors brings added efficiencies (both economic and environmental) and productivity—particularly for the largest firms—while fundamentally changing the nature of work for those they employ.

None of this dynamic change is possible without modern infrastructure to support it. Increasingly, the construction, operation, and maintenance of our transportation, water, and energy systems rely on a range of digital equipment—and our broadband connections are the glue that holds everything together. From ride-sharing apps to scooters and even autonomous vehicles, the future of mobility is increasingly digital.[95] Utilities are incentivizing efficiency and more quickly identifying and isolating failures in leaking pipes and at-risk power lines through the use of digital monitors and sensors.[96] Buildings—where Americans spend 87% of their time[97] and where we consume 75% of the country's electricity[98]—are converting operations, maintenance, and management functions to digital platforms to allow more efficient automated energy management and grid-interactive functionality benefiting both building occupants and the broader energy system. Even the equipment used to construct our built environment increasingly relies on digital connectivity to track their location, report issues, and enable remote control.

As digital products and services continue to revolutionize our business landscape and personal lives, federal policymakers must ensure our digital infrastructure enables every household and business to prosper. The following two sections explore the challenges and opportunities in doing so.

Figure 11. Share of total US retail sales in e-commerce, 2000-2020



Source: Brookings analysis of Monthly Retail Trade E-Commerce data
Note: 4th quarter 2020 data is preliminary

Challenges

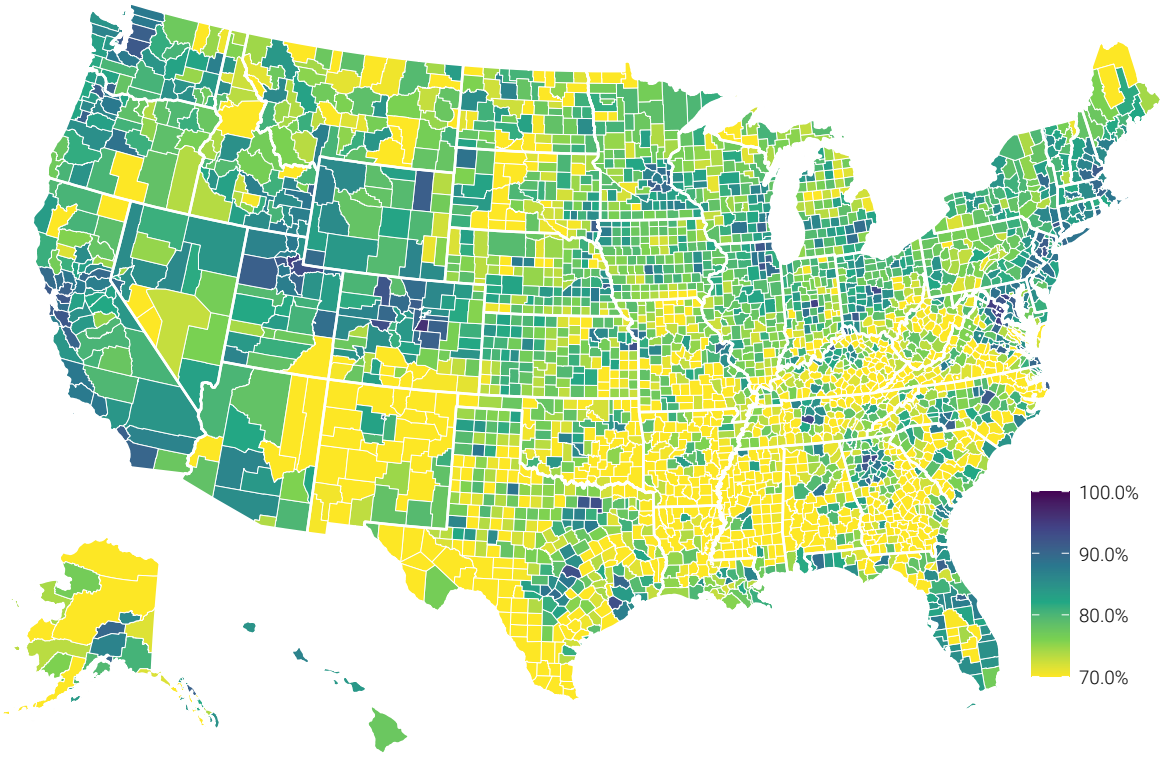
The digital divide: Broadband connectivity gaps

Broadband—defined simply as a high-speed internet connection—is the connective tissue of our digital economy and enables businesses and households to prosper every day, whether buying and selling goods, learning, or socializing.[99] Many transmission technologies deliver broadband service—including digital subscriber lines (DSL), cable, fiber, cellular, and satellite—although only certain technologies can reach the speed and latency requirements of a modern digital economy.[100] Critically, tens of millions of Americans live without wireline or wireless broadband, and its absence is felt acutely among the households, businesses, and communities left behind.

As of 2019, 14% (16.7 million) of American households lack a broadband subscription due to a combination of availability or adoption barriers (see text box). While a greater share of the total rural population lives without a broadband subscription, metropolitan areas are home to the majority (roughly 13 million) of digitally disconnected households in the U.S.[101] Broadband subscription rates also tend to be influenced by the same factors, whether looking at small towns or the biggest cities. Higher subscription rates are associated with higher incomes, lower poverty rates, higher levels of education, fewer residents of color, and fewer residents over 65.[102] Yet even in the wealthiest and most educated metropolitan areas, there are always neighborhoods with high levels of digital inequality.[103]

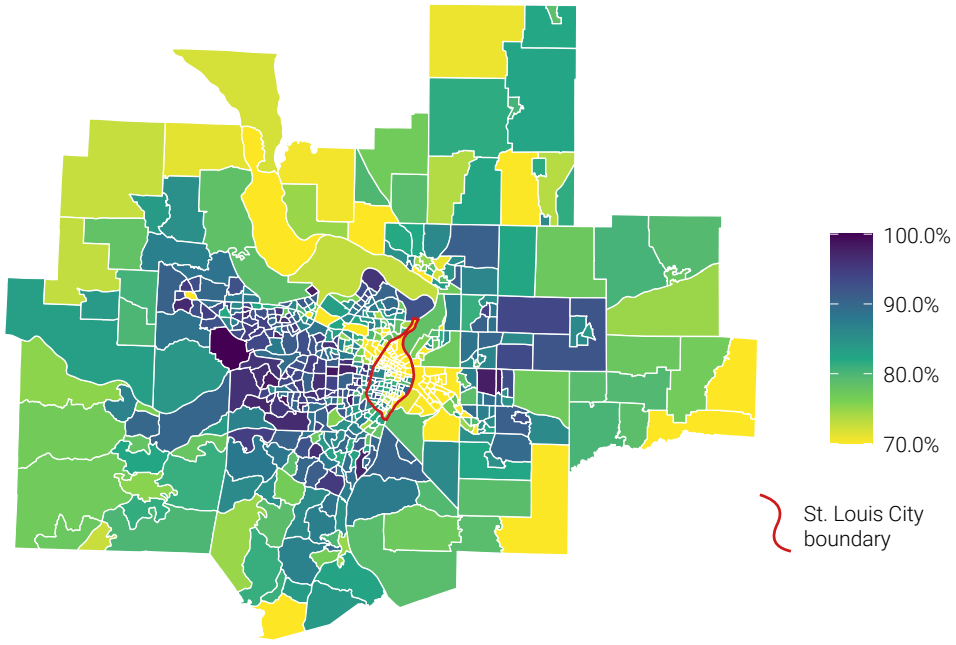
Broadband connectivity gaps have tangible negative impacts for households in both metropolitan and rural communities. Health care access can be limited in rural communities with no nearby health institutions, as only 10% of the country's physicians practice in rural areas.[104] Even those who live in urban areas with closer proximity to hospitals and clinics may not have access to the specialized or culturally competent care they need.[105] Without broadband connectivity, these communities miss the opportunity for improved health care and health outcomes through telehealth.[106] Education is inequitable when students lack home access to internet resources that can enhance their learning and are often necessary to complete homework assignments. Research by the National Center for Education Statistics has shown students without home broadband access face more academic challenges while also missing opportunities to develop digital skills.[107] Job hunting is more

Figure 12. Household broadband adoption rates across the United States, 2019



Source: Brookings analysis of 2019 5-year American Community Survey data

Figure 13. Household broadband adoption rates in the St. Louis metropolitan area, 2019



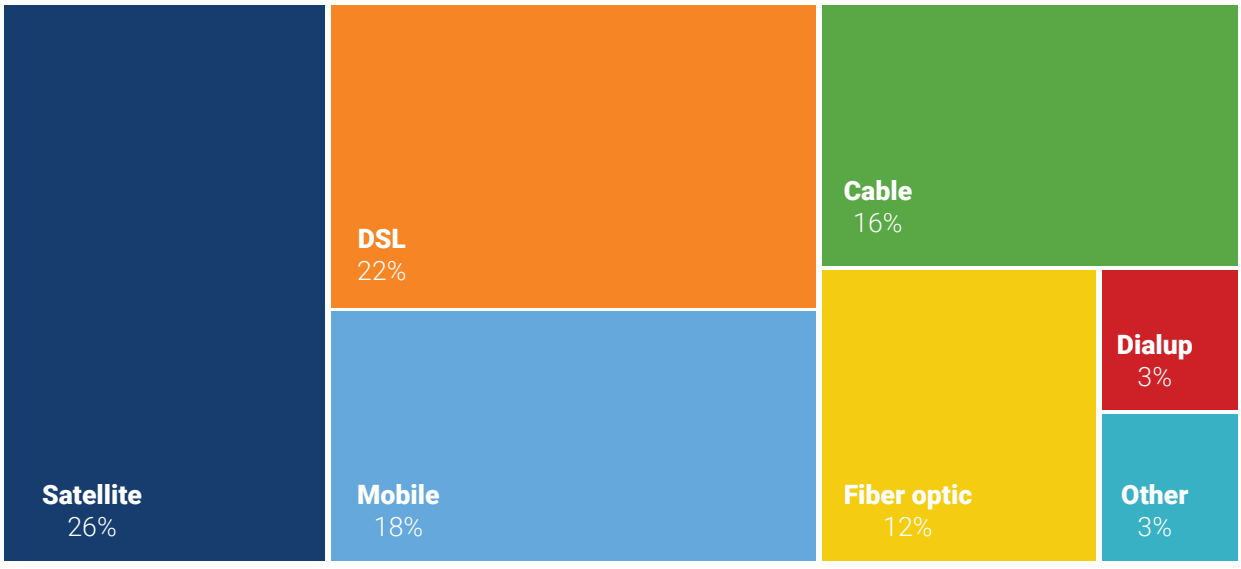
Source: Brookings analysis of 2019 5-year American Community Survey data

challenging without access to online job boards and hiring sites.[108] Broadband connectivity has also been linked positively to civic engagement and a host of other social and economic benefits that disconnected communities may miss out on.[109]

In rural areas, the digital divide also holds back agriculture industries trying to rapidly digitalize. Recent U.S. Department of Agriculture (USDA) projections estimate that rural broadband availability could bolster the agriculture industry and add a potential $18 billion annually to the U.S. economy.[110] Digital agricultural equipment can help farmers view, analyze, and provide automated, targeted care to crops. This emerging practice of precision agriculture can simultaneously increase yield and operational efficiencies while decreasing the environmental costs of production.[111] However, widespread adoption of precision agriculture is stymied by a lack of broadband availability, and adoption of these practices tends to concentrate in large industrial row-crop farms. In 2019, a quarter of American farms had no form of internet access. Among those with access, 26% used satellite as their primary method of internet access.[112] According to the USDA, current satellite connections are insufficient to support the demands of precision agriculture.[113]

Broadband connectivity gaps can also be a substantial barrier to a range of businesses beyond agriculture. Companies whose products are primarily used in areas with spotty coverage may be slow to invest in digitally connected designs, and businesses that focus on digitally connected products lose a potential customer base when households lack broadband.[114] Smaller businesses and entrepreneurs may not have the budget to afford high-speed broadband subscriptions or cloud computing services.[115] Without broadband access, it is difficult for companies to reach customers through e-commerce (which comprises 14% of national retail sales[116]) or connect with other firms through business-to-business e-commerce (a platform that 70% of businesses have launched or plan to launch in the future).[117] Other digital opportunities for businesses—such as accessing a remote workforce through telework; engaging with financiers and government services online; and conducting digital marketing and social networking activities—often require high-speed internet connections.[118]

Figure 14. Primary method of internet access on US farms, 2019



Source: United States Department of Agriculture National Agricultural Statistics Service
Note: Sample includes only the 75% of farmers with access to the internet

Disentangling the digital divide: Availability and adoption measurement challenges

The gap in broadband connectivity is twofold. There is an **availability gap**, which reflects a lack of physical connectivity at a given address. There is also an **adoption gap**, which exists due to affordability, digital skills, and other barriers. Each gap presents its own measurement challenges.

Due to unresolved questions around data collection and statistical methodologies,[119] the comparative extent of availability gaps remains stubbornly unclear. In their 2018 Broadband Report, the Federal Communications Commission (FCC) estimated that approximately 24.7 million people in the U.S. do not have access to fixed broadband.[120] However, the source of FCC data—Form 477—has consistently come under scrutiny for grossly underestimating physical network gaps. In the same year, for example, Microsoft found that 162.8 million people in the U.S. did not use the internet at broadband speeds, likely reflecting a combination of availability and adoption gaps.[121]

Fortunately, network mapping limitations should soon improve. States and metro areas have learned new ways to measure their gaps more accurately, such as a new Georgia system unveiled in 2020.[122] Federally, the Broadband DATA Act requires the FCC to improve granular data collection through a range of new authorities and a clear congressional mandate.[123]

Measuring the adoption gap is especially challenging because each individual may face different barriers. Among individuals who do not have broadband, only 22% cited lack of available service as a barrier, while half identified price as a barrier, according to a 2019 Pew Research Center survey.[124] Even pricing barriers can be split between services and computing equipment. Finally, measuring skills shortages is an intensive process; municipal and state government leaders are still learning the best way to survey their constituents.

As demonstrated above, digitally disconnected households, businesses, and communities suffer similar challenges regardless of whether their barrier is rooted in availability or adoption. It is essential to improve measurement techniques and disentangle these two causes in order to effectively target strategies to address the digital divide.

In 2017, the FCC estimated that deploying wireline broadband to the 14% of locations in the U.S. that still lack broadband availability would cost about $80 billion. Half of that cost would occur in expanding coverage to the final 2% of locations. These final 2% of locations would, unlike the rest of the country, also be unable to cover maintenance costs through subscription revenue.[125] Installing and maintaining broadband in rural areas is disproportionately expensive, especially when considering that such costs are distributed across a smaller population of end users. This well-publicized rural broadband availability gap has been the major focus of the FCC's recent universal service work, yet the challenge remains both significant and inconsistently measured.

Survey results from the Pew Research Center suggest that while broadband availability was the primary barrier for 7% of broadband nonadopters, price was the primary barrier for 27% of people.[126] Federal reporting standards make it difficult to understand the pricing American broadband subscribers face, and the country's only household broadband affordability program falls far short. In December 2016, the FCC's Lifeline phone service affordability program expanded to provide broadband affordability assistance to income-qualifying households.[127] The program currently provides qualifying households a $9.25 discount on either home phone, mobile phone, broadband, or bundled mobile phone and internet service.[128] This discount does not go far, covering only about

13% of average advertised monthly costs.[129] The participation rate among eligible households fell from a high of 33% in 2016[130] to 25% in 2020.[131]

Digital skills and knowledge also play a large role limiting broadband adoption. Over half of adults in the U.S. are "relatively hesitant" to adopt digital technologies, have limited digital skills, and have limited trust in the internet.[132] Limited digital skills also make it difficult to access the multitude of opportunities, goods, and services that are increasingly moving online. Digital skills barriers also restrict business dynamism: From farmers to entrepreneurs, comfort with and trust in new technology has the potential to transform business operations, enhancing efficiency and productivity. With six out of 10 nonadopters never having had broadband before, many may not even be aware of the full extent of these benefits.[133]

Integrating new technologies into the built environment

Even with impressive innovations coming out of the manufacturing and telecommunications industries, many of our infrastructure systems are currently underdigitalized and underprepared for new advancements. Without access to power and broadband connectivity, digital sensors cannot meet their potential to measure pressing needs, ranging from weather and environmental quality conditions to building energy use, traffic, or water pressure. Further, if the sensors installed in these systems do not have the capacity to intelligently react, the opportunities made possible by their data flows—including a projected 29% decrease in commercial building energy use—will be wasted.[134]

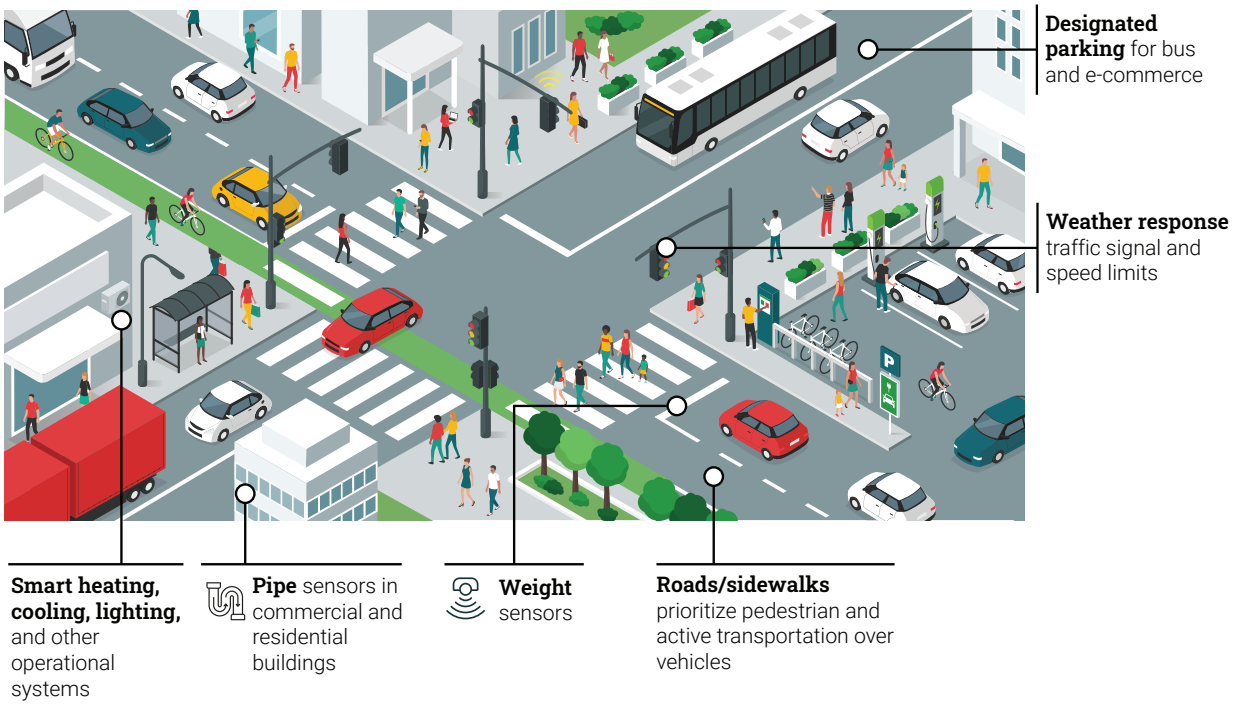
In some cases, traditional regulation or analog technology can cause undue adoption challenges of emerging technologies. Autonomous vehicles (AV), for instance, will benefit from clear, bright, and sometimes even digitalized road markings. A 2017 report from the Eno Center for Transportation analyzed the 38 existing state AV policies, finding them to be inconsistent and even contradictory.[135] Similarly, digital mobility solutions such as electric scooters have faced uneven regulatory environments and inconsistent rights of way, and drones are likely to face the same. Continued lack of coordination and early adoption among different levels of government and different regions can limit digital readiness practices and lead to challenges in technology deployment. For example, inconsistent data sharing standards could complicate communication between vehicles, central databases, and regulating entities. In many cases, digital technology is emerging and evolving faster than the built environment—and our governance frameworks—can keep up.

In other instances, the infrastructure backbone is the issue. The construction and operation of fifth-generation wireless networks (5G) will be a long-standing issue. 5G networks will use a variety of communication methods—providers use different spectrum with different advantages and disadvantages—to offer higher-speed, low-latency service that virtualizes network management through Internet Protocol.[136] While the engineering and physics is complicated, the potential to build an Internet of Things (IoT) could genuinely transform how we travel, trade goods, and conduct personal business. The challenge will be bringing 5G to every community. Installing the small cell towers and fiberoptic cabling 5G requires is expensive, especially in low-density communities like rural towns, and has already run into regulatory tensions around public right of way.[137] Without future-proofed broadband everywhere, concepts like IoT could become a spoil in only the wealthiest communities.

Managing data, cybersecurity, and AI ethics

One of the greatest benefits and risks of the digital age is the abundance of data. New technologies continually emerge with the capability to collect constant, granular, and sometimes personal or sensitive information about people, places, and systems. But standing up a functioning ecosystem of sensors and generating a multitude of data is not an end in itself.[138] The analytical and operational efficiencies of more data are only possible when it is translated effectively into action across the public and private sector. This process requires upfront planning and intention, as well as workforce capacity to manage, analyze, and use incoming data and robust cybersecurity infrastructure to ensure data does not fall into the wrong hands.

Figure 15. Digital potential in the built environment



Source: Brookings Institution

With so many new technologies and kinds of data collection emerging, standards and boundaries around data management and personal privacy rights are unclear and underdeveloped.[139] Government agencies' procurement policies may restrict use of data service subscriptions or not require interoperability with other in-house data. It can be challenging to calibrate and validate newer datasets, especially compared to established sources such as the U.S. Census Bureau. But perhaps most troubling is the threat to personal security, as people's smartphones, private vehicles, and internet browsing are all collecting personal data that frequently becomes the property of private companies. States including California, Virginia, and Washington continue to test new laws, but federal law is still unclear as private data continues to be collected and used in uncertain ways.[140]

Cybersecurity is an interrelated concern, and the ascendancy of artificial intelligence (AI) and transition to 5G networks will only intensify our cybersecurity challenges. AI is the use of human-coded algorithms to allow machines to learn how to optimize their given tasks.[141] AI is the foundation behind autonomous vehicles, facial recognition software, and the maintenance alerts water and energy utilities use. But AI also requires constant transfers of data that can frequently include sensitive information. Many AI technologies will come to depend on 5G networks, which themselves have additional cybersecurity vulnerabilities relative to older wireless standards.[142]

AI also raises ethical challenges in terms of algorithmic bias. Consider the example of facial recognition software, in which programs that public agencies currently use have already demonstrated instances of racial bias.[143] Similar concerns exist around routing and dynamic pricing among transportation providers.[144] Digital technologies could improve quality of life for many individuals living with physical disabilities, but those individuals should not see their privacy eroded by monitoring technologies and biased algorithms.[145] Regulators have a responsibility to work with ethicists and other experts to root out biases if the U.S. expects to operate truly equitable infrastructure systems in the future.

Digital workforce

American workers need increasingly sophisticated digital skills to support the rapidly digitalizing industries, products, services, and ways of life that the country's future holds. Between 2002 and 2016, digital skills increased in 95% of occupations across all industries and metropolitan areas.[146] This widespread digitalization of the American workforce has benefits: Workers with higher digital skills tend to earn higher pay and have greater job resiliency in the face of automation. But the digitalization of work also contributes to the growing divide between high- and low-wage workers. Significant workforce development efforts will need to help equip new workers, displaced workers, and older workers with the digital skills and readiness they need to grow their careers over time. This is especially important for workers in rural communities who may want to compete for advanced service jobs but don't benefit from the physical clustering of jobs within a commuting distance.

This is especially the case within infrastructure industries, which already demand a broad range of skills in analog equipment.[147] For example, while many occupations in the water industry use traditional tools such as screwdrivers and claw hammers, utilities now demand skills in software packages such as word processing, database management, and computer-aided design (CAD).[148] There could be up to 9.5 million jobs in digital mobility as the transportation industry fully digitalizes, but workforce systems from universities to apprenticeship programs may not yet teach the right combination of digital skills.[149] This report will touch on these and other workforce issues later on in greater depth.

Opportunities

The country cannot simply react as the pace of digitalization accelerates. Federal policymakers need to harness the growing technological potential by ensuring our infrastructure systems can offer greater efficiencies and help more people in more places.

Efficiency

Widespread procurement and installation of new digital technologies across our built environment could deliver operational efficiencies across all four major infrastructure sectors and the broader built environment they serve. The opportunity rests in using technologies to support more responsive measurement and performance.

For example, sensors deployed in transportation can improve traffic flow (traffic sensors) or respond to weather by prioritizing pedestrians on rainy days and alerting maintenance crews of roads that are icy or in need of repair. Sensors integrated into utility systems can provide a multitude of efficiency opportunities, from enabling accurate usage-based pricing schemes to detecting and isolating pipe leaks or problems with transmission and distribution lines. In buildings, sensors can not only inform internal climate control and building operations, but can also predict temporal energy demand, enabling buildings with distributed energy systems to draw from the grid during times of lower demand. Digital sensors and connected building control systems could potentially save 29% of energy used by the commercial building stock, and models suggest up to 20% of building peak load could be shifted or reduced to free up grid service at certain times.[150] The widespread deployment of sensors and responsive control systems has potential to bring environmental and cost savings through added efficiency.

While market forces naturally encourage the development and diffusion of many new technologies, coordinated policy and governance frameworks can focus this momentum for the public good. Digital mobility and logistics innovations such as AVs and drones can bring a range of benefits, but well-coordinated safety regulations are necessary to build public trust, while standardizing roadway design and aerial rights of way will help these products flourish. "Dig once" policies can push local governments to plan and predevelop a mix of infrastructure activities in advance to reduce total construction timelines,

materials consumption, and net budgetary costs. Standardizing formats of infrastructure data feeds—if household and business privacy is genuinely protected—could streamline governmental operations and support ancillary businesses.

Incentivizing and experimenting with new technologies is also critical to scale improvements across our built environment. For instance, technologies such as ground-penetrating radar can bring enormous safety, cost, and time savings to construction sites, yet industry is struggling to develop them. In these cases, public sector R&D leadership and support could create transformational change.

Equity

Simply creating and deploying more digital technologies isn't enough. Federal policymakers also have a responsibility to ensure all people in every place have greater access to the digital economy.

Closing the country's broadband availability gap is an essential step to even have a chance to achieve digital equity. The long distances associated with rural living make telehealth, e-commerce, and job boards especially important for rural households. Rural farms and manufacturers need access to online financial markets and other communication channels to compete. Fully connecting metropolitan areas is a necessary step to bridge the homework and skills gap among many households currently experiencing digital poverty. Ensuring all metropolitan neighborhoods have access to the same broadband quality can also directly support wealth-building opportunities for the businesses operating in previously underserved communities. Federal regulators and their state and local peers must be ready to consider a range of business and ownership models that could overcome network gaps.

Addressing the country's broadband adoption gap is just as important. Addressing affordability challenges and skills gaps can bring all households online, immediately improving economic opportunity for disconnected households and introducing millions of new potential customers to the digital economy. Boosting subscriptions will require a concerted effort between governments at all levels, private broadband providers, and computing equipment manufacturers to create more inclusive pricing programs. Governments will also need to work with educators and employers to develop durable funding for skills-focused training programs. Hiring more public sector officials to focus exclusively on digital equity issues could deliver immediate and long-run returns.

Ensuring more households can take advantage of digital technologies extends to the workforce, too. The digitalizing of America's workforce presents an opportunity for better jobs and wages, but workers need to develop more durable skills to fill the jobs of today and tomorrow. Jobs across all industries already require more sophisticated digital skills to communicate, manage, and carry out different tasks, so workers need to receive training and experience in technologies to grow their careers. As more infrastructure industries look to automate tasks, preparing more workers with digital skills will help these employers continue to be a source of middle-income jobs.

Workforce

Context

While the first two forces described above—those around climate and digitalization—show how our infrastructure is a cause of (and potential solution for) significant national challenges moving forward, this section explores how our infrastructure can serve as a powerful force for economic empowerment. But we currently lack the human capacity (the skilled infrastructure workforce) to address our mounting physical and economic challenges. How we design, construct, operate, and manage our infrastructure systems ultimately depend on people. Connecting more and different types of people to jobs in the infrastructure sector can support economic growth and equity.

Even as many American workers struggle to find economic opportunity, infrastructure jobs offer long-term pathways to economic security and success. From plumbers and electricians to truck mechanics and telecommunication line installers, 17.2 million workers—or about one out of every 10 workers nationally—construct, operate, and maintain our infrastructure systems.[151] And more than a quarter of all these workers are projected to retire or permanently leave their positions over the next decade.[152] Hiring, training, and retention needs are growing across the infrastructure sector, and with these openings come higher wages, lower formal educational barriers to entry, and a need for younger talent.[153] However, federal leaders—in coordination with employers, educational institutions, labor groups, community-based organizations, and many other actors—need to ensure these career pathways are visible and flexible to help more and different types of people fill these positions.

Doing so can help overcome our long-standing opportunity gaps. Over the past few decades, workers have faced an increasingly polarized labor market.[154] Middle-skill jobs—which typically require more than a high school diploma but less than a four-year college degree—have grown much slower than other low-skill and high-skill jobs.[155] The Great Recession amplified this trend, with the greatest job

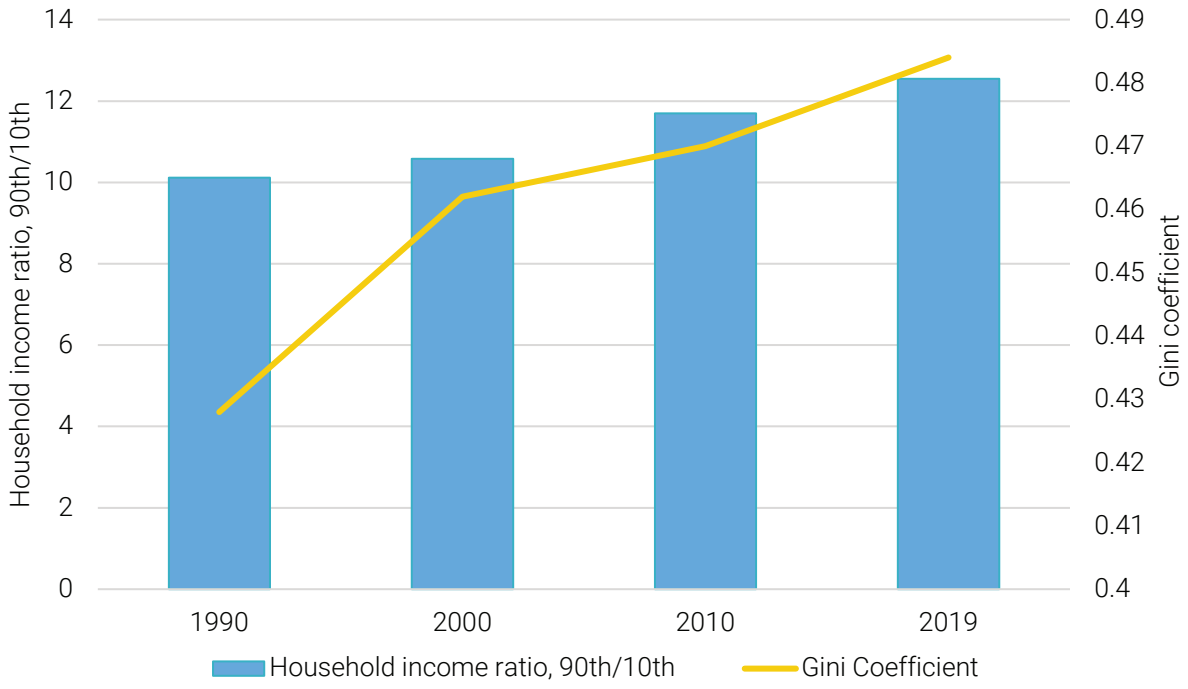
losses among workers with a high school diploma or less; 95% of jobs created during the subsequent recovery went to those with at least some college education.[156] Even before the COVID-19 pandemic, 53 million American workers—or 44% of all workers—earned only about $10.22 per hour.[157] Many of these lower-income workers have struggled to find long-term, better-paying jobs.[158]

Consequently, income inequality is increasing. The Gini index—a standard measure of income inequality with an index of 0 representing perfect equality and an index of 1 (or 100%) representing maximum inequality—has risen from 34.5% to 41.1% nationally since 1979, with distinct increases in inequality following major recessions. Over the same period, incomes grew 99% for the highest quintile of American earners, while only growing 33% for middle and lower quintiles of earners.[159] In addition, the ratio between highest earners at the 90th percentile and the lowest earners at the 10th percentile grew from 10.12% to 12.55% over the last few decades. All these changes come despite the typical American worker's productivity increasing six times faster than their income.[160]

The impacts of these macroeconomic trends are felt unequally across the labor force. Workers facing labor market discrimination— in particular, women and people of color—comprise an outsized share of those earning low incomes.[161] On average, women earn 82% of men's earnings, and the gender wage gap is even larger when combined with racial disparities. Black women earn only 64% and Latino or Hispanic women earn only 59% of what white, non-Latino or -Hispanic men earn.[162] Workers over the age of 50 often face workplace discrimination; nearly half of these workers experience involuntary job separations, and only one in 10 will ever earn as much following such separations.[163] Many young people, especially those out of school and dislocated from work, struggle to launch their careers and may simply leave the labor force.[164]

The increased divides in our labor market are tied to many factors, including automation, digitalization, and globalization. The rise of automation and artificial intelligence is affecting nearly every aspect of the labor market, especially the 70% of jobs with routine tasks in office administration, production, transportation, and food preparation.[165] The

Figure 16. Change in the Gini index and the household income ratio (90th/10th percentile), 1990 to 2019



Source: Brookings analysis of World Bank and U.S. Census Bureau data

changes facing many driving occupations—which are prevalent across the infrastructure sector—may upend the pathways for millions of new and prospective workers. However, these technological gains are not just a story of job destruction and job creation; they also signal how our current jobs may require higher levels of educational attainment and increasing levels of digital skills.

Changes in the nature of work and certain job protections have also limited opportunity for many Americans. Beyond the more widespread use of technology, the increased demand for technical skills and the complexity of job tasks has made it harder for some workers (and employers) to adapt. Many current job openings demand STEM knowledge, amid other rapidly evolving education and credential requirements.[166] The manufacturing industry, for example, faces a potential 2.4 million unfilled positions between 2018 and 2028 due to skills gaps.[167] The skilled trades, which dominate many infrastructure positions, are not immune to these changes either.[168] Meanwhile, labor protections that may have assisted some of these workers have been on the decline; union membership has fallen from a high of 20.1% in 1983 to a low of 10.5% in 2018.[169]

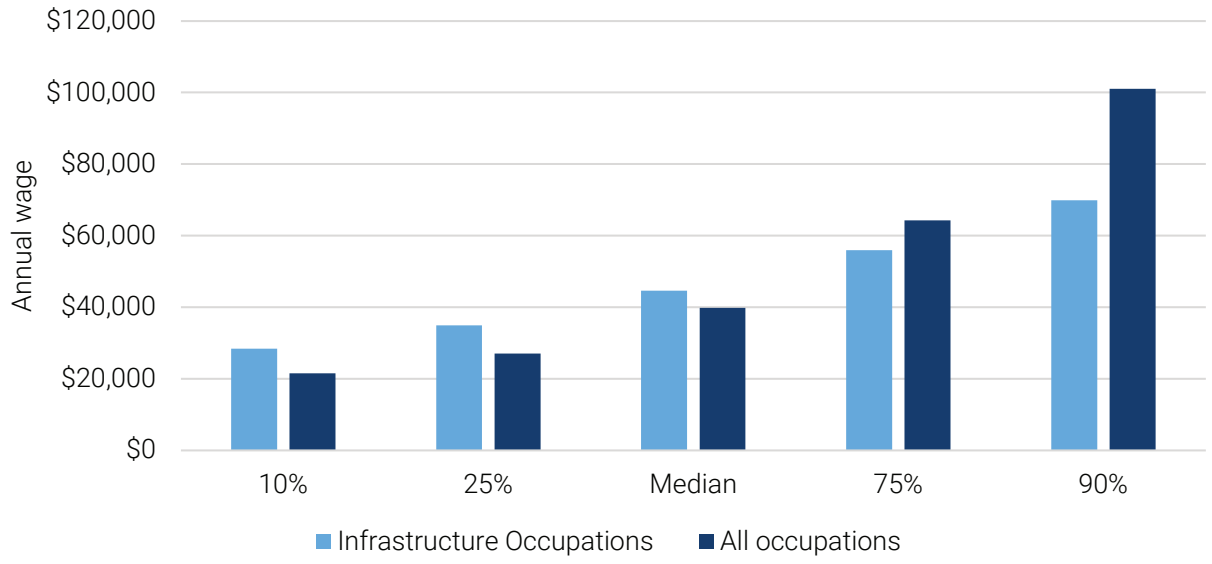
Fortunately, infrastructure offers career pathways that counter many of these trends, including higher pay, transferable skills, and clear hiring needs. But to maximize this opportunity, federal leaders cannot only look to create infrastructure jobs in the short term, as has typically been the focus in Washington. Rather, they need to focus on creating an infrastructure talent pipeline that can offer more sustained opportunity to workers and provide greater certainty to infrastructure operators and other employers. Investments in career and technical education, new earn-and-learn models, and other flexible hiring and training strategies can help current and prospective workers overcome barriers to entry and grow their careers. These issues are highlighted in the following two sections.

Challenges

Lack of workforce visibility and planning

A basic challenge facing infrastructure employers—including utilities, transit agencies, and engineering firms—is a lack of awareness among Americans that these careers even exist. Many infrastructure jobs (along with the relevant educational and training pathways to access them) lack visibility

Figure 17. Annual wage comparison, infrastructure occupations vs. all occupations, 2019



Source: Brookings analysis of Bureau of Labor Statistics Occupational Employment Statistics

among students and prospective workers. This obscurity continues even as infrastructure jobs offer more competitive, equitable wages due to prevailing industry norms and greater labor protections, including higher levels of unionization.[170] In particular, infrastructure jobs can pay 30% more to workers at lower ends of the wage spectrum—in other words, workers with the least amount of experience who are just starting their careers. Hourly wages at the 10th and 25th percentiles stand at $13.68 and $16.82 in these jobs, compared to $10.35 and $13.02 in all jobs nationally.[171]

Although these jobs pay relatively well and are widespread across different industries and regions—spanning 91 different occupations in transportation, water, energy, and telecommunications—they are often siloed in our workforce development systems.[172] These jobs are involved in the skilled trades, but also in finance, administration, and management. Since infrastructure jobs are so expansive and varied, they lack a cohesive, sector-wide strategy. For example, sector partnerships (collaborations among education, training, labor, and community organizations) can build technical and financial capacity around specific career pathways.[173] Health care, information technology, and manufacturing jobs benefit from targeted sector strategies, but infrastructure jobs do not. This is especially true at a regional level, where workforce development boards, educational institutions, and employers collaborate, plan, and prioritize needed investments.[174] Instead, these jobs can be ignored, or workers may simply be channeled into getting commercial driving licenses or other ad hoc credentials.

Regional engagement among employers and educators is important for infrastructure jobs because of the work-based learning often required in these positions. Only 12% of infrastructure workers have a bachelor's degree or higher, compared to more than a third of all workers across all occupations nationally. Instead, most have short- to long-term on-the-job training.[175] Some occupations, such as water treatment operators, need years of training and relevant work experience to qualify for entry-level opportunities and launch their careers, typically gained through apprenticeships, internships, and similar earn-and-learn opportunities.[176] Other occupations, such as truck drivers, need certain licenses and certifications.[177] Without proactive and coordinated education, training, and investment, the U.S. fails to create the talent pipeline needed to support infrastructure careers—let alone promote visibility.

Instead, the U.S. education system channels high school graduates toward four-year postsecondary degrees. In 2019, approximately two-thirds of high school graduates enrolled in college, typically in four-year degree programs.[178] While four-year degrees can increase earning potential, they are not the only pathway to do so, especially for lower-income, disadvantaged students who may lack the resources to enroll in these programs.[179] Other pathways, including career and technical education (CTE) programs, may lack funding or struggle to attract students as a preferred option, despite CTE's vital role channeling individuals into the skilled trades and the broader labor market.[180] Stigmas over the dangerous or dirty nature of this work persist among students, parents, and even educators.[181] Underfunded CTE programs can also vary widely in their offerings and classroom settings; some students may have the ability to learn to operate drones, while others may find themselves in outdated facilities catering to the labor market demands of past generations.[182] A continued lack of exposure to skilled trades and what these careers represent, even among younger students going back to elementary school, is an ongoing challenge.

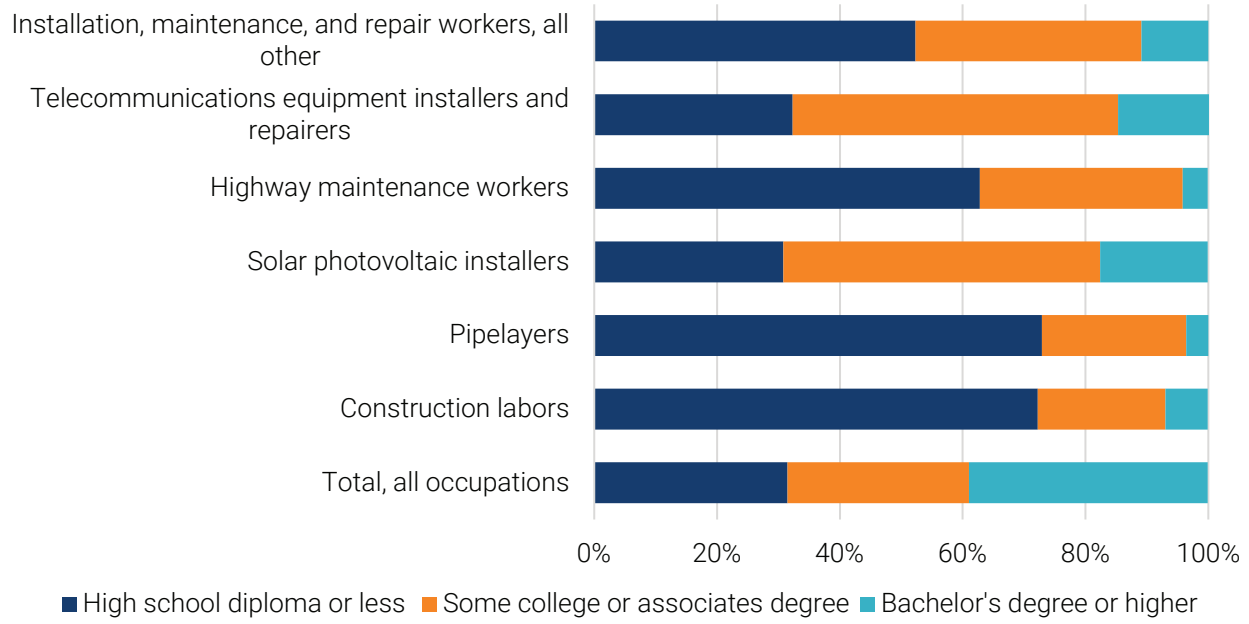
At the same time, public investment of $14 billion in employment services is far overshadowed by the $385 billion invested in higher education each year.[183] For instance, only 21% of the 1.1 million adult and dislocated workers served by the Workforce Innovation and Opportunity Act (WIOA) receive training, despite the tens of millions of low-wage and unemployed workers who could benefit.[184] Opportunities to earn and learn, including the apprenticeships so important to infrastructure workers, reach less than 1% of WIOA trainees. Instead, our workforce development systems remain highly fragmented and disorganized, with basic career services in "American Job Centers" failing to provide a high level of individualized attention and guidance.[185]

Figure 18. Selected infrastructure occupations, by employment, wages, and educational attainment, 2019

			
	Water and Wastewater Treatment Plant and System Operators	**Wind Turbine Service Technicians**	**Highway Maintenance Workers**
National workers	123,730	5,960	150,860
Mean hourly wage	$24.28	$27.26	$20.39
High school diploma or less	39.9%	53.0%	67.9%
			
	Solar Photovoltaic Installers	**Heavy and Tractor-Trailer Truck Drivers**	**Environmental Engineers**
National workers	11,080	1,856,130	53,150
Mean hourly wage	$22.52	$22.52	$45.30
Educational attainment	39.4% HS or less	39.4% HS or less	92.6% BA or more
Averages for all U.S. occupations: $25.72 **Mean hourly wage** 31.7% **High school diploma or less** 38.4% **Bachelor's degree or more**			

Source: Brookings analysis of EMSI and U.S. Bureau of Labor Statistics data

Figure 19. Educational attainment for workers 25 years and older by select infrastructure occupations, 2019



Source: Brookings analysis of U.S. Bureau of Labor Statistics data

Developing hard and soft skills

Even if students and prospective workers know these jobs exist, they must develop a broad range of cross-cutting knowledge and specialized skills to grow their careers. According to Department of Labor (DOL) surveys, infrastructure workers have above-average knowledge across 11 distinct content areas, ranging from engineering and design to public safety and security.[186] In addition, these workers use a variety of tools and technologies to carry out their job duties, from screwdrivers and hammers to personal computers and GPS devices. On average, each infrastructure occupation depends on 14 different tools and technologies, compared to the six used in occupations across all industries nationally.[187] These technical demands are only increasing; many workers face a digitalizing future and will need high levels of digital literacy as new jobs emerge— for example, technicians and mechanics in the autonomous vehicle industry, which do not even exist yet. [188]

Since most infrastructure workers develop technical knowledge and experience (or "hard skills") on the job, continued learning and employer engagement is paramount. Only 71% of infrastructure workers need up to three months of on-the-job training to qualify for their jobs, but these initial barriers to entry do not fully reveal the continued need to build competencies over time.[189] Depending on the particular employer, location, and duties involved, workers need to develop familiarity with several operational and management practices to grow their careers and ultimately fill leadership positions. This demands a clear identification and measurement of skills for years, if not decades.[190] Indeed, interacting well with colleagues, demonstrating flexibility, and staying motivated are all key "soft skills" needed for career growth; when combined with greater work experience, they can allow individuals to achieve higher pay and job satisfaction.[191] These soft skills go beyond emotional intelligence; workers need to show they have the dependability and foresight to learn and grow on the job.

An aging infrastructure workforce that lacks diversity

A lack of visibility combined with a growing need for related experience and skills is challenging enough to seize America's infrastructure

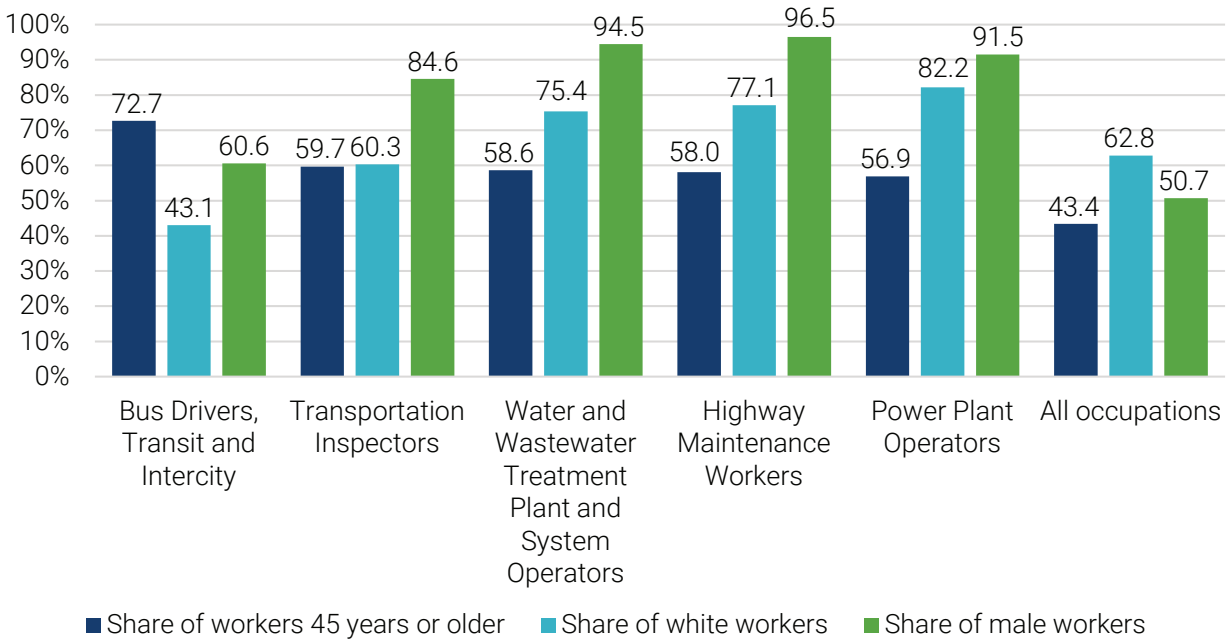
workforce opportunity. But since the pipeline to fill infrastructure jobs has been ignored for so long nationally, our hiring, training, and retention needs are now massive.

While some infrastructure jobs are projected to grow in coming years, the replacement needs—filling positions left vacant by retired workers or those leaving the sector permanently—are even more dire. As noted earlier, nearly a quarter of all infrastructure workers will need to be replaced over the decade, but some occupations are expected to see 10% or more of their workers leave *each year* on average.[192] That's especially the case for infrastructure jobs with older workers nearing or eligible for retirement; 73% of bus drivers, for instance, are over the age of 45, and many are in their 50s.[193] The "silver tsunami" across several occupations—from electricians to wastewater treatment operators—poses a short- and long-term threat to employee retention, knowledge transfers, and other operational needs in public and private employers alike.

In addition to a graying workforce, many infrastructure workers are predominantly white and male, signaling our inability to attract and hire a younger, more diverse generation of workers. In occupations such as power plant operators and highway maintenance workers, up to 82% of workers are white. Meanwhile, 82% of all infrastructure workers are male.[194] In particular infrastructure sectors such as water, these racial and gender gaps can be even more extreme: 99% of pipelayers are male, and Black and Asian American workers tend to be underrepresented overall, filling 12% of water jobs compared to 18% of all jobs nationally.[195]

Such imbalanced racial and gender statistics reveal underlying inequities in our current hiring, training, and retention models. For instance, demonstration projects, mentorships, and other early, repeated opportunities for career exploration can be lacking for students and prospective workers.[196] Work-based learning and other bridge programs and internships are important tools to help disconnected youth gain skills and experience while navigating the transition from school to work and fostering positive relationships with adults along the way.[197] And beyond the young adults struggling to enter the workforce for the first time, older displaced workers in other economic sectors—including veterans and

Figure 20. Age, race, and gender, selected infrastructure occupations vs. all occupations, 2019



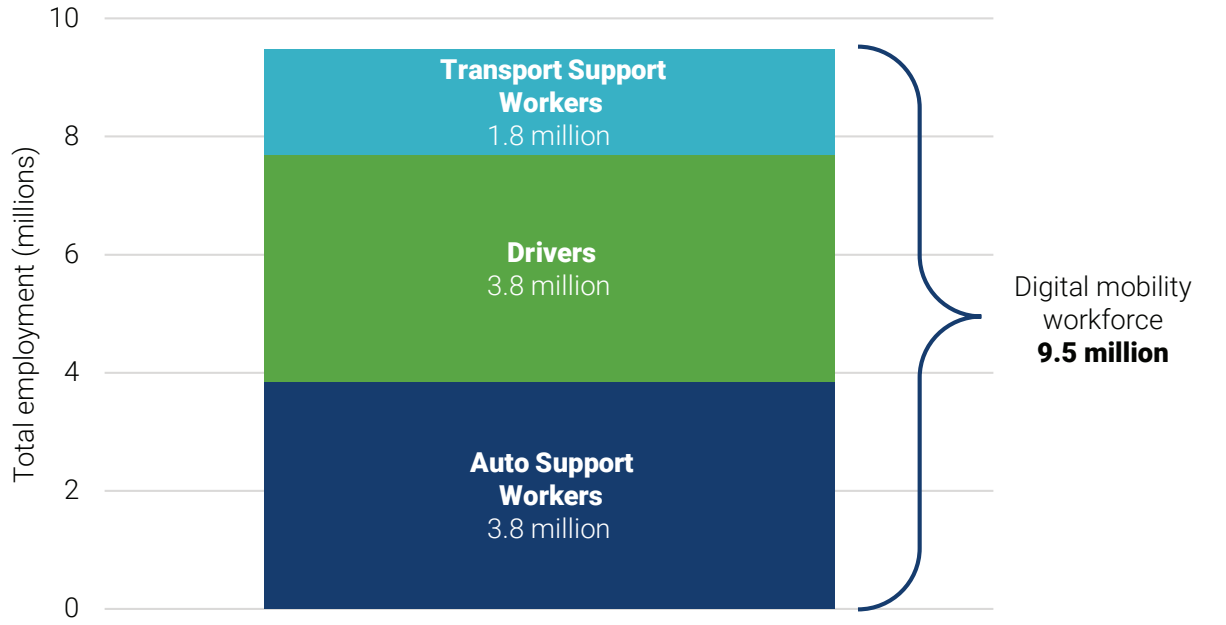
Source: Brookings analysis of BLS Occupational Employment Statistics and EMSI data

the formerly incarcerated—may also experience challenges. Adult and dislocated worker training programs are often underfunded, and the available transition pathways lack flexibility.[198]

Emergence of new technologies and climate needs

As challenges and innovations around rapid digitalization and increased climate risks continue to shape our lives, new infrastructure careers will undoubtably emerge to meet growing needs. Between 2002 and 2016, 95% of 545 occupations nationally—including those in infrastructure—involved increased digital skills and knowledge in computers and electronics.[199] This trend is likely to accelerate in the future. For example, the future digital mobility workforce—which will drive, operate, and manage our new connected and autonomous vehicle technologies—could employ up to 9.5 million workers.[200] Other emerging digital challenges in warehousing and logistics, sensor deployment, and cybersecurity and data management will require skilled, knowledgeable infrastructure workers. [201] A more extreme and changing climate not only demands new mitigation and adaptation strategies, but also workers to manage these activities. This is especially true in the clean energy workforce. Over the next decade alone, wind turbine service technicians and solar photovoltaic installers are projected to grow dramatically—61% and 51% respectively, compared to an average of 4% job growth for all jobs nationally. But the clean energy workforce extends to 320 unique occupations across the clean energy production, energy efficiency, and environmental management sectors. And since many of these occupations are involved in the skilled trades, they will demand work-based learning and other on-the-job training opportunities to realize their full potential.[202] Climate adaptation efforts will implicate a variety of infrastructure workers, from horizontal directional drill operators who will help move utility lines underground to workers installing and maintaining new green infrastructure designs to better manage wastewater and stormwater needs.[203]

Figure 21. Workers in digital mobility by occupation category



Source: Brookings analysis of BLS Occupational Employment Statistics
Note: The digital mobility workforce refers to those who will create, manage, and maintain autonomous vehicles, other digital services, and the built environment around them. Read more here: https://www.brookings.edu/blog/the-avenue/2018/11/15/how-big-could-the-av-industry-be-9-5-million-workers-and-counting/

Opportunities

Infrastructure jobs are varied and widespread, offer more competitive and equitable wages, do not demand as much formal education, and have immediate and long-term hiring needs. Seizing this economic opportunity hinges on proactive federal leadership to ensure greater visibility and flexibility to fill careers. That will require an emphasis on supporting a robust talent pipeline for decades to come. Expanded financial and technical capacity around regional planning and employer engagement is a must, as is an expanded focus on future-looking skills development and flexible training opportunities.

Visibility: Proactive regional planning and employer engagement

Work-based learning helps students and prospective workers develop and apply new skills, and provides them with the experience needed to qualify for entry-level opportunities across the infrastructure sector.[204] Such programs can introduce younger students to these careers earlier and more often, while especially empowering disadvantaged or disconnected workers of all ages.[205] However, supporting these programs depends on proactive regional planning and employer engagement boosted by federal funding and technical capacity.

Employers can partner directly with community colleges, technical schools, and similar educational institutions—along with other community-based organizations—to help students gain the necessary skills, knowledge, and qualifications to be hired. Water utilities and other workforce groups in the San Francisco Bay Area, for instance, have banded together as part of a regional "BAYWORK" effort to hold workshops, meetings, and other events around the water workforce challenge; to clarify strategic priorities and measure hiring needs around mission-critical occupations; and to provide on-the-job training opportunities.[206] Similar regionwide planning efforts have emerged in Louisville, Ky. and Camden, N.J. to provide flexible training programs and boost workforce diversity.[207] In Washington, D.C., Mayor Muriel Bowser started a new "Infrastructure Academy" to serve as single, postsecondary educational institution and regional destination to help with workforce screening, training, and recruitment.[208] Similar efforts have also emerged in Los Angeles, including LA Metro's "Transportation School," which will train students in STEM-related classes and fill transit jobs upon graduation.[209] Such local collaborations between employers, educators, and workers/learners can build trust and value across multiple stakeholder groups.

New platforms for collaboration and data collection are also essential to understand, evaluate, and respond to industry and occupational needs across the infrastructure sector. At a state and local level, for instance, sector partnerships—traditionally focused on IT, health care, and other fields—can help infrastructure employers, educators, and other leaders better manage labor market information, support peer-to-peer learning, establish clear training standards, and build technical and financial capacity for planning efforts.[210] Workforce development boards can facilitate many of these activities and target resources, but many do not treat infrastructure as a distinct sector or may not actively engage with all employers. Fortunately, federal leaders have looked to boost the capacity for such efforts. The development and application of competency models by the Employment and Training Administration chart the types of skills, knowledge, and training needed for infrastructure career growth.[211] Likewise, the Environmental Protection Agency (EPA) has launched a water workforce initiative to improve awareness, planning, and investment in utility-related careers.[212] The focus of these efforts needs to be on both prospective workers and current workers throughout the infrastructure sector; just as there are hiring and training needs, there are retention and retraining needs as well.

Apprenticeships and pre-apprenticeship programs offer another earn-and-learn opportunity for workers entering the infrastructure workforce. These programs typically last several years and span the worksite and the classroom, and play a strong role in the construction and utility trades.[213] Labor groups and unions have launched awareness campaigns and looked to boost investment in these programs as well. Yet, the U.S. apprenticeship ecosystem is quite small in comparison to global peers, most notably Germany. Expanding

apprenticeship opportunities to connect with more workers would provide yet another viable on-ramp to the infrastructure career pipeline. For example, the ICATT Apprenticeship Program, which is modelled after and benchmarked against the German dual education system, allows employers to invest in a local talent pipeline and build a loyal workforce through extended earn-and-learn opportunities.[214] Even shorter-term learning opportunities such as internships can quickly immerse students in the type of work available in the infrastructure sector, among small and large employers alike.[215] And ongoing mentorships with current employees can offer common points of contact and bridge generational divides for prospective workers.[216]

Through these more visible and proactive planning approaches, federal leaders can help regions form stronger pathways into the promising infrastructure jobs of today and tomorrow.

Flexibility: Skills development and more accessible training opportunities

On-the-job training is nearly ubiquitous among infrastructure workers, even though they do not require as much formal education. Developing STEM knowledge and other digital skills, in addition to gaining familiarity with a variety of tools and technologies, requires ongoing skills development at the beginning, middle, and end of a worker's career. Federal leaders need to ensure that there are flexible training opportunities in place to help more and different types of workers—including younger, more diverse, and other nontraditional, underrepresented workers—grow their knowledge and experience over time. Ultimately, these career pathways can help more American workers secure better pay and better opportunity.

Programs focused on younger workers—particularly those out of school, out of work, and facing other social and economic disadvantages—can grow and diversify the infrastructure workforce. While obtaining a four-year college degree has been the default objective that federal leaders and many others have pushed on students for decades, a range of postsecondary options needs to be available.[217] Bridge programs, for instance, combine education and training through contextualized instruction, promoting basic math and literacy skills.[218] Job training programs, including those geared toward specific certifications and credentials, can jump-start careers.[219] And workforce intermediaries, including community-based organizations, can connect younger workers to specific training opportunities and offer supportive services such as child care and transportation.[220]

However, younger individuals are just one segment of the prospective infrastructure workforce. Many other nontraditional and underrepresented workers—including women, people of color, and middle-aged workers—can realize greater opportunity in this sector as well. Infrastructure career pathways need to provide a variety of on-ramps to ensure a more inclusive workforce. From eliminating implicit bias in the hiring process to combatting microaggressions in the workplace, employers and other workforce groups must take the lead to ensure infrastructure, manufacturing, and other skilled trades careers are welcoming to all workers, regardless of gender or race.[221] Better defining the entry points for older workers can help too, especially for veterans and formerly incarcerated workers who have been underserved by the workforce system.[222] Lastly, helping unemployed and underemployed workers transition to careers in the infrastructure sector—including through career guidance and other supportive services—can make a difference. As just one example, the Economic Development Administration, Appalachian Regional Commission, and other federal agencies have transitioned displaced fossil fuel workers into clean energy careers through the POWER Initiative and the Assistance to Coal Communities (ACC) program.[223]

The reality, though, is that all types of prospective infrastructure workers—young, old, or of any demographic—still face hurdles to qualify for positions and grow their careers. Even if a college degree is not necessary in many cases, some type of license, certification, or demonstrated experience is required. More portable, versatile, and accessible credentials hold promise in reducing these barriers.

National associations in water, transportation, and other infrastructure sectors have pushed for more flexibility in recent years.[224] Such credentials would be based on a commonly agreed upon framework of necessary knowledge and skills for each occupation, and would be considered equally credible by all employers and educational institutions nationally. This would allow the investment in credentialing workers and learners to carry over between jobs, regions, and educational settings. The ideal versatile credentialing program would offer a series of short-term credentials that could fit into a working learner's schedule and could be "stacked" together to achieve increasing labor market value. Versatile credentials, ideally, can be part of a larger jobs framework and linked to clear pathways for career growth.[225]

The infrastructure workforce opportunity is not static either. Future job growth and replacement needs throughout the sector are not only shifting our hiring needs; the emergence of new tools, technologies, and processes is transforming the very nature of the work performed. Existing occupations—and workers—are increasingly working with computers and other digital equipment, requiring continued skills development and retraining efforts. Whether employed as engineers, technicians, or delivery drivers, there are evolving work tasks and expectations facing both new and existing workers.[226] Increased automation and artificial intelligence are leading to rapid changes throughout our infrastructure networks, and younger students in particular need access to high-quality, relevant work-based learning opportunities that can stand the test of time.[227]

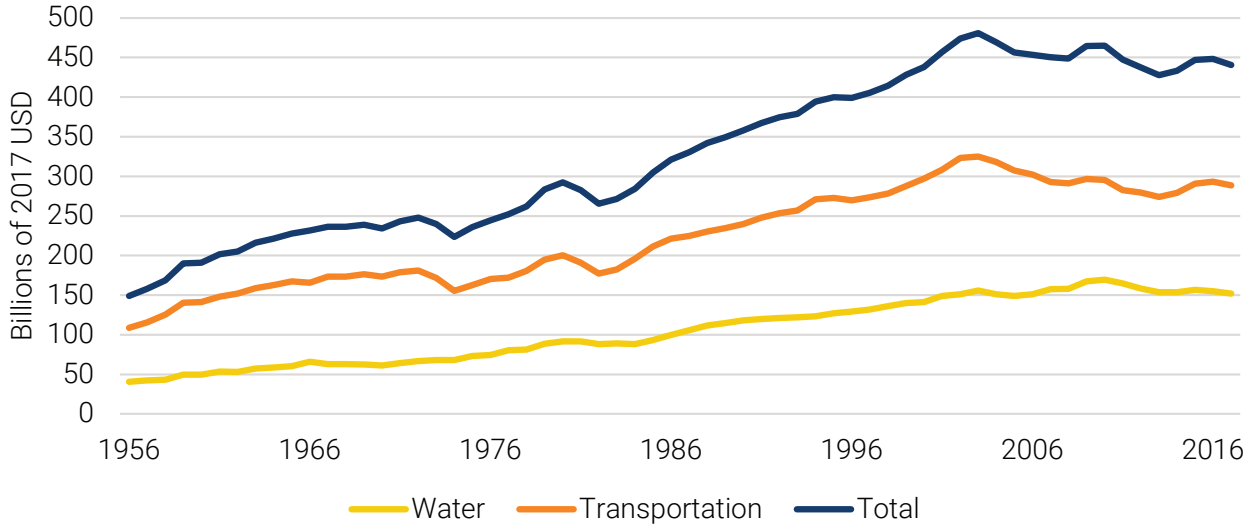
Fiscal health

Context

Investing in infrastructure matters for building and maintaining an efficient, reliable network of assets to support a productive, opportunity-rich economy. But too often, federal policymakers focus on *how much* to invest and *what* to invest in, while lacking detail on *why* and *where* to invest. Calls for spending more money—$1 trillion, $2 trillion, or more—dominate media headlines and policy proposals.[228] Calls to spend more on particular projects—from flood barriers in New York City to high-speed rail in California—capture the public imagination.[229] Yet, nationally, we lack clear objectives to inform and target our future infrastructure investments, relying on 1950s-era policy frameworks to expand capacity rather than developing 21st century models to better maximize the value of our existing and new systems.[230] Federal policymakers, alongside state and local leaders, need to acknowledge and overcome the fiscal hurdles that are limiting our ability to invest and achieve long-term economic impact.

In many ways, we do need to invest more in infrastructure. Increased spending on new capital projects and capacity expansions are warranted, especially in areas with expanding economies and populations.[231] Integrating new technologies and designs also holds potential to improve operational performance, particularly amid a more extreme and uncertain climate. And the U.S. especially needs to spend more on repair and replacement needs; many roads, ports, pipes, and other systems are aging and at the end of their useful life, where maintenance is lagging and upgrades are necessary.[232] The U.S. spends about $440.5 billion on our transportation and water infrastructure each year on both capital and operations and maintenance—an amount that struggles to keep up with our mounting infrastructure demands, the rising cost of materials, and other emerging trends.[233] More recently, over the last decade, our spending fell by $9.9 billion in inflation-adjusted terms.

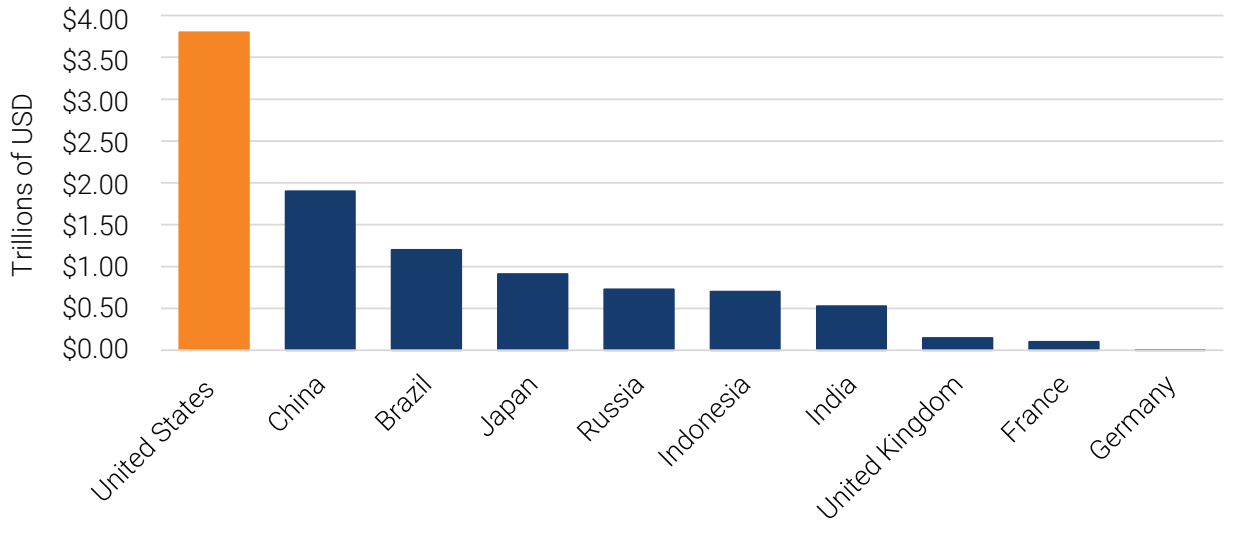
Figure 22. US public infrastructure spending by sector, 1956-2017



Source: Brookings analysis of Congressional Budget Office data

The U.S. also lags behind its global peers when measuring infrastructure spending across transportation, water, energy, and telecommunications. While the G20 measures the United States spending over $300 billion on these four infrastructure categories in 2018, that is a relatively small share of our GDP (1.5%) when compared to the United Kingdom (2.0%), France (2.4%), and Australia (3.5%). Critically, our domestic spending levels do not currently match estimates of need.

Figure 23. Gap between current investment and investment needed by country



Source: G20 Infrastructure Hub
Note: Baseline forecasts of infrastructure investment under the assumption that countries continue to invest in line with current trends, with growth occurring only in response to changes in each country's economic and demographic fundamentals

However, not everything is broken, and the federal government only controls so much when it comes to infrastructure investment.[234] Basic repairs and ongoing maintenance remain the areas of greatest need nationally, and state and local governments are the primary owners and operators of up to 87% of the roads, transit systems, water systems, and other assets in need of investment.[235] State and local governments are also responsible for more than three-quarters of public infrastructure spending each year.[236] And while private energy utilities and internet service providers make the vast majority of investments in those systems, there are increasing calls for the public sector to improve broadband and energy services.

The fiscal pressures facing states and localities are immense, and only growing following the COVID-19 pandemic. But infrastructure repair is just one budget item alongside education, public safety, and other community services, and state and local leaders are mostly on their own to address these needs; federal aid accounts for just 5% of total municipal revenue.[237] The margin for error is also small: The median rainy day fund balance as share of general fund spending was 7.8% in 2020, while median own-source revenue has increased by only about $3 per capita over the past decade.[238] The fiscal standing of different states and localities varies widely; while places with vibrant economies and growing populations can generate the predictable and sustainable revenues needed for infrastructure maintenance and upgrades, places with more sluggish economic and population growth often lack the capacity to invest.

The competitiveness of American infrastructure depends on a healthy fiscal system. One component is the public funding made available for infrastructure capital projects and operations, including federal funding made available to states and local governments. There is a balancing act between ensuring funds can be accessed more easily and developing projects to advance shared interests. Another component are financial instruments, as states and localities use debt markets to support projects and pay back lenders with interest, using indirect taxes and user fees to service the debt obligation. The federal government is an important actor here too, both approving tax laws to reduce borrowing costs and even offering their own credit assistance instruments.

The challenge is ensuring federal, state, local, and private leaders collaborate to address current needs while striving for future-looking innovations and improvements. No single actor or action can bridge our infrastructure investment gaps; the U.S. needs a coordinated approach to identify, manage, and target more support to the people and places of greatest fiscal need. The following two sections explore the fiscal barriers and possibilities to do so.

Challenges

Asset management

Perhaps the biggest challenge for our current and future investment requirements is a lack of consistent information on the scale of our physical infrastructure needs. Underlying any fiscal decision about infrastructure is a basic set of questions: what infrastructure assets already exist, who owns them and is responsible for their operation and maintenance, and what is their condition? In many cases, infrastructure owners and operators cannot readily answer such questions, let alone policymakers.

For example, a 2015 survey of water utilities nationally found that 71% did not have designated staff members to manage asset inventories, and only about half of surveyed utilities had an asset inventory plan. Nearly half did report storing basic asset data (identification, location, age, and material), but only 12% reported storing advanced asset data (condition, criticality, replacement value) and only 10% had organized their asset inventory into a hierarchy.[239]

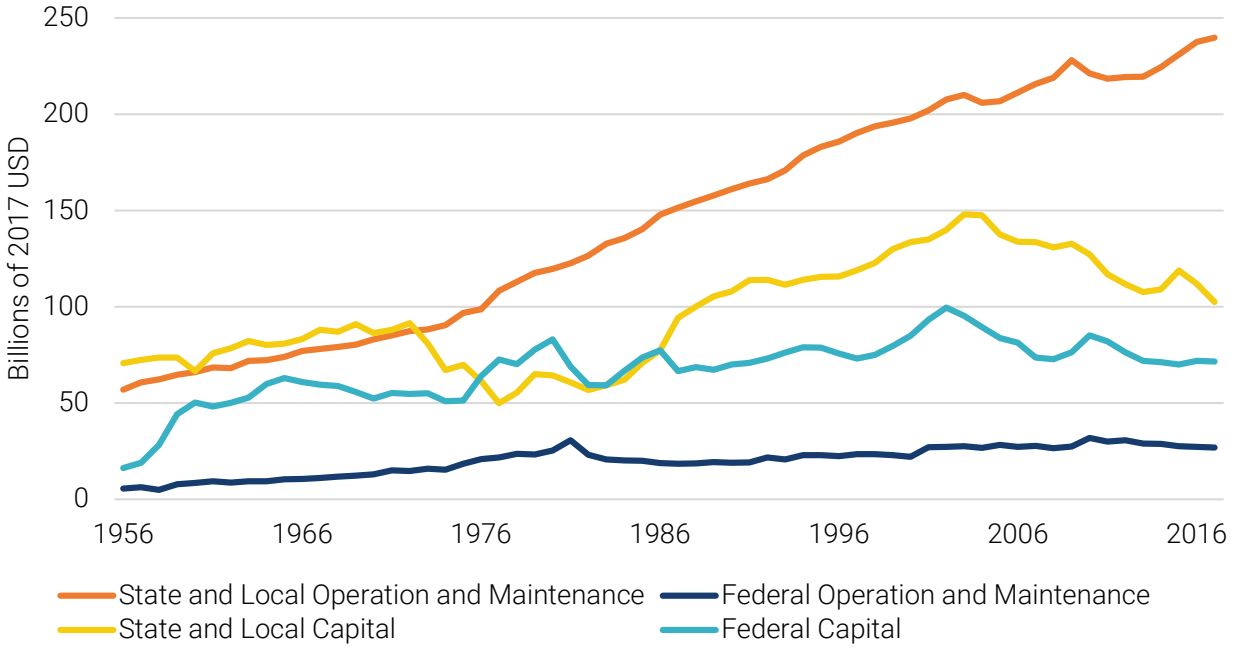
Incomplete asset inventories can cause major problems for infrastructure operations and budgets. If a water utility is unaware that some of their most important pipes are in poor condition or reaching the end of their useful life, they may fail to identify or prioritize these assets in capital planning budgets. Deferred maintenance can saddle utilities with escalating costs over time, including more frequent repairs, service interruptions, and widespread system failures. Local transportation agencies are

more likely to know exactly where their streets are, but monitoring pavement quality is challenging, and monitoring and improving sidewalk quality can be even harder.[240] Localities may not know where their municipally owned telecommunications poles are or may not have control over the poles installed on public right of way, both of which limit improvement opportunities.[241]

Failing to measure, monitor, and maintain assets can lead to challenges accelerating and targeting future capital improvements. While states and localities bear most of the direct responsibility for asset management, this challenge spans all types of infrastructure and regions. And the current lack of federal planning around this issue only compounds the problem; there is not enough technical guidance or funding flexibility to encourage better state and local asset management. Since states and localities have to cover 90% of all transportation and water operations spending nationally each year, there is often little wiggle room to pursue bigger maintenance projects and capital upgrades.[242] Meanwhile, only four states—Alaska, California, Hawaii, and Tennessee—clearly disclose the cost of deferred maintenance in their budgeting process.[243] Many states spend below 1% of annual expenditures on deferred maintenance, leaving an estimated $873 billion maintenance gap in state capital budgeting.[244] Appropriate asset management plans paired with effective capital planning can push actors to better plan for the entire lifecycle of assets, and to consider long-term operation, maintenance, and even environmental costs.[245]

Federal spending programs often do not incentivize more resilient spending practices, stabilize places with unstable fiscal footing, or help high-growth markets invest more in themselves. The Department of Transportation's (DOT) largest single spending program uses outdated formulas that reward states based on greater road lengths and higher driving levels.[246] Among many central controls on local transportation revenue streams, federal law places a cap on the passenger facility charge (PFC) that airport authorities can charge flyers, even though it limits borrowing capacity.[247] Federal legislation discontinued EPA capital grants to water authorities, which now rely on State Revolving Funds that can be unattractive to overextended communities

Figure 24. US public infrastructure spending, by category of spending and level of government, 2007 to 2017



Source: Brookings analysis of Congressional Budget Office data

like Flint.[248] Meanwhile, mandates to eliminate combined sewer overflows (CSOs) come with limited matching funds to support construction.

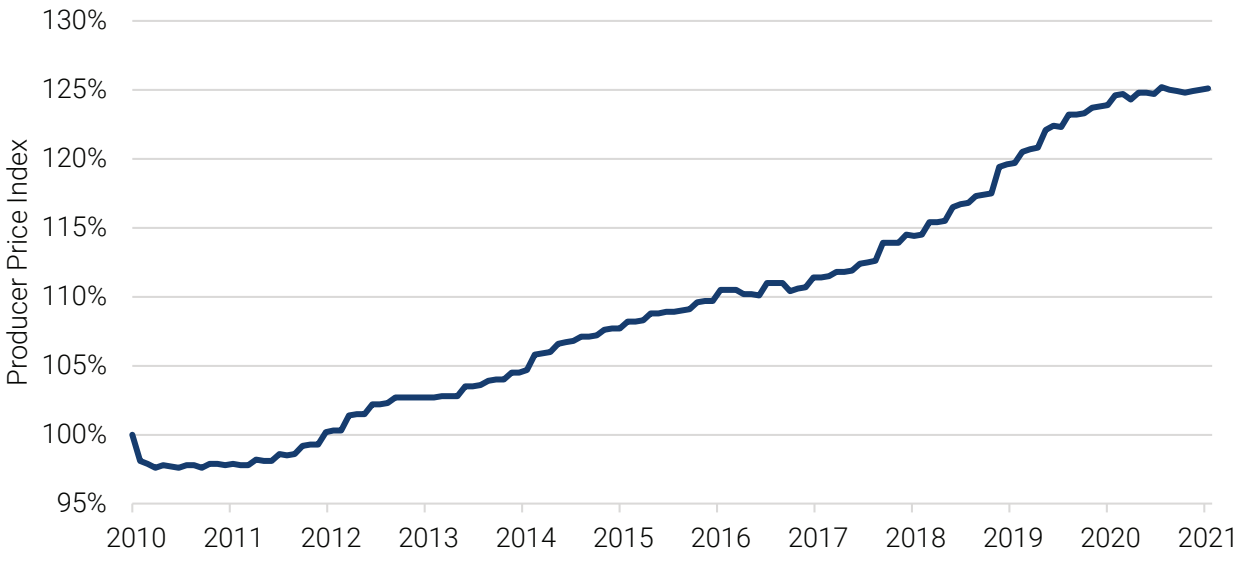
High project costs

Beyond struggles to measure and target needed investments, public and private leaders often confront high costs to carry out projects. Even though researchers have found inconsistent explanations for higher costs, there is little question that U.S. infrastructure is relatively expensive.[249] In a study comparing 144 rail projects across 44 countries, researchers found the top four most expensive projects (on a per kilometer basis) to be in the U.S.[250] And the cost of construction in the U.S. continues to grow: The Producer Price Index shows a 25% increase in national construction costs in the past 10 years, exceeding the overall Consumer Price Index.[251] While productivity growth in construction industries has been historically difficult to estimate, recent Bureau of Labor Statistics research found labor productivity *decreasing* in the construction of highways, roads, and bridges.[252]

This challenge is complicated; no single cost from labor to materials to even land is significant enough to account for our remarkably high prices, especially in the case of highway infrastructure. Unionization rates, for example, are often considered to drive construction prices higher, yet construction costs are lower in France than the U.S. despite virtually all workers covered by collective bargaining there.[253] While the cost of land in dense, coastal U.S. cities is high, land is also expensive in dense cities around the world. One of the most likely explanations is the post-1970s rise of property owners' power and protections in the project planning process.[254] With a variety of policy tools, property owners can object to projects that would bring additional pollution, noise, and nuisances—highways, for example, may therefore take more time and money to complete.[255] Presidential administrations and the Government Accountability Office have pointed to insufficient predevelopment activities—such as engineering assessments and economic impact analyses—as causes of increased project costs.[256]

Policymakers and practitioners often see the federal infrastructure permitting process as a major cost contributor. There is little question that various environmental reviews required under the National Environmental Policy Act (NEPA)—which are triggered when federal funding is involved in a project—often take extensive time and staff resources to execute. However, the reviews are an

Figure 25. Increase in US construction costs, 2010 to 2021



Source: Brookings analysis of U.S. Bureau of Labor Statistics data
Note: Producer Price Index, Construction (Partial) indexed to June 2009 prices

important tool to protect environmental quality. Finding ways to streamline reviews while still protecting environmental quality (including human-centric environmental justice) is an issue that demands policymakers' and advocates' attention.

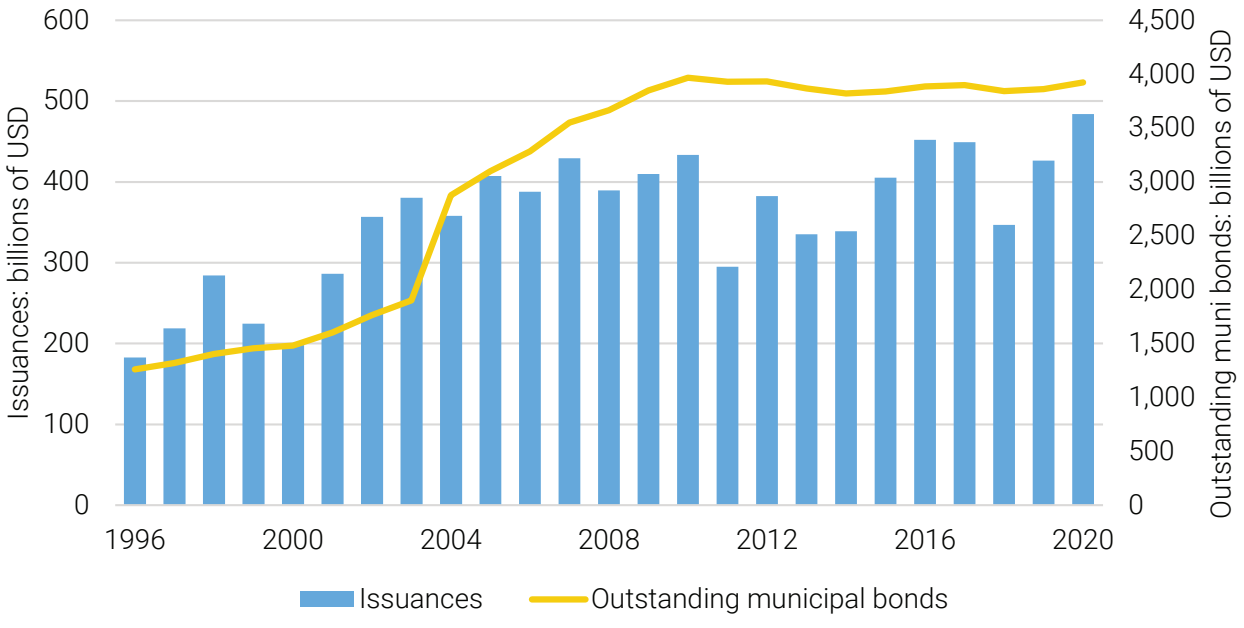
Capacity constraints

In the face of increasing construction costs and daunting maintenance backlogs, federal, state, and local leaders often opt for faster repairs and familiar designs. Band-Aid projects often appear to be the only practical option when compared to the scale necessary to modernize entire systems. Yet more and more Band-Aids cannot stem the ever-increasing flow of problems, and in the long run, avoiding system modernization is more costly.[257]

Fortunately, American credit markets work well for infrastructure owners. The municipal debt market consistently holds about $4 trillion in outstanding debt, and the combination of long-standing tax benefits, rating agency expertise, and issuer experience help muni markets operate efficiently.[258] Meanwhile, private energy and broadband owners also can go to corporate debt markets to make long-term investments when necessary. The bigger issues are ensuring those investment dollars flow to the best projects and that no community is left behind.

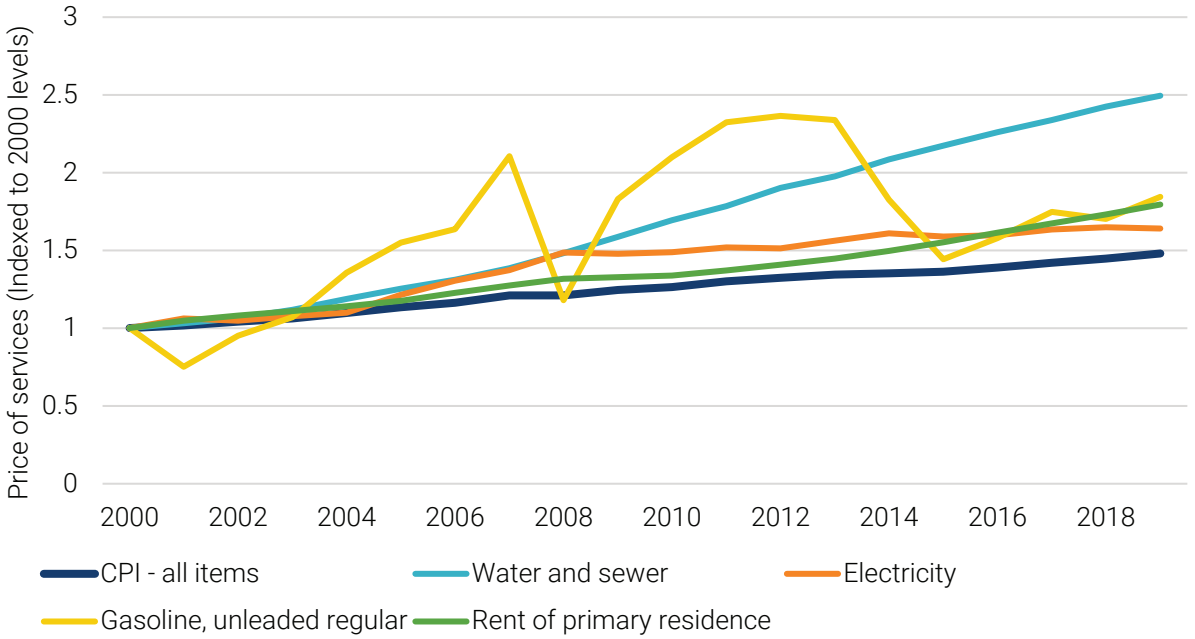
Even with efficient credit markets, many states and localities still do not have the fiscal capacity to maintain current assets, and even many large communities cannot pursue new projects. States and localities are responsible for over 75% of public spending on infrastructure each year, and 95% of public spending on water infrastructure alone. Many of them struggle to keep up with these spending needs, creating a vicious cycle of raising property taxes, direct user fees, or other revenue sources, which further strains local household budgets and leads to economic equity concerns.[259] For example, between 2010 and 2018, the average U.S. monthly residential water bill increased 50%.[260] Transit agencies who fill budgetary shortfalls with higher fares frequently lose riders, compounding the budget problems while often leading to greater service losses.[261] Meanwhile, many states and communities have explored transportation and water public-private partnerships to test techniques such as accelerated project delivery schedules,

Figure 26. The size of the US municipal bond market and new issuances, 1996-2017



Source: Securities Industry and Financial Markets Association
Note: Available outstanding municipal bonds data ends in Q3 2020

Figure 27. Indexed change in the price of selected infrastructure services, 2000 to 2019



Source: Brookings analysis of Consumer Price Index data, seasonally adjusted. Prices are based on monthly changes

risk transfers, and financing instruments that could expand the project pipeline but also lead to negative outcomes.[262]

The converging impacts of these challenges are felt most acutely in the communities who can least afford it. Communities with slowing population and economic growth are stuck with legacy infrastructure systems built for a different time, which has led to rising debt burdens. Legacy cities—those that have lost at least 20% of their population from peak levels, have poverty rates above the national average, and have at least 50,000 inhabitants—face an average of $5,300 in long-term debt outstanding per capita.[263] Both tax revenues and user-pay revenues fall with slowing population and economic growth. Own-source revenue in legacy cities, on average, is $3,094 per capita, compared to $3,272 per capita among all cities.[264] Thus, reactive user fee increases are spread across a narrower population and are proportionally higher. Fiscally constrained communities also confront the challenge of being deemed less creditworthy in private markets and in accessing federally supported financing programs.

Regional fragmentation and state politics

From the smallest towns to the largest metro areas, places benefit when local infrastructure networks strike a balance between a region's physical scale and prevailing user demands. If a state or region builds too much infrastructure, long-run maintenance costs can become a strain on public sector budget. Build networks too small, though, and congestion can increase, dragging down economic productivity and quality of life in the process—if not long-run economic opportunity as well. U.S. infrastructure governance often makes this balancing act harder than it needs to be, leading to cost inefficiencies that impact every household and business.

Jurisdictional fragmentation and regional political demands within metropolitan areas can lead to mismanagement. While the majority of the country's population and economic output is metropolitan, individual metro areas are relatively informal constellations of counties and sometimes over 100 independent municipalities.[265] Each of those governments may run their own transportation

department and sometimes telecommunications authority. Water utility footprints are often disjointed across metro areas, with watersheds and service areas bleeding over jurisdictional boundaries. The fragmentation can lead to higher infrastructure costs in multiple ways, including limiting governments' combined purchasing power, over-construction on the metro area periphery, and duplicate operations.[266] Fragmented governance forces peers to collaborate to maximize cost efficiencies—and when they don't, as in the case of many greenfield developments on the metropolitan fringe, it can lead to excessive construction and broadly inequitable outcomes.[267]

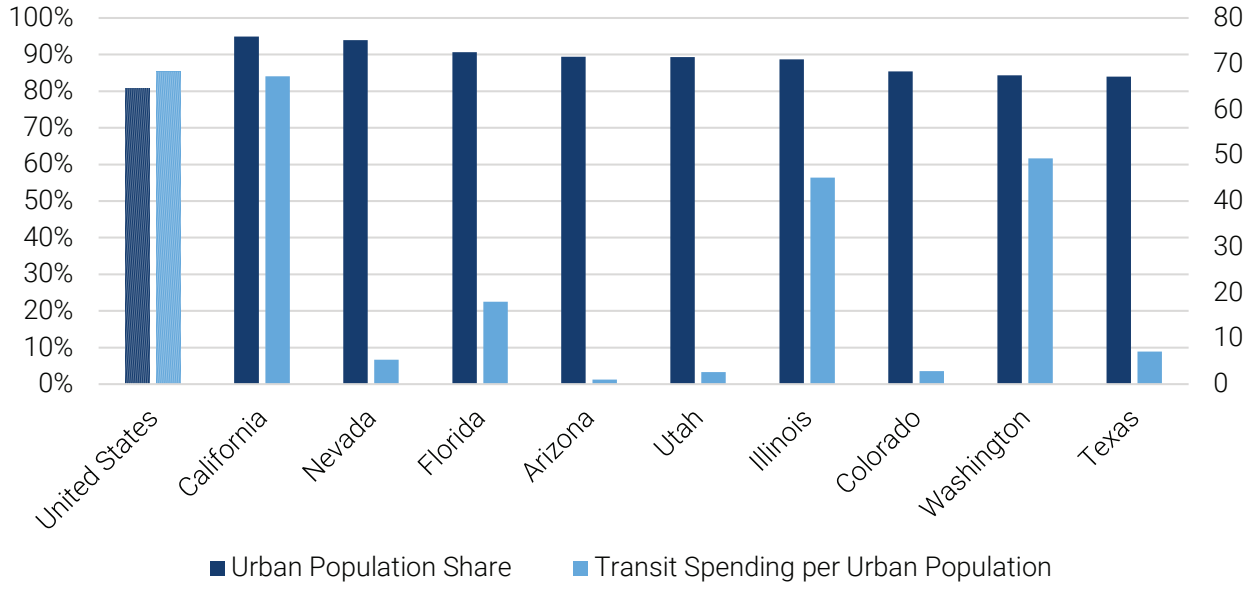
A similar scale issue occurs at the state level, but here the culprit is often political geography. Lower-density rural and exurban communities often have disproportionate representation in state legislatures. Where states own infrastructure like highways or heavily influence spending through other funding flows, the tilted representation incentivizes legislators to proportionally spend more in underpopulated regions, many of whom have had slower population growth for decades.[268] The political effect can also work in reverse, like in the case of many state legislatures who underinvest in transit infrastructure to the detriment of their denser communities. In the end, the misalignment between politics and population leads to misaligned infrastructure networks.

Emerging trends and volatility of demand

State and local governments approach infrastructure planning from a long-range perspective. They build multiyear capital budgets, delicately organizing the order of projects based on expected need and available resources. Their infrastructure offices are filled with budget experts and economists who estimate consumer demand for decades at a time, using data to inform how big future projects may be and how long it may take to payoff project-related debt. A long-term perspective makes uncertainty a nemesis, as is already the case with current roadway traffic forecasting.[269]

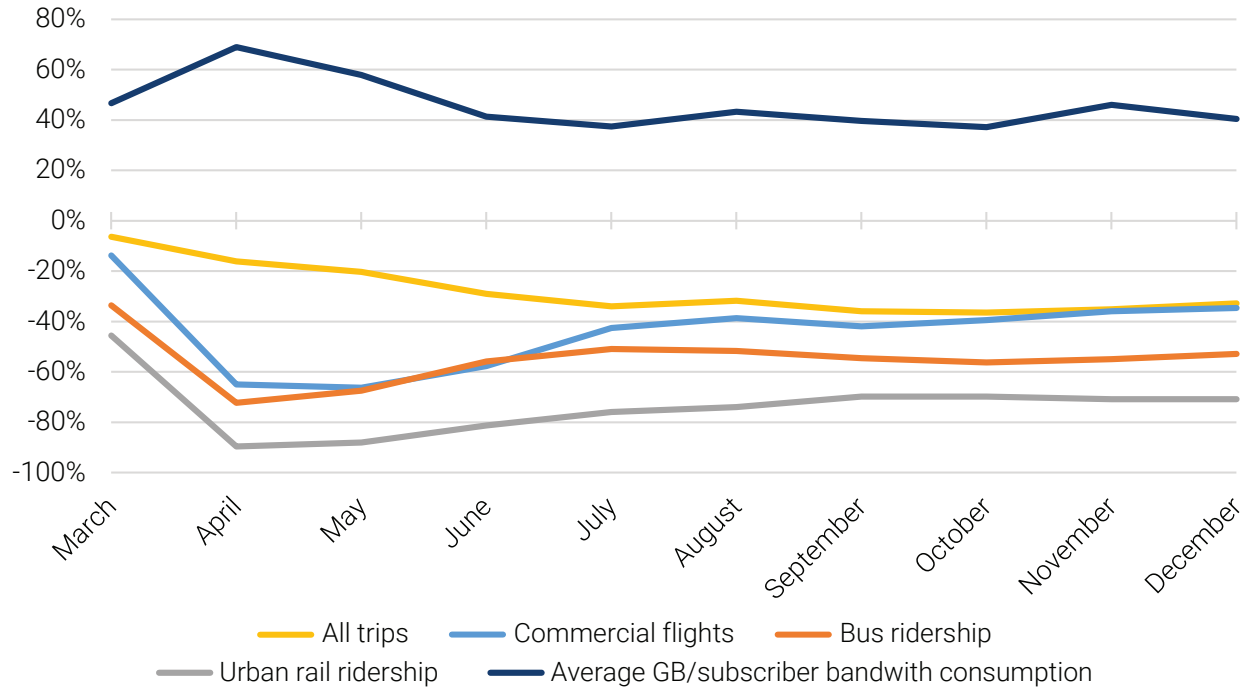
Moving forward, infrastructure planners are dealing with far more uncertainty than usual. The rise of e-commerce has already upended traditional estimates of demand for retail parking, freight deliveries, and local tax revenues. COVID-19 only confirmed how much higher the e-commerce ceiling may be. COVID-19 also showed us a world with less

Figure 28. State transportation spending and urban population share, 2019



Source: Brookings analysis of IPUMS and Federal Transit Administration data

Figure 29. State transportation spending and urban population share
Year over year percent change in infrastructure usage, 2019 to 2020



Source: Brookings analysis of Bureau of Transportation Statistics and OpenVault Broadband Insights Report data

office work and long-distance travel, both of which make past highway and aviation investments seem far too big and expensive. The changing geography of work disrupts water and energy utilities who plan especially for large enterprise customers. Heightened online activity increases the pressure on broadband providers to deliver ample bandwidth and regulators to make sure those networks are truly equitable.

While vaccines and changing behavior will help overcome COVID-19, infrastructure planners can't safely assume a return to past usage patterns. That's especially the case with a more extreme and unpredictable climate. This demands planning for fiscal uncertainty, including the use of scenario planning. One possible scenario is a significant revenue shortfall in many municipalities and states to maintain prior investments. Where those scenarios become real, the economic fallout will be significant and long-lasting.

Opportunities

A forward-looking infrastructure vision puts significant pressure on states and localities. As the owners of transportation and water assets, they must balance the need to maintain current networks while still investing for the future, including their collaborations with private owners of energy and broadband infrastructure. Federal policymakers have an opportunity to address both by helping states and localities overcome the fiscal barriers described above. That means maintaining what we have more consistently and cost-effectively, while pursuing new projects with greater intentionality and flexibility.

More consistent and cost-effective maintenance

Better asset management is essential to identify, measure, and target needed investments.

Governments need inventories to more clearly know where assets are installed, their age, and their material components. Sensors and other data reporting systems can connect to those inventories to monitor build quality, network usage, and to design new programs to promote more efficient resource use. Procurement policies can tap asset inventories and monitoring data to plan purchases in advance and secure lower market prices. The net effect is to help governments plan their capital budgets, execute cost-efficient maintenance projects, and avoid expensive emergency repairs. The federal government can support adoption of better asset management practices by either promoting or incentivizing their use among state and local governments, plus providing the technical expertise and funding support to ease adoption.

There are also ample opportunities to bridge gaps between our siloed planning and institutional frameworks, especially at a regional level. Redundancies and intersections in government units can be combined, and assets shared. Consolidation, for instance, could benefit smaller water utilities that lack economies of scale to hire staff, keep up with maintenance, and achieve operational excellence. With more than 50,000 highly localized and fragmented water utilities across the country, there are challenges around capacity for leadership and collaboration.[270] Utilities could gain operational efficiencies, stabilized revenues and user fees, and coordinated planning improvements by consolidating.[271] Similarly, empowering metropolitan planning organizations with greater revenue-raising authorities or compelling local governments to adopt regional capital budgets can deliver long-term cost savings and service improvements across the surface transportation system. Finally, there should be formal incentives for localities to synchronize the timing of their capital and operational budgeting processes.

Across both asset management and consolidation practices, the federal governments should consider how to offer additional support to the most fiscally constrained local governments and metro areas. Many of the most pressing fiscal health challenges are bearing down upon the communities that are least prepared to address them, especially low-growth rural towns or small metropolitan municipalities with a shrinking tax base. Whether it be access to new credit vehicles or new approaches to intergovernmental fiscal support, these communities need fiscal assistance. The best opportunities for such leadership will incentivize modernization of the costly legacy infrastructure systems that strain local budgets. Federal officials should also consider decommissioning infrastructure assets in certain areas, which can reduce long-term infrastructure budgets and reenergize local economies.[272]

More intentional, flexible, and risky capital upgrades

In addition to more consistent maintenance, federal policymakers also need to help states and localities pursue long-term capital upgrades. The pace of digital innovation is leading to a perpetual stream of new products and services, while the climate crisis demands a new approach to infrastructure design and construction. More stable fiscal footing would allow governments to invest in and regulate infrastructure with confidence, create a more entrepreneurial business environment, and deliver a higher quality of life to all residents.

That starts with experimenting with new fiscal tools designed on both the benefits principle and the ability-to-pay principle. More resilient approaches to infrastructure revenue could unlock more forward-looking investment. Infrastructure networks deliver sweeping benefits, allowing both businesses to grow their operating profit and households to increase their income. Our global peers and competitors understand this relationship and use general funds to invest more in infrastructure than the U.S. does. The federal government should follow their lead and rely more on general funds, ensuring higher corporate and household incomes get recycled back into long-term infrastructure investment.

A higher revenue baseline would also allow the federal government to work with state and local partners to adopt different user fees so that those who benefit from infrastructure also pay for its use. Drivers could pay vehicle miles traveled and gas taxes, sending clear market signals about

congestion and environmental impacts.[273] Water and energy utility fees could be better matched to usage through the installation of digital sensors and smart metering, lowering costs and incentivizing efficiency and environmentally friendly behavior. Even data innovations such as merging revenue and spend data with household and business information could unlock areas for cost savings and improved customer assistance programs.

Federal agencies can design new competitive grant programs to reduce the riskiness of testing new technologies and incentivize long-term planning among applicants. Both DOT's Smart City Challenge and Department of Housing and Urban Development's (HUD) National Disaster Resilience Competition sparked hundreds of communities to design and execute digitalization and resilience programs, proving competitive grants can extend impacts far beyond the finalists and winning applicants.[274] Oversubscription of DOT's BUILD and INFRA grants demonstrates the same issue.[275] Considering long-run questions about the economic and environmental returns from formula-funded capital projects, there is space for Congress and federal agencies to consider rebalancing the share of spending committed to competitive versus formula grant programs.

Finally, the federal government has an opportunity to deliver more equitable economic outcomes by supporting a grand redesign of infrastructure affordability programs and explicitly recognizing a user's ability to pay. The EPA could better measure and support water utilities' customer assistance programs, including the potential to better identify households of need, gauge eligibilities, and lower or offset bills. The FCC's $9.25 monthly Lifeline subsidy is woefully too small, and a COVID-19 emergency program to offer $50 monthly broadband service will only last months.[276] Demand for the Low Income Home Energy Assistance Program will only grow as temperature changes become more extreme. DOT only offers indirect, flat tax subsidies to drivers, transit riders, and bicyclists, and the subsidies grossly promote driving over more sustainable, healthier travel. The opportunity for a more comprehensive infrastructure affordability program is clear.

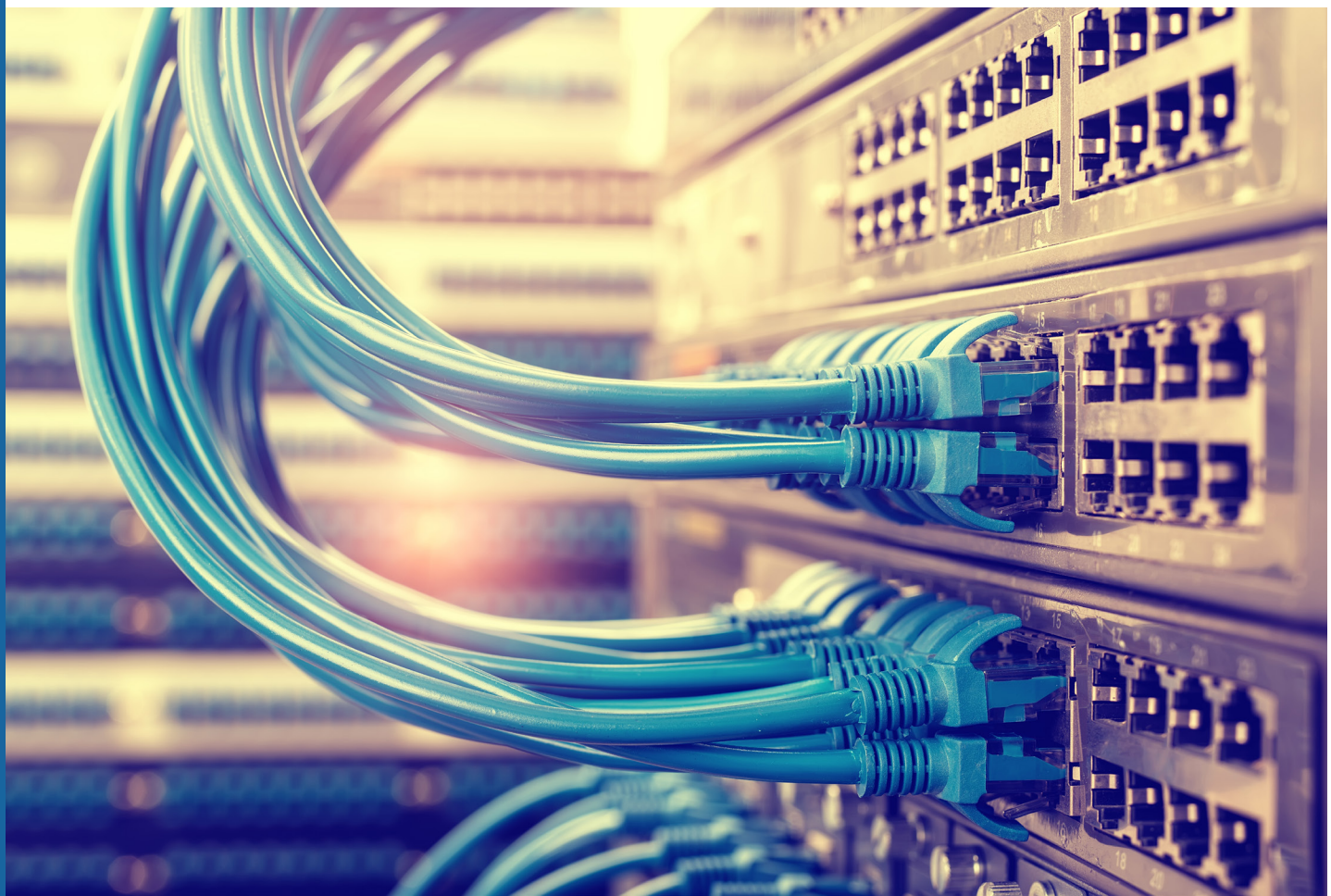
Building a 21st century infrastructure vision

The American economy ended the 20th century in an enviable position, in no small part due to historic infrastructure investments. The national commitment to high-quality highways, expansive aviation networks, and modernized ports boosted the country's trade. The build out of reliable electricity and telecommunications networks allowed industrial innovation to flourish. A commitment to safe drinking water and clean wastewater kept people healthy and reduced pollution to our rivers, lakes, and streams.

As America's economy, society, and environment continue to transform, its infrastructure must confront an evolving set of challenges. A fragile and uncertain climate requires cities, towns, and industries to reduce their environmental footprint and better manage chronic and acute events. A rapidly digitalizing economy demands faster, ubiquitous broadband, an equitable approach to skills development, and new data management techniques. A shortage of middle-skill, middle-income jobs—and a lack of coordinated and flexible training pathways—necessitates a new approach to workforce development. State and local governments need fiscal support to maintain their historic infrastructure and rebuild for tomorrow.

The opportunity, then, is to adopt a future-looking vision for American infrastructure policy that can respond to these challenges in ways that improve the quality of life for all people, reinforce our global economic standing, and protect our planet. That process begins with federal leadership.

One component of federal leadership is clearly articulating the shared goals our infrastructure systems should advance. Some goals are the same as ever, such as facilitating trade, supporting entrepreneurship, maximizing regional economic strengths, and promoting safety. Some goals have grown more urgent, such as talent development, poverty reduction, environmental protection, and civic engagement. Some new goals have emerged



based on new technologies, such as enforcing data privacy and supporting a clean energy economy. It's incumbent on congressional leaders and executive agencies to formally adopt these goals within legislation and agency mission statements, respectively.

Federal leadership also means retiring outdated approaches. The country cannot blindly support capital projects without first understanding how spending will impact shared goals such as racial inclusion, data security, or environmental resilience. Congress cannot afford to appropriate more infrastructure funding without first considering long-term maintenance responsibilities, lifecycle costs, or design standards. Finally, the U.S. will fall behind its global peers if the federal government does not commit enough resources to testing new technologies, new training programs, and other emerging ideas.

Most importantly, federal leadership means adopting a cohesive vision to achieve these goals. To this end, we recommend the federal government anchor a new infrastructure vision around three interdependent strategies. First, the federal government should update how agencies **measure** infrastructure need and connect that information to shared goals. Second, the federal government should use these improved measurement systems to **modernize** physical assets and better serve user needs. Third, the federal government should commit more resources to **experiment** with physical technologies, fiscal practices, training systems, and applied management practices.

The following three sections recommend general actions the federal government should take to bring a new infrastructure vision into practice. We do not explicitly tie these recommendations to specific legislative cycles, nor are they an exhaustive list of every step legislators or bureaucrats will need to take—or all the various impacts to state, local, and private infrastructure owners and operators. We also do not characterize the political circumstances surrounding the recommendations, many of which—like environmental permitting or data privacy standards—will cause significant fights among opposing parties.

Instead, these recommendations are meant to strategically shift how policymakers and their colleagues approach policy reform. Ideally, focusing on a future vision will help build trust in designing policy in the present.

Measure

Measurement systems—including data, data management platforms, and statistical programs to lead collection and analysis—forge the connection between goals and performance. They enable leaders to evaluate the operational performance of infrastructure systems, determine progress toward certain goals (e.g., safety), and adjust strategies and priorities based on demonstrated need. For the federal government, policymakers should enhance existing measurement systems to better monitor, evaluate, and address our pressing infrastructure needs.

High-quality data is the fundamental building block of any measurement system, and the federal government has long supported multiple high-quality data programs to lead collection efforts. Programs at the departments of Transportation, Energy, Commerce, the Environmental Protection Agency, and the Federal Communications Commission all monitor various forms of infrastructure usage and asset quality. The Department of Labor provides high-quality data around household spending patterns and the labor market, including employment, wages, and demographics for hundreds of different occupations. The Department of the Interior has an astounding database of land-focused resources.

But these data-focused programs aren't perfect. For example, Congress passed the Broadband DATA Act in 2020 due to failures in mapping wireline availability—and even that law will not fill gaps around broadband pricing and service quality.[277] There is no precise national atlas of transportation infrastructure, a prerequisite for many kinds of autonomous vehicles. Labor-focused programs do not have timely or geographically granular data on several workforce issues, including infrastructure-related skills or credentials.[278] Even among high-quality data programs, the fact that each agency operates their data infrastructure independently

makes it harder to create interdisciplinary performance measures around cross-cutting topics such as environmental justice.

The federal government also confronts data limitations when working with their state and local partners. State and local governments own transportation and water infrastructure, but many do not know the precise location or condition of all their water pipes or track the changing quality of physical assets such as sidewalks. They also may not know the exact location or condition of their telecommunication poles, an essential element of broadband right of way.[279] These limitations make it difficult for federal agencies to judge where they should prioritize capital investments and technical assistance.

The federal government should enhance existing measurement programs to improve data collection and management, which can accelerate infrastructure repairs and other upgrades nationally. The four categories below describe these enhancements in greater detail.

Asset inventories

Asset inventories are an emerging practice among infrastructure and other public agencies to assemble detailed information related to their physical assets. The digitalization of everything has made it easier than ever to track asset quality, while climate instability amplifies the need to protect current and future assets. The federal government must work with their state and local partners—the primary owners of public infrastructure—and private network owners to establish common inventory standards and upgrade the quality of infrastructure asset intelligence.

Accurately recording the location and quality of physical assets is an important place to start. Water pipes are a stark example, as many utilities have limited knowledge of the specific condition or history of their pipes to identify, prevent, and fix leaks and other failures.[280] In addition, local governments often do not know exactly where various infrastructure is buried underneath their roads or exactly where telecommunication poles are. The federal government should find a way to support a national audit of where public and private infrastructure are and dedicate funding to maintain the inventories over time. Washington, D.C.'s Capital Asset Replacement Scheduling System is an example of the effort such an audit can take and the invaluable information it conveys.[281]

Federal agencies should complement geographic audits with data around infrastructure spending and other underlying fiscal indicators, such as capital installation and energy consumption. Theoretically, practitioners should be able to connect capital spending directly to specific locations and the quality of the components used in each project (and across whole systems). However, current federal spending data is not always tracked to this detail. An interagency database should help federal policymakers and practitioners understand exactly where federal dollars flow and the quality of the asset built.

Asset inventories also should serve as a standard platform to store data around infrastructure operation. Digital sensors continue to fall in price, making it easier than ever to automate asset monitoring, ranging from detecting water pipe leaks to air quality alongside high-volume transportation infrastructure. Asset inventories will allow the agencies responsible for monitoring to relate their performance data to specific assets, which can in turn inform long-range investment plans.

More closely tracking the location, condition, and ongoing use of different infrastructure assets will enable the federal government and its state, local, and private peers to better manage lifecycle costs and invest more efficiently. The U.S. has the public resources and private financial capital to build physical assets for long-term sustainability and resiliency, including any higher upfront construction costs that lead to long-term savings.[282] Creating a clear, reliable database of lifecycle costs—coupled with federal grant and lending programs—can help infrastructure owners and operators make sound long-term fiscal decisions. Rather than focusing on individual modes or projects in isolation, policymakers and practitioners should use lifecycle management practices to respond to shifting demands over time, reduce system risks, and avoid uncertain costs.[283]

There is precedent for the federal government to establish asset management standards, including how federal funding can incentivize the creation of local asset inventories. The 2012 Moving Ahead for Progress in the 21st Century Act (MAP-21) required recipients of formula highway grants and transit agencies to adopt asset management plans.[284] Likewise, the EPA has had a role promoting and coordinating asset management strategies across water utilities nationally.[285] Courts have required local governments to inventory their sidewalks to ensure compliance with the Americans with Disabilities Act (ADA) standards.[286] Congressional and agency leadership should learn from—and ideally expand—these types of efforts.

Environmental impact analysis

The country has struggled to mitigate and adapt to a changing climate. Federal infrastructure agencies need to develop and implement new measurement tools to judge the environmental impacts of their capital investments and operational programs. This is especially true when it comes to gauging how environmentally equitable these impacts can be, given the uneven costs often experienced by lower-income households and communities of color. We recommend at least three interdependent actions to do so.

To start, the federal government needs to significantly upgrade its existing environmental data resources, which tend to be specific to individual agencies, regulations, and types of infrastructure. These often fail to reflect the rising number and severity of environmental impacts that traverse multiple agencies, regions, and facilities. For example, place-based emissions inventories should track particulate matter, nitrogen oxides, and other airborne pollutants related to both transportation and land use practices. The same applies to airborne pollutants such as methane and waterborne pollutants such as nutrient runoff related to agricultural practices. Governments at all levels need to have frequent updates of their watersheds, including wetlands, groundwater resources, and other sensitive land features, whether in rural or urban environments.[287] Critically, regulations to upgrade environmental data should work in tandem with asset modernization, specifically to require sensor deployments. Improved environmental data will then enable federal, state, and local agencies to execute environmental justice audits at a greater geographic scale. Academic research has consistently found that historic and ongoing infrastructure investments have disproportionately impacted economic mobility and social determinants of health for residents of certain neighborhoods.[288] To ensure infrastructure systems build shared opportunity for all, environmental justice audits can help policymakers understand the impacts of current infrastructure networks and proposed investments and operational reforms. For example, studying urban heat islands can enable local practitioners to prioritize activities ranging from tree plantings to setting up cooling centers to dispatching mobile health care services.[289]

Federal agencies should also leverage improved environmental data to develop scenarios of environmental risk in all states and communities. The public sector must be flexible in the face of heighted environmental instability, and scenario planning is an established practice to prepare governments for a wide range of possible situations. Climate scientists and researchers have developed—and updated—many different assessments to model and predict environmental impacts over time, which should be integrated into federal infrastructure planning efforts.[290] The USDA, for instance, has carried out climate change impact assessments to diagnose risks, and Federal Emergency Management Agency (FEMA), among other agencies, has looked to further prioritize climate adaptation in future programmatic activities.[291]

Delivering environmental justice: Moving beyond environmental impact assessments

The National Environmental Policy Act (NEPA) of 1970 is a foundational piece of environmental legislation that (among other things) requires federal agencies and partners to preemptively assess and document the environmental impacts of federal actions—and, if necessary, adjust plans according to the findings. In 1994, an executive order explicitly added environmental justice to federal agency missions, and a related memorandum detailed that "human health, economic, and social effects, including effects on minority communities and low-income communities, be included in the analysis of environmental effects pursuant to NEPA."[292]

This critically important mandate has taken decades to define, culminating in a 2016 report[293] from the Environmental Justice Interagency Working Group on "Promising Practices" for incorporating environmental justice considerations into NEPA processes and a 2019 report[294] offering communities advice to navigate the process. But the Trump administration's court-filed challenges against NEPA are still in motion, and so the future of the law's environmental justice portions are also tied up. [295]

American communities need environmental justice to be an "all of government" priority, and that includes the work of federal infrastructure agencies. Decades of evidence prove the impacts highways have had on business owners, community vibrancy, and property values.[296] Lower-income communities located just outside freight hubs like ports experience disproportionate health impacts.[297] Fiscally constrained communities are far more likely to experience unsafe drinking water conditions.[298] Delivering economic justice—including health improvements—will require these agencies to right the wrongs of the past while investing for a more equitable future.

Benchmarking workforce, household, and small business prosperity

Infrastructure does not have to represent an economic hurdle; it can play an affirmative role in addressing American income and wealth inequality. However, doing so will require more specific data and benchmarks to gauge workforce needs, household outcomes, and business conditions.

Connecting workers to infrastructure careers depends on a clearer assessment of the hiring, training, and retention needs facing current employers. Right now, DOL measures employment and wage levels in infrastructure-related industries and occupations, projected growth and replacement needs, and general knowledge and skill requirements.[299] However, multiple federal agencies—from DOT to EPA to the Department of Energy—should work more closely together alongside DOL to identify mission-critical occupations, measure demographic characteristics (including retirement concerns), and track changing skill considerations, especially in light of new technologies. The development of additional technical training resources for infrastructure employers and other regional workforce leaders—including competency models and curricula templates—can also build capacity and encourage more consistent measurement efforts nationally.

Federal agencies should also more purposefully benchmark how infrastructure service pricing and service availability are impacting U.S. households. Transportation, water, energy, and broadband services represent a sizable portion of household budgets, with the share of total spending especially large for the lowest-earning households.[300] The White House Domestic Policy Council can convene relevant infrastructure agencies and other central offices—notably the Council of Economic Advisers—to design affordability targets for households based

on need. These standards can inform the operations of current affordability programs like the Low Income Home Energy Assistance Program (LIHEAP) or help launch new ones. While the complexity of these affordability issues demands more attention, research, and testing—as the National Academy of Public Administration identified in the water sector—that should not prevent policymakers and practitioners from exploring different models toward implementation.[301]

The same affordability and availability concerns can apply to many small businesses, especially startups or businesses operating in disadvantaged neighborhoods. The Department of Commerce and the Federal Reserve banks and branches should collaborate with local lending institutions and other economic development agencies to monitor infrastructure needs among their small business community.

Bridging the affordability divide: Improving broadband pricing data

Anyone who has moved to a new home and searched for a broadband provider understands the pricing challenge. The bundling of television and phone service makes it difficult to see a single price for broadband service, while ancillary costs can be hidden.[302] Federal agencies face the same pricing data collection barriers as private households do—and it's limiting the country's ability to solve the digital divide.

Public officials and researchers have long understood the importance of price in attracting broadband adoption and tapping its full potential. Trusted surveys such as those from the Pew Research Center regularly find price to be the top barrier to broadband subscription, and the situation has grown worse during COVID-19.[303] The challenge is that federal regulation does not require internet service providers (ISPs) to provide detailed pricing information in publicly available datasets. For example, data limitations mean the Bureau of Labor Statistics' Consumer Expenditure Survey cannot report isolated broadband spending.[304]

Fortunately, some states and local communities are forging ahead by collecting pricing data as part of their efforts to increase broadband access. For example, Tennessee Broadband Accessibility Act grants are administered and evaluated through the Tennessee Department of Economic and Community Development (TNECD), which requires quarterly reporting and a final project closeout report—without which, grantees cannot collect the final 15% of their award.[305] Project closeout reports must include the prices charged for service, the speeds those prices deliver, and coverage metrics like the number of businesses or homes the broadband runs by, home connections, and other measurements.[306] These reporting requirements, combined with data on digital literacy education from the State Library and Archives, are submitted in annual TNECD reports to the state legislature.[307]

Research based on samples of publicly advertised prices can produce helpful estimates, but this is not a perfect substitute for the accurate, well-defined, and place-based price data that could help researchers and public officials understand the market conditions households face. Building on the connectivity and speed components of the Broadband DATA Act of 2020, regulators at the FCC and Congress should require ISPs to provide transparent pricing data to start studying the affordability issue in greater detail.[308] While price transparency alone will not make subscription services or devices any cheaper, the information can inform future policy.

Federal Data Reserve

The exponential growth in data creation, data privacy issues, and data sharing demands among governments and businesses has heightened the urgency to update federal data management practices. It is no longer safe or efficient to have each federal department independently manage their own data operation standards. We recommend the creation of a new central office—a Federal Data Reserve—to address these needs. The office should have three broad responsibilities.

First, the office should establish data privacy and cybersecurity standards for all federal agencies. The federal government collects and stores some of the country's most sensitive private information, including household demographics, taxpayer data, and business finance and payroll information. The global surge in cyberattacks intensifies the need to protect these sensitive resources, and the successful federal data breach in December 2020 only affirms the need.[309] Following a model like 18F, the office should hire expert staff and rely on outside counsel to stay at the forefront of privacy practices and cybersecurity techniques—and then collaborate with federal agencies and state and local partners to adopt their standards.[310]

Second, the office should establish interagency and external data sharing standards. One of the advantages of the digital era is the nearly frictionless environment to share data between agencies or their outside partners. However, data sharing inherently creates opportunities for third parties to illegally capture data. Formatting standards are also necessary to facilitate data sharing. The federal government has an established practice of promoting sharing standards. For example, the federal government already benefits by using the Census Bureau's geographic standards to code certain spatial information. Infrastructure systems will benefit if Congress can adopt a safe sharing standard like the Health Insurance Portability and Accountability Act (HIPAA) does for health care. Wherever possible, the office should also use established open-source data standards.

Third, the office should serve as a central repository for sensitive public or procured data, ranging from vehicle movement data to business tax records. Using the same privacy, security, and sharing standards, the new office could become a central storage point—or data lake—for certain public and private data. In particular, the new office could lead federal regulations and procurement for acquiring emerging private data sources such as geospatial movement patterns.[311]

Modernize

When combining major equipment and structures, the country's major infrastructure systems—including transportation, water, energy, and telecommunications—are conservatively valued at $13.9 trillion.[312] Maintaining those physical assets is a prerequisite to keep the economy moving and to protect the natural environment. But the country's long-term competitiveness requires more than routine upkeep of networks. To deliver long-term prosperity for all households and businesses, the country needs modern infrastructure networks that respond to the future-looking challenges outlined in this report.

The federal government is well positioned to lead a national, decades-long effort to rebuild and reimagine our physical networks. Federal agencies typically distribute direct funding to states, localities, and private owners to build out infrastructure networks. Those same agencies can use grants and loans to incentivize or mandate construction in certain places, use certain materials, or follow certain construction processes. The federal government also has the regulatory authority to require specific design and operational standards for a wide range of infrastructure activities, from the emissions associated with power plants and vehicles to the nutrients and pollutants released into fresh bodies of water. Finally, federal programs can offer direct aid to households and businesses to influence their personal infrastructure decisions, including making services and equipment more affordable for those in need.

To develop modern infrastructure networks, then, the federal government has a responsibility to use its legal authority and financial influence to steer infrastructure development toward projects, places, and people with demonstrated, long-term, national

need. When infrastructure programs no longer advance shared values, the federal government must also be willing to change its practices. For example, federal powers can help manage a retreat from flood plains or coastal areas threatened by sea level rise. This principle also works in reverse, like rethinking broadband investment and regulation to reach neighborhoods left disconnected.

The following section proposes four categorical actions that will continue to refine how the federal government invests in infrastructure assets, their maintenance, and their long-term use.

Physical standards

The construction and manufacturing sectors are undergoing significant changes in the 21st century. Digital innovation led by private companies and research institutions has flooded the market with new tools to design, build, and monitor physical assets. Materials science researchers often invent new products that can extend a project's useful life or sustainability. The federal government should use new standards to leverage technological innovation and inspire ongoing research and development.

Digital sensors can monitor infrastructure quality and use, and the federal government should use its financial or regulatory authority to accelerate their deployment across the country. To start, the federal government should develop clear, flexible standards—based on prevailing and evolving needs measured at a state and local level—around integrating digital sensors into infrastructure assets. Agencies should then reform existing grant and loan programs to require installation where sensible. For example, a mix of roadway and in-vehicle sensors will be necessary to transition to a vehicle miles traveled (VMT) fee system, and DOT should initially lead these efforts as it considers other new technologies, such as AVs. The EPA should likewise look to develop and apply more consistent standards to better monitor the extent of our drinking water and wastewater pipe replacement needs and other environmental concerns, including air quality, that could benefit from more digital sensors. As the federal government grows its monitoring mandates, federal programs should cover the relatively small costs to procure and maintain sensors.

To respond to ongoing environmental stressors, federal agencies should upgrade their design manuals and funding programs to incentivize more resilient infrastructure construction and maintenance. Green infrastructure designs and other distributed infrastructure upgrades—including rain gardens and pervious pavers that reduce stormwater runoff—should become a standard within transportation, water, and other related programs.[313] The federal government should also promote the burying of essential energy and telecommunications in areas with minimal underground risk exposures to protect against major and chronic climate impacts.[314] These programs will have the dual benefit of reducing long-term maintenance costs for infrastructure owners and helping the U.S. stay at the forefront of materials science and construction methods innovation.

Finally, federal regulators should use definitional standards and benchmarks to incentivize innovation. Federal emissions guidelines can push automakers to manufacture vehicles with the most sustainable inputs, whether related to battery components, fuel efficiency, or fuel sources. The FCC and Department of Commerce should regularly update how they define broadband based on the economy's growing intensity of data use and compel faster and ubiquitous broadband coverage. Likewise, energy regulators should continue to push utilities and product manufacturers to shift to renewable electricity sources and more sustainable energy consumption practices.[315]

Adopting new design standards: Building information modeling and the UK approach

A coalition between the Centre for Digital Built Britain, British Standards Institution, and UK BIM Alliance is working to design, communicate, and implement a set of building information modeling (BIM) standards.[316] Building information modeling, or the "use of a shared digital representation of a built asset to facilitate design, construction and operation processes to form a reliable basis for decisions" is an emerging global practice. The UK's collaborative effort to set shared standards can serve as a model for data and information sharing standards in the U.S.[317]

BIM standards are an attempt to bring greater efficiency to construction practices by using a purpose-built collaborative platform and integrating digital monitoring and design services into projects from the onset. The BIM standards themselves include how shared information should promote values of efficiency and privacy while also ensuring transparency so all project parties are informed of necessary design components and data flows. Standards also determine the ideal quantity of data to be shared to a similar end.[318] The collaboration ultimately seeks to eliminate the inefficiencies—from resending files to rebuilding project components—that come from data mismanagement and miscommunication.

Academic research confirmed the UK's BIM standards deliver sizable cost savings to project delivery, including over 20% total cost reductions in transportation projects executed soon after BIM adoption.[319] With the emergence of the Internet of Things (IoT), BIM will have even more opportunities to reduce project costs and enhance collaboration as digital inputs grow.[320]

Physical network upgrades

American infrastructure is not falling apart.[321] However, the country's physical networks do demand regular upkeep and—when components reach the end of their useful life—wholesale reconstruction. Federal agencies should use a mix of asset inventories, environmental impact analyses, prosperity benchmarks, and new design standards to inform the next great wave of physical network upgrades. These will require a mix of updated agency strategic plans, direct spending, and retooled regulations.

Broadly defined, the nation needs to upgrade its interstate and local energy delivery systems to reflect the shift to clean and renewable energy sources. Both long-range transmission systems and local distribution networks will need to reflect the science and geography of a grid reliant on renewable sources, including environmentally safe redundancy during peak loads and extreme weather events.[322] Executing these actions will require federal coordination with the private owners of energy transmission and distribution, as well as state-level regulators and commissions. Federal agencies will need to adjust regulations and Congress will need to determine if public funds should help cover private network operators' construction costs.

With many assets nearing the end of their useful life and a range of new user behaviors taking shape, the country's transportation networks require some clear, long-term upgrades. For those assets directly under federal ownership, the transition to satellite-based aviation navigation is a top priority, as is modernizing locks and other navigation activities within the inland waterway system.[323] For the roadways, railways, and bridges owned by state and local partners, DOT can support construction techniques that reflect updated physical standards for resilience and durability. Addressing poor road quality on local streets is especially important too.[324]

The federal government should also ensure public right of way has the sensors to enable autonomous vehicle usage and more flexible user charge schemes, including for local deliveries.[325] Improving freight rail access to ports, industry facilities, and intermodal terminals can also greatly improve the flow of goods in years to come.[326]

The federal government also has a unique responsibility to consider the best infrastructure to service inter-metropolitan travel. The U.S. commitment to "drive or fly" is well established outside a handful of regions, most notably the Northeast Corridor from Washington, D.C. to Boston. However, consolidation within the aviation industry, the uncertainty about eliminating fossil fuels from commercial flights, questions around private vehicle ownership models, and the interstate nature of many metro-to-metro connections make modernizing passenger rail infrastructure—including significant network expansions—a uniquely federal issue to address in the coming decades.

Local water systems have some common modernization needs that the federal government should assist in. The most immediate is to replace outdated distribution infrastructure, including lead pipes.[327] All U.S. systems should be built to safe standards, and direct federal spending plus new asset inventories can accelerate that process. Repairs to pipes and conveyance systems for our wastewater needs are also urgent, in addition to continued upgrades of outdated combined sewer systems that are susceptible to costly overflow concerns.[328] Innovations in our drinking water and wastewater plants remain crucial to energy, water, and resource efficiency as well, including the implementation of reuse technologies.[329] The Oroville Dam disaster was visceral evidence of the need to upgrade dams and levees, many of which are aged beyond basic repair.[330]

The nation's industrial competitiveness and levels of economic inclusion go hand in hand with our ability to keep improving digital telecommunications. It should be a national goal to ensure every household and business address can access either fiber wireline, 5G wireless, or both. Like the New Deal-era pursuit of bringing electricity and telephone service to every community, reaching this goal will require the federal government to test a range of regulatory and spending models, plus continued innovation from the private sector. As long-term national upgrades are underway, federal policies should prioritize those neighborhoods underserved by current wireline and wireless networks.

Reconnecting metropolitan America: Rebalancing aviation and passenger rail connectivity

The Airline Deregulation Act of 1978 set into motion decades of deregulation and consolidation within the commercial aviation industry. While the total number of annual passengers continued to set records with each successive non-recessionary year, airline consolidation also led to a loss of connectivity in many markets. Metro areas such as Cleveland, Cincinnati, Memphis, Tenn., and Raleigh, N.C. lost their hub status, and many smaller markets also lost their direct connections. With so many direct flights rerouted through a few elite hubs, air travel from any non-hub metropolitan area is increasingly inconvenient and environmentally destructive.[331]

The American economy can't afford to keep people apart, and our environment can't handle more solo driving than necessary.[332] Yet two decades into the new century, America faces what might be a historic first for the country: the permanent loss of metropolitan connectivity.

Seeing the logical endgame of a deregulated commercial aviation industry, federal officials now have an opportunity to consider two alternatives, both of which could be pursued at once. The first would be reintroducing some level of aviation regulation that incentivizes greater connectivity. This could push emerging technologies such as electric motors in smaller planes, which also may tilt the economics of smaller metro-to-metro connections. The other option is to follow the lead of our European and Asian competitors and reinvest in regional passenger rail networks.

A reinvigorated passenger rail network can improve environmental outcomes while promoting growth in places that airline consolidation left behind. The North Atlantic Rail, a proposed high-speed rail project that would tunnel under the Long Island Sound to Hartford, Conn., Providence, R.I., and Boston—and eventually up to Vermont, New Hampshire, and Maine—is one example of several regional rail projects being proposed to address these needs.[333] Projects like this could simultaneously improve access and economic growth for smaller cities and transform regions into united commuter hubs. With the election of President Joe Biden and his long-established commitment to Amtrak, the next three years could be a grand opportunity to use passenger rail to rebuild the connectivity we've lost.

Improving our invisible infrastructure: Identifying and addressing our aging water pipes

Our water infrastructure is outdated and deteriorating in many regions, especially the pipes that handle our drinking water, wastewater, and stormwater. Out of sight and out of mind, many of these pipes—whether made of iron, steel, concrete, plastic, or even wood—have increasingly fallen into disrepair due to age, neglect, and increased environmental and economic pressures.[334] Decades of underinvestment, combined with a lack of clear measurement and coordinated planning, have resulted in a national crisis of growing proportions that utilities and municipalities (the primary owners and operators) cannot solve on their own. Federal leaders need to boost our financial and technical capacity around pipe repair, replacement, and modernization.

Doing so requires better identifying and measuring our most pressing water infrastructure needs, which remain highly fragmented and localized. Nearly 50,000 community water systems (CWS)—publicly owned and operated water systems that serve the same population year-round—vary widely in their scope. For example, about 4,500 of these systems serve half of the total CWS service population (314.6 million people) nationally, while more than 27,000 of these systems serve a total of only 4.6 million people, which averages out to about 169 people served per system.[335] Meanwhile, there are more than 1.2 million miles of water pipes nationally that range in age from only a few decades old to pre-Civil War.[336] Our watersheds and service boundaries also differ markedly within and across regions, with some places having multiple water systems and pipe histories.

Addressing the complex web of water assets and pipes nationally not only requires more investment, but also more coordinated planning. Although the Clean Water and Safe Drinking Water acts of the 1970s initiated more comprehensive federal regulation and oversight of our water infrastructure—primarily through the EPA—states and localities have largely had to contend with the day-to-day challenges of maintaining and upgrading our systems. They are responsible for 95% of total public spending on water infrastructure each year, while the federal government has scaled back grant funding and opted for more loans.[337] Yet, balancing water investment and affordability has remained a struggle for many utilities, especially as regulatory needs, system repairs, service demands, climate pressures, and other costs have escalated over time.[338] Smaller systems in particular may lack the staffing or financial resources to effectively manage their pipes. As a result, recent national assessments show $472.6 billion is needed over the next 20 years to maintain and improve our drinking water infrastructure, on top of our wastewater and stormwater needs. Most of this total ($312.6 billion) is to replace or refurbish distribution and transmission pipelines.[339]

Even with additional measurement, investment, and planning, the national challenge is massive and growing, and will require greater federal leadership to effectively scale solutions. In addition to all the leaking pipes nationally—which waste 14% to 18% of our treated water every year—lead service lines (LSLs) are perhaps the most glaring need for federal leadership.[340] While cities such as Flint have highlighted the urgency of this challenge, there are an estimated 6.1 million LSLs nationally, which threaten our public health, environment, and economy.[341] Updates to EPA's Lead and Copper Rule to test LSLs has raised awareness, but the ultimate responsibility to replace LSLs still mostly falls on individual utilities and customers across different jurisdictions.[342] And while some places require consumer consent for utilities to access and replace the lines, others enact municipal ordinances requiring homeowners to hire private contractors to replace them.[343] This patchwork setup is inadequate and inefficient to deal with such a massive challenge; replacing LSLs is a national priority with significant equity implications that demands additional federal leadership, funding, and action.[344]

Equitable access

Modernizing the physical quality of infrastructure networks is important, but those networks only optimize their economic, social, and environmental value if every household and business can access and afford them. The federal government should improve service access by amplifying this issue in several existing programs.

Federal household affordability programs are in dire need of updates and expansions. While the development of new affordability standards and benchmarks remains a work in progress, the federal government should look to connect these data collection and measurement efforts with practical implementation. For example, expanding support for water utilities' customer assistance programs (CAP) can help them meet current needs and address evolving concerns, as can expanding existing federal programs such as LIHEAP and the FCC's Lifeline program.[345] The federal government should also launch affordability programs in the transportation space, which is the number-two household expense after housing.[346] These can include zero-fare transit programs and targeted rideshare subsidies for low-income households. The COVID-19 pandemic also made a case for federal regulators adopting permanent "shutoff moratorium" regulations during economic, environmental, and public health crises.

The Department of Commerce should also begin to partner with financial institutions to design a new enterprise program focused on small businesses' and startups' infrastructure needs. For example, telecommunications discounts or water and energy utility forgiveness could help businesses survive during lean times or experiment with business concepts that require heavy infrastructure use. Utility bill relief has already attracted interest among federal policymakers during the COVID-19 pandemic and could jump-start future conversations and actions.[347] Tax credits or direct subsidies could use targeted businesses as a place to test green construction techniques or accelerate the rollout of emerging technologies.

Fiscal capacity-building

The federal government should use infrastructure programs to build long-term fiscal capacity at the state and local level while also making more efficient use of federal budgetary resources.

Federal procurement reforms are one clear area to do more with less. For example, calls for the U.S. Postal Service to transition to electric vehicles can both save long-run vehicle maintenance and energy costs for the agency, while the bulk purchase could incentivize further innovation within the vehicle manufacturing industry.[348] Federal grant programs—such as the Federal Transit Administration's Grants for Buses and Bus Facilities Program—can have the same effect by incentivizing state and local vehicle procurements within transit and similar agencies.[349] Exploring ways to help localities reform their procurement process for green technologies can also unleash innovation and cost savings nationally.[350]

The federal government should also start to use equity- and environmental-focused accounting methods to ensure federal grants and loans improve fiscal health. On the one side, fiscal shortfalls in many communities mean infrastructure assets can quickly turn from drivers of economic growth to long-run liabilities. The federal government must have thoughtful processes to help communities understand which assets they can maintain and where they should consider downsizing their infrastructure obligations. National examples of this include Iowa officials considering how to manage so many paved rural roads and Detroit's program to move the last remaining residents in a neighborhood in order to shut off utilities and stop road maintenance.[351] The federal government can also offer technical assistance to communities to better understand their budgetary scenarios. In the water sector, for instance, more consistently surveying and mapping the fiscal health of utilities can expand peer-to-peer learning and best practices around asset management.[352]

There is an immediate need to use new accounting methods to consider the future of the national highway system (NHS), many parts of which are nearing the end of their useful life. Decades after their construction, analysts now better understand how highways benefit long-distance local travel and goods trade, but also suppress nearby land

values and negatively impact public health.[353] The federal government should actively work with local civic networks, including adjacent neighborhood groups, to determine which NHS portions should be modernized and which should be decommissioned to make way for healthier neighborhood growth.

In the coming decades, the federal government should directly interrogate the strains caused by fragmented governance at the metropolitan level, continued outward population growth, and the mounting infrastructure costs required to service greater land areas. Metropolitan areas often include tens if not hundreds of local governments, all of whom share a common labor pool and industrial base.[354] Such fragmentation can lead to higher infrastructure costs due to duplicative services in capital planning, uneven levels of service due to unequal distributions of wealth, and a mix of both.[355] The water sector is especially fragmented, and steps toward greater utility consolidation could help; smaller systems in rural and urban regions alike lack the financial resources, staffing capacity, and economies of scale to invest in needed repairs and comply with regulatory demands.[356] The federal government should use federal policy (especially grant funds) to incentivize regions to explore ways to regionalize infrastructure management, mitigate the climate-related impacts of excessive land consumption, and promote more equitable land use practices.

Finally, the federal government must consider how permitting reforms and supporting predevelopment activities can promote fiscal capacity-building at the state and local level while still protecting existing natural resources and environmental justice priorities.[357] Environmental permitting reform is a deeply complex and politically contentious issue, yet the upside to government balance sheets and the natural environment is too big to not address.[358] Ideally, the federal government can use demonstration projects to test how fast-tracked reviews can reduce long-run fiscal costs while still increasing environmental sustainability. Similarly, the federal government should continue to explore how limited support for state and local predevelopment activities could lead to accelerated project delivery and improved project outcomes.[359]

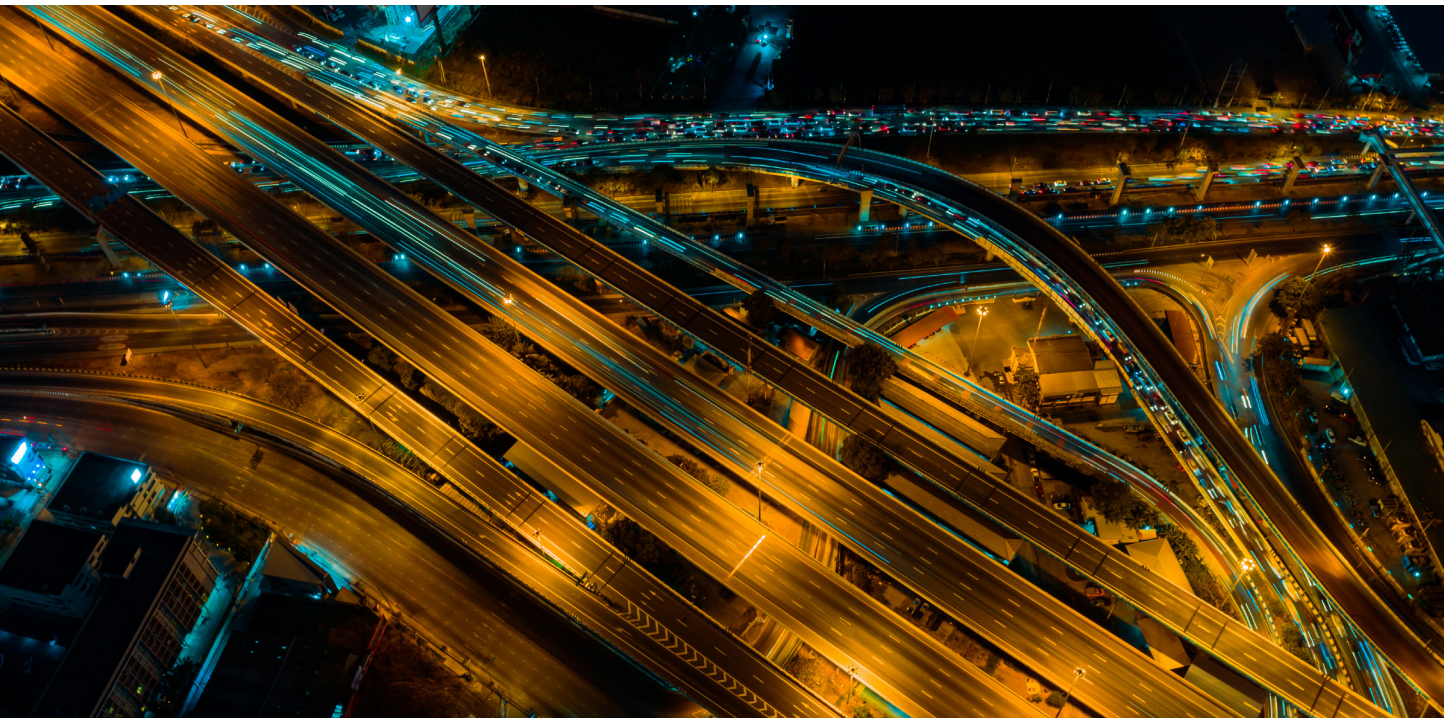
Experiment

Infrastructure has the power to capture our imagination. From the infamous Futurama exhibit at the 1939 New York World's Fair to computer-rendered cityscapes in movies like "Minority Report," infrastructure is often a central way for artists and the public to envision communities of the future. Yet artistic renderings are more than just for show. Recasting today's infrastructure with the newest technologies is an essential part of preparing our cities, suburbs, and towns for the future, giving the public a forum to debate which new concepts may reflect our shared values.

Real-world experimentation with new designs, technologies, and ideas is also an essential component of adopting a future-looking infrastructure vision.

American federalism is well suited to testing new ideas. Independent governments at the municipal, county, regional, and state level all have the resources to experiment with different technologies, funding and financing models, engagement strategies, and management systems. This "laboratory of democracy" enables a broad range of original ideas to move into testing, creating feedback loops and helping the best ideas to get replicated while relative failures get scrapped or updated.[360]

Congress and executive agencies should help shape this experimentation process. The federal government can provide seed funding and competitive grants to incentivize widescale conceptual testing, as in the case of the Smart City Challenge program that launched in 2015.[361] The federal government can pursue risky scientific efforts, which research programs under the National Science Foundation and other agencies regularly do. The federal government can use field offices and central agency staff to communicate best practices across the country, similar to how the EPA's Office of Community Revitalization engages nationally.[362] And once best practices are established, the federal government should have the regulatory and financial reach to help successful experiments inform wholesale network modernizations.



The following section details four conceptual areas where the federal government should inform future-looking infrastructure experimentation. These concepts and short summaries are not intended to capture every worthy idea. Instead, they are examples of how the country should take risks and doggedly pursue cutting-edge ideas. The federal government should commit to relentless experimentation, learn from it, and further scale best practices, designs, and other improvements.

Technology testing

American infrastructure networks support—and enjoy direct access to—the world's leading innovation engine. The high number of domestic and foreign-born university graduates, a financial system and corporate culture that reward research investments, and a legal system that protects new ideas all incentivize the creation of new infrastructure-related technologies.[363] The federal government should support a national infrastructure pipeline by helping test products and ideas that address the country's shared challenges. Many of the following recommendations can expand on the responsibilities and ongoing achievements of the various National Laboratories programs.[364]

Capital construction and operational expenditures are a sizable share of every state and local government's budget, meaning cost-saving construction techniques are an important area for exploration. For example, American transit projects often cost considerably more than peer countries, and new evidence shows that underground construction is a clear problem area.[365] Testing cost-efficient tunneling alternatives would benefit transit agencies and their local economies who would have the extra budget to expand transit networks. More efficient tunneling could even lead to other innovative uses, such as more efficient underpasses or bicycle highways. Innovative gray and green construction techniques, including new cisterns to harvest rainwater, can lead to upfront cost savings and long-term operational efficiencies, too.[366] The federal government should purposefully research and deploy cost-saving technologies whenever possible, including purposeful pilots with states and localities.

The country also needs to build the inventory and expertise around sustainable construction practices. Distributed infrastructure improvements such as green roofs and onsite wastewater treatment technologies can better manage our water, energy,

and other natural resources.[367] Unlike traditional, centralized infrastructure facilities—including large pipes, pumps, and plants that are inflexible and costly to maintain—distributed infrastructure tends to be smaller, more flexible, and responsive to local environmental and economic conditions. For instance, following Hurricane Sandy in 2012, New York City promoted more on-site water reuse and treatment technologies to reduce waste and conserve resources, during good times and bad.[368] Likewise, Austin, Texas, has launched a "Water Forward" plan to capture and treat up to 100 million gallons of water each year by 2040, as part of one of the nation's most ambitious rainwater harvesting projects.[369]

The federal government should continue to support experiments with advanced materials and ascendant technologies to address both fiscal and environmental challenges. Mass timber is an emerging concept in the construction industry that offers sustainability benefits over concrete or steel but could also be used in a factory setting to further reduce marginal costs.[370] Ground-penetrating radar can make roadway and utility projects more efficient (especially when preserving older assets) and could also lead to burying more essential infrastructure, which has other climate-related security benefits in the right places.[371] Regions would benefit from an interagency pilot program to consider building resilience into physical assets that serve multiple purposes, like how San Francisco's Embarcadero Seawall includes miles of utilities within the wall.[372] Every federal agency that oversees capital grant programs should have programs to incentivize materials testing and other emerging technology pilots, similar to the Department of Energy's Advanced Building Construction Initiative.

Energy generation and delivery pilots are another essential area for federal leadership, from local distributed energy systems to major electricity generation to innovative energy storage concepts. The federal government should continue supporting tax-related policies that incentivize development of renewable energy sources, ranging from the Residential Energy Credit for homeowners to the Renewable Electricity Production Tax Credit for energy providers.[373] Similarly, Congress should provide the Department of Energy with growing financial resources for the Loan Programs Office—which can offer debt financing for commercial-level projects to reduce GHG and other air pollutants—and its direct funding to state and local governments.[374] The federal government should also support the development of new products through funding renewable energy-related R&D, such as through the ARPA-E program, the new QIS research institutions, or a future ARPA-Climate program.[375] There are many more energy opportunities, so the whole of the federal government should aim for energy infrastructure that pursues zero-carbon generation and dependable interstate transmission and distribution.

Transportation is the top source of greenhouse gas emissions, and the economy and the environment need an electrified transportation system. The federal government should incentivize this generational transition through a broad series of policies. Programs to help cover the costs of public charging infrastructure plus in-home and small business electrical upgrades can accelerate household and fleet electric vehicle adoption. Based on success in peer countries such as Norway and Denmark, Congress should increase federal tax credits to reduce vehicle purchase costs.[376] It is essential that the federal government work with utilities and local governments to incentivize bidirectional vehicle-to-grid communication, and related pricing policies can encourage off-peak charging and create grid resiliency.[377] The federal government should also continue sponsoring transportation decarbonization research, such as discovering more sustainable battery models.[378]

The hype surrounding autonomous vehicles (AV) may have overstated their arrival date, but federal leaders should expect commercial-ready AV technology in the next decade or two. The level of private investment in AV technology, coupled with the extensive race among some states and localities to permit and promote testing, reduces the need for direct federal research funding. However, the federal government will need to consistently monitor the best ways to authorize safe in-vehicle and roadway sensor technology.[379] The federal government should also use applied research to test how AVs interact with pedestrians and other transportation modes, especially to preserve the economic and

social value pedestrians bring to businesses and their neighborhoods.[380]

Finally, private research into emerging aviation technology will continue to put pressure on federal regulators to manage new products and on federal researchers to determine the best place to add value. Drones, especially those associated with e-commerce and other freight deliveries, are market-ready and demand a thoughtful regulatory approach.[381] It is also fair to expect that the next few decades will see new products related to urban passenger flight. The Federal Aviation Administration will need to regulate those products for safety and airborne right-of-way considerations, and study their potential impacts on competing travel modes.

Data systems

The sheer size of the federal executive branch, combined with its regulatory authorities, makes the federal government an ideal place to experiment with new data management practices. The following four experimental projects represent ways to use new infrastructure measurement policies to address emerging societal, economic, and environmental challenges.

Artificial intelligence (AI) has already begun to impact infrastructure networks, much like every other economic sector.[382] Rideshare companies and e-commerce fleet operators use machine learning to determine where vehicles travel, set variable pricing for customers, and optimize customer assistance programs. Transportation security companies and public agencies use image-based algorithms to screen passengers and shipments. Yet in each of these instances, plus many others, infrastructure operators cannot fully understand the biases of the original code writers or how those biases may impact people and businesses, like the demonstrated racial and sexual biases within government-run facial recognition software or continuation of historic biases against those with physical disabilities.[383] Infrastructure-focused agencies should convene AI ethics experts to consult on both philosophical priorities and filter those priorities into operational programs.

Similar to AI, infrastructure operators are already facing difficult cybersecurity and data privacy issues. The personal data collected by digital telecommunications firms is the original source of both massive threats to personal privacy and the overwhelming possibilities from using encrypted, anonymized data.[384] Water utilities, energy utilities, and transportation agencies often manage their own databases of sensitive personal information, which are under threat of cyberattack. As evidenced from cases at Atlanta's Hartfield-Jackson Airport and water utilities in Florida, it is not a hypothetical to say targeted cyberattacks can unexpectedly stop essential services.[385] Federal agencies should work with partners at the National Institute of Standards and Technology, the Office of Science and Technology Policy, and this report's proposed Federal Data Reserve to establish cybersecurity and privacy best practices, both for federal agencies and interested private sector partners.

Even with data security and privacy threats, the federal government should not overlook the potential to use emerging data practices to test new affordability programs. Much like how the Supplemental Nutrition Assistance Program (SNAP) uses digitized tax records to digitally distribute benefits, infrastructure systems could benefit from a consolidated affordability program that delivers portable, flexible benefits for essential infrastructure services. A new "Boost Program" and associated "Boost Card" could provide direct subsidies to lower-earning households, effectively reducing the cost of water, energy, broadband, and transportation bills.[386] The federal government could also go a step further, standardizing and encrypting identification cards—say, through state transportation offices—to carry affordability benefits plus other digitized records for airport screening, library services, and more.

Finally, federal agencies should use clearer environmental accounting standards and interagency programming to reduce total spending and improve environmental outcomes. The creation of a new Climate Planning Unit (CPU) within the Office of Management and Budget could centralize multiple functions.[387] The CPU would combine expert environmental and budgetary staff to identify resilience-focused, cost-saving opportunities within agency operations. In turn, those savings would

fund the unit's operations and create opportunities to test larger, more expensive resilience projects. Each of these functions could be informed by the federal government's growing inventory of environmental impact analyses and related performance measures.

Future of work

U.S. workers and employers need systems to keep pace with technological change, and that truism certainly applies to workers in infrastructure-related occupations and the industries that employ them. Current and prospective workers will need to develop an emerging set of knowledge and skills to use cutting-edge digital and resilience-focused products. At the same time, employers still need a healthy pipeline of workers to complete traditional tasks alongside these more innovative demands. The federal government should help infrastructure workers and employers prepare for the future of work by investing in a range of programs.

Sector partnerships are crucial to coordinate planning, pool financial resources, and pilot new workforce development collaborations. In a sector as siloed and traditional as infrastructure, these partnerships can not only bridge long-standing divides among employers, educational institutions, and community-based organizations, but they can also reach out to new companies and individuals who might be launching innovative technologies and designs with rapidly evolving training and hiring needs. This is especially the case for workers and employers involved in the "digital mobility" space, including mechanics, technicians, and drivers of AVs.[388] In Michigan and Ohio, for instance, auto equipment manufacturers have coordinated with local technical schools to train a new generation of talent around AV technologies.[389] The emergence of new green infrastructure designs and cleaner technologies are also remaking the water and energy space. Federal agencies need to embrace these shifts and help build the financial and technical capacity of regions through additional sector partnerships.

The changing nature of work—including the emergence of new tools, technologies, and processes—also demands continued federal leadership. While many infrastructure workers are involved in the skilled trades and accustomed to handling a variety of instruments, carrying out complex tasks, and building their skills on the

job, work-based learning opportunities remain especially important for the emergence of new digital platforms and technologies. For example, in Pennsylvania, "tech apprenticeships" have generated interest among students and employers to build greater knowledge and experience with robotics, artificial intelligence, and big data.[390] Pre-apprenticeships also remain vital conduits amid a changing work landscape, where prospective workers can quickly gain skills, experience, and marketable credentials.[391] Retraining efforts are key for existing workers too; in Georgia, logistics analysts and workers can now take courses focusing on automation impacts.[392]

But given the rapid pace and impacts of new technologies, federal leaders cannot simply aim to boost regional coordination and invest in more work-based learning, which represent traditional workforce development approaches. They need to ensure a broader range of students and prospective workers can benefit from infrastructure careers, including those who are underrepresented in this sector and disconnected from the labor market. That means providing more flexible training pathways, supportive services, and opportunities for quick immersion. Bridge programs and other nimble models such as boot camps can introduce workers to tech careers, and infrastructure should be part of that equation; Black Girls Code is one model that offers parallel lessons to consider.[393] Providing rehabilitative services and other logistical supports can also help veterans enter infrastructure careers—digitally focused or not—as the EPA and the Department of Veterans Affairs have done in the water sector.[394] These are just a sampling of the multiple branching pathways and programs that the federal government should pioneer in coming decades to assist all types of workers and employers in the transition to an increasingly digital infrastructure reality.

State and local fiscal laboratory

Delivering a future-looking infrastructure vision will not be cheap. States and localities will shoulder an especially large burden to modernize their transportation and water networks. The federal government should use innovative fiscal practices to help reduce the burden on their state and local partners while still pursuing national goals related to environmental and economic resiliency.

The federal government should leverage its role as the country's central financial regulator to streamline investing in green infrastructure.[395] To start, infrastructure owners and private investors need a common, certifiable system to define and measure the benefits of more resilient infrastructure systems. A clear set of benefits and costs associated with public infrastructure systems could foster a resilience marketplace where infrastructure owners can standardize the data behind their requests for private investment, and private investors can use the data to routinize their evaluations. The Treasury Department, the Securities and Exchange Commission, EPA, and the Department of Energy should work with local infrastructure owners and other capital market experts to develop new resilience-focused rules and learn how they can inform current financial instruments like green bonds.

Congress should also explore launching a federal green bank to scale up successful practices at the state and local level.[396] Similar to current federal loan guarantee programs focused on transportation, water resources, and energy generation activities, a federal green bank could focus on supporting state and/or local projects that would improve local environmental performance but may not be viable without federally reduced borrowing rates. Multiple states and localities already operate their own green banks to accelerate resilient infrastructure project delivery, including Connecticut, California, and Montgomery County, Md.[397] In addition to loan guarantees, a federal green bank can also offer financial expertise and other technical assistance to communities that need assistance.

Turning to economic resilience, federal infrastructure funding is an ideal place to test new methods to empower regional governments. The majority of the American population and economic output comes from metropolitan areas, yet our jurisdictional geography does not yet match our regional economic footprints. Instead, most metropolitan areas are constellations of independent local governments. This creates inherent conflicts at the regional scale, especially

when outlying jurisdictions pull growth away from established neighborhoods, leading to the loss of natural ecosystems, inefficiencies in local labor markets, and—critically, for this report—higher per capita infrastructure costs.[398] Congress should work with DOT, HUD, EPA, and metropolitan planning organizations to design regional empowerment pilots that would use tax reforms and other fiscal programming to incentivize local governments to regionalize infrastructure services. For example, DOT could launch a congestion pricing pilot that requires certain consolidation activities.

Finally, Congress should explore new methods to automatically deploy emergency support during economic downturns. During the country's two most recent recessions—the Great Recession beginning in 2007 and the COVID-19 recession in 2020—the federal government used emergency spending packages to support essential infrastructure services in a time of need. While the timing of recessions is unpredictable, their impacts on infrastructure are not: households unable to pay their utility bills, owners of car loans losing their titles, drops in tax revenues delaying capital projects, etc.[399] The federal government can test "automatic spending triggers" that provide immediate aid when certain national economic conditions are met, whether it's loss of employment, output, or a similar measure. A study of the Federal Reserve's Municipal Liquidity Facility—which began in 2020 as a response to the COVID-19 recession—showed that it reduced distress at the local level.[400] Emergency support can create space for longer congressional debate while immediately protecting community health, people's livelihoods, and local construction budgets.

Experimenting with place-based strategies to boost climate adaptation: Gentilly Resilience District

Adapting to a more extreme, unpredictable climate is a must, and will mark a clear departure from past federal efforts that focused more on recovery than resilience.[401] As states and localities grapple with rising environmental and economic risks, they often endure widespread destruction and escalating costs; FEMA's National Flood Insurance Program has helped insure these risks, but it has teetered on the edge of insolvency for years. However, in hard-hit New Orleans, the Gentilly Resilience District—an extensive green infrastructure effort across dozens of acres in the city—shows the merits of an innovative, place-based approach to climate resilience driven by local leadership and federal investment.

As part of the HUD's National Disaster Resilience Competition, the Gentilly Resilience District was awarded $141 million, in addition to prior urban water management investments from FEMA's Hazard Mitigation Grant Program. Launched in 2014, HUD's competition awarded nearly $1 billion in disaster recovery funds to 13 states and communities to improve water and energy infrastructure, upgrade bridges, repair and replace housing, and assist with ongoing capacity-building and community engagement.[402] New Orleans boasted many of these elements in its proposed plans.

In particular, city leaders in New Orleans structured the project in several phases and components to enhance the Gentilly District's climate resilience. A total of 12 different projects aim to reduce flood risks, slow land subsidence, improve energy reliability, and encourage neighborhood revitalization.[403] Project activities range from rain gardens to stormwater innovations to the strategic integration of green space for water and heat management. The four biggest projects include: the new "Blue & Green Corridor" ($28 million) that combines multimodal transportation and green infrastructure improvements; the "Mirabeau Water Garden" ($23 million) that creates a 25-acre recreational and educational site; the "Pontilly Neighborhood Stormwater Network" ($20.8 million) that includes extensive canal and related improvements; and the "St. Anthony Green Streets" ($13.4 million) that improves the streetscape.[404] Other activities engage community members in art projects or revitalize local playgrounds, in addition to targeted workforce development efforts.[405]

The Gentilly Resilience District remains an ongoing effort, but it exemplifies how proactive federal investment and imaginative local leadership can lead to more resilient, place-based solutions. Initial funding from FEMA identified both need and potential in the Gentilly District, and HUD funding allowed the project to expand and scale. The project prioritized a place that had high needs but lacked resources to innovate on its own. And fortunately, other emerging federal efforts—including FEMA's Building Resilient Infrastructure and Communities (BRIC) program—are positioned to expand on these collaborative successes in years to come.[406]

Where's the money? Funding and financing a new infrastructure vision

The United States is in a terrible rut when discussing infrastructure policy and spending needs. Instead of leading with a clearly articulated vision of what the country's infrastructure could deliver, policy conversations often start with eye-popping estimates of spending shortfalls. Spending estimates are easy to repeat through media outlets and make for great stories. But they also create a false impression that American infrastructure is falling apart everywhere and that the country doesn't have the money to execute a new infrastructure vision.

It's time to flip this approach. Federal leaders should build a cohesive vision of how infrastructure networks can support societal needs, and then demonstrate how public spending will bring that vision into reality. It's difficult to build political will for more spending if the public doesn't know what it's buying. But even if federal leaders agreed on this vision and the future direction for our infrastructure—included in some mix of transportation, water, energy, and telecommunications legislation—how would the federal government fund that comprehensive agenda?

While funding conversations are complex and ever-evolving, we recommend future federal investments adhere to three core principles. First, general funds should be the primary revenue source for most infrastructure spending, based on the expectation that this spending should lead to general economic growth benefitting everyone. Second, user fees—which can more directly impact specific infrastructure-related behavior—should augment general funds and support specialized projects. Third, federal financing instruments and regulations should continue to reduce the costs of state and local borrowing, since they reflect infrastructure's intergenerational benefits. Together, these core principles can guide more targeted conversations to bring national infrastructure visions to life.

General fund

Federal policymakers and infrastructure advocates often use global benchmarks to confirm that the United States is spending too little on infrastructure. The most straight-forward comparison is to chart total spending as a share of gross domestic product (GDP). Not only do most peer countries, including the United Kingdom, Canada, and Japan, invest more per capita, they also overwhelming rely on general tax revenues to fund their infrastructure spending accounts.[407] Although the physical infrastructure facilities, geographic scale, economic context, and political histories of these countries vary, their spending patterns still offer helpful comparisons for the U.S. and potential pathways to reconsider our current strategies.

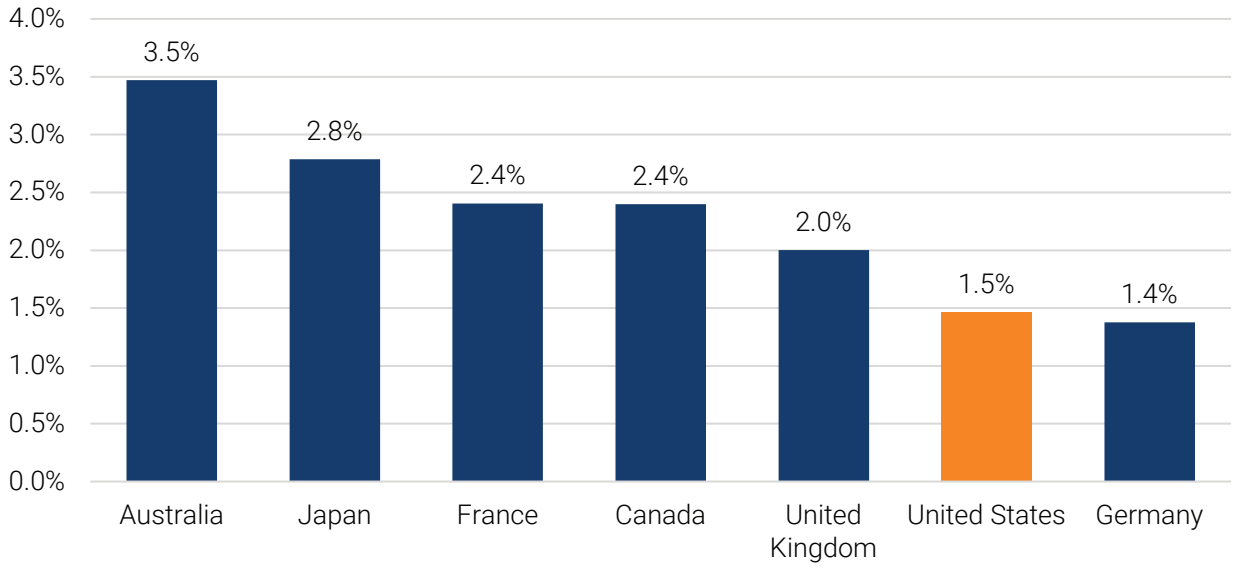
The United States should follow the lead of our global peers and use general funds as the primary source of total federal infrastructure spending. The economic arguments supporting a general fund approach are clear.

To start, public investments in infrastructure should help the economy grow, including through increasing labor productivity, facilitating greater goods and services trade, and promoting greater business investment across all regions. When the economy grows, it invariably leads to increases in business and household income. And when household and business income grow, they lead to greater federal tax revenue.

Fiscal multipliers are some of the most distinct evidence of this effect. A multiplier is a measure of how much spending in one area impacts another economic measure. In the case of infrastructure, estimates from the Congressional Budget Office and Council of Economic Advisers compare infrastructure spending in terms of GDP impacts.[408] These two sources, plus a wide range of other academic sources, consistently find that greater infrastructure spending leads to higher economic output.[409]

Infrastructure improvements can also create net societal benefits, which would aid the federal budget via reduced spending. An example here would be using resilient infrastructure to improve social determinants of health, which have the capacity to reduce long-term demands for health care and therefore societal spending.[410] Healthier populations are also correlated with higher total economic output and quality of life.[411]

Figure 30. Total infrastructure investment, as a share of GDP, 2018



Source: G20 Infrastructure Hub

Finally, relying more on general funds would increase the progressivity of federal infrastructure spending. The country's individual income tax system is more progressive than direct user fees such as gas taxes, which are collected equally for all individuals. Corporate income and capital gains taxes are also inherently progressive, since higher-earning and wealthier individuals own more of the country's equities and directly held stock.[412]

Direct taxes

Even with a shift to general fund revenues, taxes on specific infrastructure activities—what are informally referred to as "user fees"—should still be a core component of any comprehensive infrastructure funding system. User fees inherently function as intensity taxes, charging more to each user based on their demand for a given infrastructure service or input product.

For example, the federal government currently uses gas taxes to fund a large share of the surface and aviation transportation programs, and those fees should continue with clearer economic justifications—not just to continue prevailing approaches or amass funding resources based on past years. Since transportation is now the largest single source of greenhouse gas pollution, gas taxes should become transportation-based carbon fees and reflect the environmental impacts of a given fuel source. As more vehicles transition to electric motors, the federal government can use vehicle miles traveled (VMT) fees to charge for road use based on congestion, household income, or other conditions.

Telecommunications, water, and in-building energy consumption are all well suited to user fees. The FCC already operates digital telecommunications fees, which should be modernized to the broadband era and can be progressively designed. Although water and energy bills represent highly localized and system-specific revenue sources, they can struggle to reliably generate enough support for mounting infrastructure needs. As just one example, the federal government could apply a consistent progressive tax on certain water and energy utility ratepayers to help fund affordability and other federal programs within these respective sectors. Congress should also explore federal policy to promote more state and local experimentation with new user fees. For example, the long-term rise in e-commerce and shared personal mobility raises questions about how to physically reconfigure public right of way and charge access to it, whether on the road or the sidewalk. The federal government could learn from DOT's early 2000s Urban Partnership program, which was a competitive program to test innovative, fee-based approaches to manage urban congestion.[413] Additional explorations around land value taxes, impact fees, and resilience fees should also attract more attention and testing.

Financing

State and local governments look to the federal government to provide fiscal certainty and reduce their borrowing costs within financial markets. The federal government should continue to serve that role going forward.

The size and efficiencies of the $4 trillion municipal bond market—which is how local, regional, and state governments obtain up-front financial capital for many large-scale infrastructure programs—is clear evidence of how consistent federal borrowing rules combined with market features such as bond ratings can lead to long-term construction benefits. The federal government should not waver from its commitment to tax benefits for the holders of municipal bonds.

There is also a long-term place for direct federal lending programs, which have the benefits of offering discounted interest rates, providing greater flexibility, and steering projects toward federally informed goals. A long-term infrastructure vision should include a thoughtful review of infrastructure financing programs—including the Transportation Infrastructure Finance and Innovation Act (TIFIA), the Railroad Rehabilitation and Improvement Financing Program (RRIF), and the Water Infrastructure Finance and Innovation Act (WIFIA)—to inform a larger package of direct lending programs.

Finally, the federal government should review how regulatory models manage private financing of private telecommunications and energy networks. Unlike transportation and water sectors, the predominantly private ownership model of the telecommunications and energy sectors complicates how the federal government could serve as a co-investor—specifically, how to reach underserved neighborhoods through entire regions.

Market dynamics will always create inherent tensions between maximizing shareholder value and society-focused returns, especially inclusivity. As the country seeks to expand and improve these private networks while also making them more equitable, Congress and regulators will need to explore regulation that delivers equitable access and still promotes ongoing research and capital investment.

Conclusion

American infrastructure is operating from a position of strength. A country of over 330 million people enjoys some of the best infrastructure networks in the world. People and businesses can plan their entire lives around the expectations of safe drinking water, dependable electricity, abundant roads, and high-speed internet service. In turn, this confidence has helped build one of the planet's most competitive economies.

The investments of the past, however, are not guaranteed to deliver competitiveness today or tomorrow. An unpredictable and extreme climate has already begun to threaten our communities, whether through reducing the reliability of our water and energy systems or adding more inequities in our transportation systems. Rapid digitalization has exposed a country without equitable broadband or a comprehensive approach to data security. Fiscal limitations in many communities threaten to make maintenance backlogs even larger. And the lack of an infrastructure talent pipeline has limited the ability of our workers and leaders to address these challenges.

Fortunately, the country has all the tools it needs to respond. Local pilot projects and advanced research continue to demonstrate the effectiveness of resilient infrastructure investment. The emergence of new digital products underscores the business case to invest in broadband, digital skills, and data management systems. There is overwhelming evidence that rebuilding the country and strengthening work-based learning opportunities can create career pathways for more infrastructure workers. These are affirmative ideas that can help our businesses, our people, and our environment.

Federal policymakers should build a future-looking infrastructure vision through a three-part framework. Federal agencies should reform their measurement programs to ensure their investment policies and other programs advance shared goals. Congress and federal agencies should then use these new measurement systems to modernize physical assets and better serve user needs. Finally, the country needs the federal government to tap its extensive financial and information resources to experiment with new technologies, fiscal practices, training systems, and applied management practices.

For nearly two decades, federal leaders and their state, local, and private peers have recognized the need for a new infrastructure vision. Now is the time to put good ideas to work.

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More information

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