THE U.S. NATIONAL BLUEPRINT FOR TRANSPORTATION DECARBONIZATION

A Joint Strategy to Transform Transportation

THE VISION

Transportation connects us. It connects people, countries, and cultures, and draw us closer to one another. It is also the backbone of our economy and critical to supporting the daily needs of all Americans. Our transportation system has been an engine for growth and prosperity over many decades, but that growth has not come without consequences, and that prosperity has not been shared equally. The transportation sector is now the largest source of greenhouse gas emissions in the United States, contributing to the climate crisis that is worsening quality of life in cities, towns, and rural communities throughout America. Emissions from the transportation sector also contribute to poor air quality. In the United States, these effects disproportionately impact underserved and disadvantaged communities.

To address the climate crisis, we must eliminate nearly all greenhouse gas (GHG) emissions from the sector by 2050 and implement a holistic strategy to achieve a future mobility system that is clean, safe, secure, accessible, affordable, and equitable, and provides sustainable transportation options for people and goods. This *U.S. National Blueprint for Transportation Decarbonization* (Blueprint) is the roadmap for how we can address these issues to provide better transportation options, expand affordable and accessible options to improve efficiency, and transition to zero-emission vehicles and fuels.

This *Blueprint* offers a whole-of-government approach to transform the transportation sector and sets forth an interagency call to action to coordinate and work effectively together. Achieving our goals will require close cooperation with industry, local, regional, state, and Tribal governments, non-profits, and other stakeholder groups, as well as allies around the world. With bold, coordinated actions, together we can build a clean transportation system that is clean, safe, secure, accessible, affordable, and equitable, for all Americans to help create a more sustainable future for generations to come.

"The domestic transportation sector presents an enormous opportunity to drastically reduce emissions that accelerate climate change and reduce harmful pollution. The Department of Energy is prepared to implement this Blueprint alongside our partners within the Biden-Harris Administration to ensure all Americans feel the benefits of the clean transportation transition: good-paying manufacturing jobs, better air quality, and lower transportation costs."

Jennifer M. Granholm
Secretary, U.S. Department of Energy

"Transportation policy is inseparable from housing and energy policy, and transportation accounts for a major share of U.S. greenhouse gas emissions, so we must work together in an integrated way to confront the climate crisis. Every decision about transportation is also an opportunity to build a cleaner, healthier, more prosperous future. When our air is cleaner; when more people can get good-paying jobs; when everyone stays connected to the resources they need and the people they love, we are all better off."

Pete Buttigieg
Secretary, U.S. Department of Transportation

"Under the leadership of President Biden, the Environmental Protection Agency is working with our federal partners to aggressively reduce pollution that is harming people and our planet—while saving families money at the same time. At EPA, our priority is to protect public health, especially in overburdened communities, while advancing the President's ambitious climate agenda. This Blueprint is a step forward in delivering on those goals and accelerating the transition to a clean transportation future."

Michael S. Regan
Administrator, U.S. Environmental Protection Agency

"The Department of Housing and Urban Development is proud to join our federal partners in ensuring an equitable transition toward a decarbonized transportation future. Any investments we make must provide opportunities for all, including the communities and households that have historically been underserved by our transportation sector. We look forward to working with our local and federal partners to make sure the built environment fully supports a clean, affordable, and efficient transportation sector: from planning to the construction of affordable housing near transit."

Marcia Fudge
Secretary, U.S. Department of Housing and Urban Development

Decarbonizing our transportation sector is achievable, and the benefits will improve the lives of Americans for generations to come.

CONTENTS

I. Executive Summary	2
1. Introduction	12
a. Context & Vision	12
b. Plan & Strategy	14
2. A Whole-of-Government Approach	21
a. The Agencies	21
b. Guiding Principles	23
c. The Levers	24
3. Transportation Challenges Today	28
a. Current Status	28
b. Changing Mobility Needs	30
c. Mobility Costs and Impact of Fuel Prices	32
4. Strategies to Decarbonize Transportation	34
a. Increasing Convenience by Implementing System-Level and Design Solutions	36
b. Improving Efficiency through Mode Shift and More Efficient Vehicles	43
c. Transitioning to Clean Options by Deploying Zero-Emission Vehicles and Fuels	49
5. Applying the Strategies by Transportation Mode	56
a. Light-Duty Vehicles	58
b. Medium- and Heavy-Duty On-Road Trucks and Buses	61
c. Off-Road Vehicles and Mobile Equipment	64
d. Rail	66
e. Maritime Vessels	68
f. Aviation	71
g. Pipelines	74
6. Conclusion – A Call to Action	76

I. EXECUTIVE SUMMARY

The transportation sector is the largest source of greenhouse gas emissions in the United States, responsible for one-third of all emissions. To address the growing climate crisis, and to meet the goal of net-zero GHG emissions economy-wide by 2050, it is **critical to decarbonize transportation by eliminating nearly all GHG emissions from the sector**.[1,2]

Transportation costs are the second largest household expense for Americans and a well-planned transition to a sustainable transportation future will also result in a more affordable and equitable transportation system, with improved transportation services; more mobility choices; improved air quality and health; greater energy security; better quality of life and accessibility; improved health outcomes; enhanced access to a variety of housing options, services, and amenities; well-paying jobs; and safer, more vibrant and resilient communities throughout the country. A decarbonized transportation system can mobilize a sustainable economy that benefits everyone. As our transportation system and communities are increasingly threatened by worsening climate impacts such as hurricanes, wildfires, flooding, heatwaves, and drought, decarbonizing the sector is essential to addressing this existential crisis.

The recently enacted Bipartisan Infrastructure Law (BIL) and Inflation Reduction Act (IRA) together represent historic investments in the future of our nation that will transform how we move and live while we build the backbone of a safer and more sustainable transportation system. This *Blueprint for Transportation Decarbonization* follows the momentum

Decarbonizing the transportation sector will require multiple strategies and resources to deliver safe, effective, affordable, and sustainable solutions to existing and emerging challenges.

from those investments to crystallize a first-of-its-kind strategy for federal leadership and partnerships to decarbonize the entire U.S. transportation sector. Decarbonizing transportation will affect everyone, and solutions must address the needs of all urban, suburban, and rural communities; businesses of all sizes; and individuals and families at every socioeconomic level. The scope, scale, and speed of the shift will continue to require solutions that leverage market forces and private sector investments, which government policies and investments should jumpstart and guide.

[1] The Long-Term Strategy published by the White House in 2021 calls for an 80-100% reduction in transportation emissions by 2050, that combined with some carbon dioxide removal, or negative emissions, allows achieving a net-zero-emissions economy.

[2] This Blueprint uses the term "decarbonization" to refer to all greenhouse gas emissions.

Decarbonizing the transportation sector will require multiple strategies and resources to deliver clean, safe, secure, accessible, affordable, and equitable solutions to existing and emerging challenges. Working with partners to enhance land-use planning will tackle the problem at the root and make it appealing and practical for people to take fewer or shorter trips, or to walk or bike on those trips where that is feasible. Implementing large investments in rail, public transportation, and safe active transportation infrastructure will give people the option to safely use more energy-efficient forms of transportation. And, thanks to significant strides in research, development, and demonstration (RD&D), technologies to decarbonize most transportation systems are within sight and offer realistic and viable pathways. The electrification of cars, trucks, and buses and providing the necessary infrastructure to charge them is underway and must accelerate. Given different applications and requirements, decarbonizing the entire transportation sector will require a diverse portfolio of solutions and technologies. This Blueprint focuses on those solutions that are viable and have sufficient resources to scale. Additional RD&D will be needed to further improve certain solutions and reduce costs, but progress and demonstration of promising technologies is well underway.

COORDINATION IS NEEDED

Implementing a holistic decarbonization strategy will require coordinated actions from federal, regional, state, local, and Tribal governments; non-profit and philanthropic organizations; and private industries. In recognition of our critical roles, the United States Department of Energy (DOE), the United States Department of Transportation (DOT), the United States Environmental Protection Agency (EPA), and the United States Department of Housing and Urban Development (HUD) signed a joint memorandum of understanding (MOU) in September of 2022 to formalize our commitment to the highest level of collaboration and coordination on transportation decarbonization.

As an essential part of the MOU, the four agencies committed to creating a decarbonization strategy for the entire transportation sector to **guide future policymaking and research, development, demonstration, and deployment in the public and private sectors**. This Blueprint articulates that strategy and enumerates the actions needed to transform how people and goods move throughout the United States, all built upon five guiding principles:

- **Implement Bold Actions to Achieve Measurable Results:** Act upon the urgency of the climate crisis and seize the critical opportunity to improve lives by prioritizing efforts that measurably and rapidly reduce GHG emissions and improve health outcomes, especially for overburdened communities.
- **Embrace Creative Solutions Across the Entire Transportation System:** Evaluate a broad set of solutions to reduce emissions; including battery electric vehicles (EVs); improved land-use planning; infrastructure investments; and new policies; technologies; and business models that support clean modes of travel and zero-emission vehicles, including battery electric, plug-in hybrid electric, and hydrogen fuel cell electric vehicles, for passengers and freight.
- **Ensure Safety, Equity, and Access:** Focus on approaches that prioritize safety; include community engagement; address consumer needs and reduce emissions; expand accessibility and affordability of travel; distribute benefits more equitably and address disproportionate burdens; enhance infrastructure resiliency to a changing climate; and improve quality of life, health outcomes, and economic opportunity, particularly in overburdened and historically underserved communities.
- **Increase Collaboration:** Create and support collaborative programs that leverage the combined expertise of DOE, DOT, EPA, HUD, and other federal

partners, and expand the federal government's partnerships with regional, state, local, and Tribal governments; private industry; community-based organizations; and other stakeholders.

- **Establish U.S. Leadership:** Position the U.S. to lead the global race to clean transportation solutions, creating well-paying domestic jobs, strengthening U.S. energy independence and security, and developing robust and sustainable new domestic and international supply chains for clean transportation technologies.

IMMEDIATE ACTIONS AND LONG-TERM PLANNING

Implementing immediate strategies that achieve meaningful emissions reductions this decade is essential to reaching our nation's 2030 emissions reduction goals in line with the president's commitment and the U.S. Nationally Determined Contribution under the Paris Agreement. We must work concurrently to develop solutions that will result in full economy-wide decarbonization by midcentury. This Blueprint provides a comprehensive, system-level perspective of the entire transportation system across all passenger and freight travel modes and fuels, and lays out three key strategies to achieve decarbonization:

1. **Increase convenience** by supporting community design and land-use planning at the local and regional levels that ensure that job centers, shopping, schools, entertainment, and essential services are strategically located near where people live to reduce commute burdens, improve walkability and bikeability, and improve quality of life…
   …Because every hour we don't spend sitting in traffic is an hour we can spend focused on the things and the people we love, all while reducing GHG emissions.
2. **Improve efficiency** by expanding affordable, accessible, efficient, and reliable options like public transportation and rail, and improving the efficiency of all vehicles…
   …Because everyone deserves efficient transportation options that will allow them to move around affordably and safely, and because consuming less energy as we move saves money, strengthens our national security, and reduces GHG emissions.
3. **Transition to clean options** by deploying zero-emission vehicles and fuels for cars, commercial trucks, transit, boats, airplanes, and more…
   …Because no one should be exposed to air pollution in their community or on their ride to school or work and eliminating GHG emissions from transportation is imperative to tackle the climate crisis.

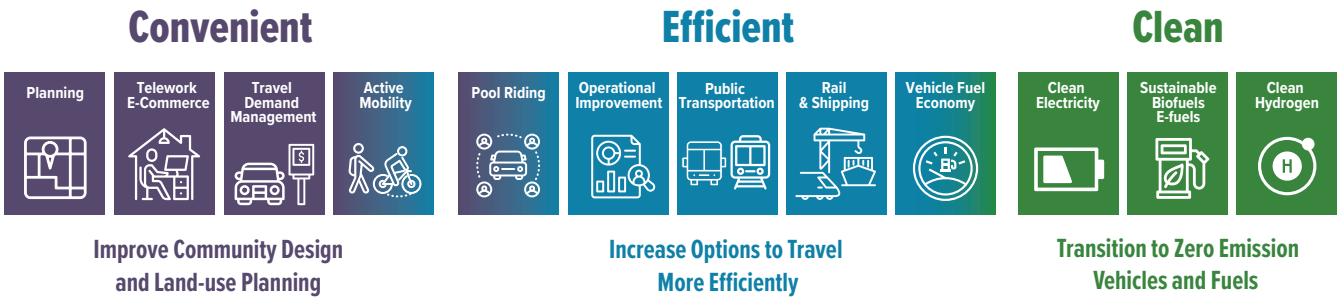


Figure A. Summary of transportation decarbonization strategies.

While the first two strategies—increasing convenience and improving efficiency—will contribute to reducing GHG emissions and produce significant co-benefits, transitioning to clean options is expected to drive the majority of emissions reductions. Given the broad array of vehicle types, technologies, and usage patterns, a successful transition will require various vehicle and fuel solutions and must consider full life-cycle emissions. This Blueprint focuses on each major transportation mode and identifies specific decarbonization opportunities and challenges, highlighting the role of various clean technologies for various applications.

1 icon represents limited long-term opportunity 2 icons represents large long-term opportunity 3 icons represents greatest long-term opportunity	BATTERY/ELECTRIC	HYDROGEN	SUSTAINABLE LIQUID FUELS
Light Duty Vehicles (49%)*		—	TBD
Medium, Short-Haul Heavy Trucks & Buses (~14%)			
Long-Haul Heavy Trucks (~7%)			
Off-road (10%)			
Rail (2%)			
Maritime (3%)		†	
Aviation (11%)			
Pipelines (4%)		TBD	TBD
Additional Opportunities	• Stationary battery use • Grid support (managed EV charging)	• Heavy industries • Grid support • Feedstock for chemicals and fuels	• Decarbonize plastics/chemicals • Bio-products
RD&D Priorities	• National battery strategy • Charging infrastructure • Grid integration • Battery recycling	• Electrolyzer costs • Fuel cell durability and cost • Clean hydrogen infrastructure	• Multiple cost-effective drop-in sustainable fuels • Reduce ethanol carbon intensity • Bioenergy scale-up

* All emissions shares are for 2019

† Includes hydrogen for ammonia and methanol

Figure B. Summary of vehicle improvement strategies and technology solutions for different travel modes that are needed to reach a net-zero economy in 2050 (more details provided in Section 5).

To achieve a decarbonized transportation sector, the four agencies and our partners will need to deploy and leverage the full extent of our tools, expertise, and resources, such as:

- **Policy and Regulation:** The federal government, along with regional, state, local, and Tribal governments, and with international partners and allies, can use a variety of policy and regulatory levers, including long-term planning, standards, and coordinated procurement to support decarbonization of the transportation sector.
- **Investments and Financing:** All levels of government and the private sector can support decarbonization through strategic investments to deploy infrastructure and support manufacturing that accelerate the transition to cleaner, active, and more

efficient modes of transportation and vehicles and facilitate the transition to zero-emission vehicles and sustainable fuels.

- **Research and Innovation:** All levels of government, the private sector, and philanthropy can focus resources on RD&D to identify and scale technologies and tools that will achieve decarbonization. Reducing the cost of clean energy transportation technologies will be required to drive the scale and pace of adoption needed for sector-wide decarbonization and to achieve market pull to accelerate deployment.
- **Data and Tools:** Complete and comprehensive information is needed for the public and decision makers to understand the benefits of clean mobility options and the implications for energy, infrastructure, the economy, and our environment.
- **Education and Training:** Workforce training and education are essential to support a transition to diverse and well-paying clean transportation sector careers. Expanded training opportunities will be especially important for residents and businesses in disadvantaged communities[3].
- **Stakeholder Engagement and Public-Private Partnerships:** Stakeholder engagement that ensures representation from traditionally underrepresented, overburdened, and underserved communities across all the proposed strategies in this Blueprint will be essential to achieving an equitable transportation future. Partnerships among regional, state, local, and Tribal governments, with disadvantaged communities, the private sector, and philanthropic organizations, will also be critical. All levels of government need to align their efforts and work with private industry and community stakeholders to support sustained and targeted actions.

A CALL TO ACTION

This Blueprint, which is an important step toward a decarbonized transportation future, will be followed by more detailed decarbonization Action Plans. The agencies will develop and implement the Action Plans and will work with other federal agencies, governments at the regional, state, local, and Tribal levels, philanthropic organizations, the private sector, and with global partners to achieve the following milestones:

[3] As set forth in Executive Order 14008 on Tackling the Climate Crisis at Home and Abroad, disadvantaged communities are those that are marginalized, underserved, and overburdened by pollution. For more detail on specific indicators, see the Council on Environmental Quality's Climate and Economic Justice Screening tool.

Before 2030 – Turning the Tide on Transportation GHGs: Research and Investments to Support Deployment

Maximize the impact of the historic BIL/IRA investments and catalyze collaboration and private investments

Partner with local communities to develop and demonstrate effective, equitable, and scalable local or regional land-use and planning solutions to increase convenience and reduce emissions by making it possible for people to take fewer or shorter trips Provide best practices, data, tools, and technical assistance on system-level design solutions to increase convenience and reduce emissions
Work with public and private sector partners to identify and advance solutions for a more equitable and healthier transportation system including support for transit-oriented development
Support land-use, street design, and development policies that make walking and biking easier, safer, and more convenient
Reduce national transportation cost burden by at least 5% by 2030 REF
Invest in rail, public transportation, and active transportation infrastructure to provide the option to use more affordable and energy-efficient forms of transportation
Provide incentives to support greater use of efficient travel modes and vehicles and reduce the transportation cost burden on disadvantaged communities. Continue to strengthen standards to improve vehicle efficiency
Set clear, ambitious but achievable targets across all travel modes (e.g., sales shares of zero-emission vehicles, volumes of sustainable fuels, emissions reduction targets)
Work with international partners to define targets, infrastructure standards, and implementation plans to encourage international shipping and aviation to rapidly decarbonize
Invest in research and innovation to further develop and demonstrate clean technologies (e.g., achieve battery, hydrogen electrolysis, and sustainable fuel cost targets) and enable seamless integration with energy systems
Continue and expand funding and market incentives to accelerate the uptake of low- or zero-emission vehicles and invest in supporting infrastructure (e.g., vehicle rebates and EV charging infrastructure), especially in low-income and overburdened communities
Develop a robust workforce including by engaging residents and businesses in disadvantaged communities and secure domestic and international supply chain solutions to ensure the U.S. can manufacture enough clean vehicles and fuels to meet rapidly growing demand

2030-2040 – Accelerating Change: Scaling Up Deployment of Clean Solutions

Adapt strategies and implementation plans in response to global events, consumer response, and technology progress

- Continue to implement land-use and planning solutions and policies at the appropriate scale while ensuring transportation infrastructure is equitable and resilient to a changing climate
- Administer forward-looking policy to maximize the positive impact of transformative technologies, like automation, in terms of quality of life and emissions
- Continue to invest in and encourage greater use of efficient travel modes for passenger and freight to optimize travel and freight logistics and improve fuel economy
- Leverage technologies and innovative business models to enable multimodal and shared travel
- Continue to strengthen standards to further improve vehicle efficiency
- Transition all new vehicles sales to zero-emission technologies and scale up production and use of sustainable fuels
- Ensure infrastructure needed to support clean technologies is in place (e.g., EV charging, clean hydrogen and sustainable fuel refueling) and is fully integrated in the energy systems
- Continue to build resilient supply chains, expand infrastructure, and implement a robust workforce development strategy to enable a full transition to zero-emission solutions

2040-2050 – Completing the Transition: A Sustainable and Equitable Future

Ensure that no one is left behind and do our part to achieve a net-zero-emissions economy

- Continue to support the implementation of equitable regional or local land-use and planning solutions and policies to reduce emissions and achieve net-zero-emissions goals
- Fully leverage the system-wide potential for efficient travel modes like rail, transit, and shared multimodal mobility and maximize vehicle efficiency
- Support fleet turnover to fully replace legacy vehicles and petroleum infrastructure with clean zero-emission solutions
- Fully integrate the clean transportation and clean energy systems to ensure reliable operations of mobility, freight, and energy supply and delivery networks

The above efforts will complement and support the various GHG emissions reduction goals and targets the nation has committed to:

Transportation Mode	Share of Current Transportation Emissions	Federal GHG Emissions Reduction Goals
Light-Duty Vehicles	49%	• Achieve 50% of new vehicle sales being zero-emission by 2030 supporting a pathway for full adoption, and ensure that new internal combustion engine vehicles are as efficient as possible • Deploy 500,000 EV chargers by 2030 REF • Ensure 100% federal fleet procurement be zero-emission by 2027 REF
Medium and Heavy-Duty Trucks and Buses	21%	• Aim to have 30% of new vehicle sales be zero-emission by 2030 and 100% by 2040 REF • Ensure 100% federal fleet procurement is zero-emission by 2035 REF
Off-road	10%	• Work to establish specific targets • Focus resources to develop technology pathways and set efficiency and zero-emissions vehicle and equipment targets
Rail	2%	• Work to establish specific targets • Focus resources to develop technology pathways and set efficiency and zero-emissions vehicle targets • Encourage greater use for passenger and freight travel to reduce emissions from road vehicles
Maritime	3%	• Continue to support the Zero-Emission Shipping Mission (ZESM) goals to ensure that 5% of the global deep-sea fleet are capable of using zero-emission fuels by 2030, at least 200 of these ships primarily use these fuels across the main deep sea shipping route, and 10 large trade ports covering at least three continents can supply zero-emission fuels by 2030 REF • Support the U.S. domestic maritime sector by performing more RD&D into sustainable fuels and technologies and incentivize U.S. commercial vessel operators to move towards lower GHG emissions • Work with countries in the International Maritime Organization to adopt a goal of achieving zero emissions from international shipping by 2050 REF
Aviation	11%	• Reduce aviation emissions by 20% by 2030 when compared to a business-as-usual scenario • Achieve net-zero GHG emissions from the U.S. aviation sector by 2050 • Catalyze the production of at least three billion gallons of SAF per year by 2030 and ~35 billion gallons by 2050, enough to supply the entire sector REF

Pipelines	**4%**	• Work to establish specific targets • By 2036, repair or replace 1,000 miles of high-risk, leak-prone, community-owned legacy gas distribution pipeline infrastructure, as well as an estimated reduction of 1,000 metric tons of methane emissions REF • Eliminate leakages and enable use of pipelines for clean sustainable fuels
Total Sector	**100%**	• 80–100% Emissions Reductions by 2050 (**in line with the U.S. LTS**)

Climate strategies must also help communities fulfill their equity and environmental justice responsibilities. Overburdened and historically underserved communities continue to bear the economic and health burdens of higher emissions, noise, and worsened air quality, and it is critical that these communities are not left behind in the transition to a decarbonized economy, as called for in the President's Justice40 Initiative (see textbox on page 16). Strategies that combat the climate crisis have the ability to strengthen all communities and ensure that infrastructure investments will address current and future needs and avoid the unequal impacts of the past. Moreover, we must ensure that our investments in low-carbon solutions build resilience to the impacts of climate change that disproportionately affect some communities. Building a **clean, safe, secure, accessible, affordable, equitable, and decarbonized** transportation system will ultimately deliver significant co-benefits to all communities.

Many aspects of consumer decisions and business actions will shape the strategies in this Blueprint, and the strategies themselves will continue to be influenced by evolving macroeconomic trends, technological progress, behavioral changes, and other factors. Therefore, this Blueprint should not be viewed as static. To effectively address the climate crisis, we must be able to adjust course and act quickly to meet the decarbonization goals outlined here. With the resources available in the BIL and the IRA, a path to achieving our climate goals and avoiding climate catastrophe is clearer than ever. But realizing these goals and doing so in a way that maximizes equity and environmental justice will require careful planning and decisive coordinated actions. Our agencies are committed to meeting our nation's goals, and we call on other stakeholders to help us. **Success will require unprecedented coordination among every level of government, private industry, community-based organizations, stakeholder groups, and all Americans**. Decarbonizing our transportation sector *is* achievable, and the benefits will improve the lives of Americans for generations to come.

The time to act is now.

TO EFFECTIVELY ADDRESS THE CLIMATE CRISIS

we must be able to adjust course and act quickly to meet the decarbonization goals outlined here.

THE BIPARTISAN INFRASTRUCTURE LAW AND INFLATION REDUCTION ACT

On November 15, 2021, President Biden signed the Infrastructure Investment and Jobs Act, also known as the Bipartisan Infrastructure Law (BIL), into law. The BIL is the first infrastructure law in U.S. history that acknowledges and addresses the climate crisis and has a dedicated climate title, and it invests $660 billion into transportation systems and technologies over five years. On August 16, 2022, President Biden signed the Inflation Reduction Act (IRA) into law, representing the most aggressive action on tackling the climate crisis in U.S. history.

Together, the BIL and IRA represent a once-in-a-generation investment in infrastructure, technology, and supply chains, giving us an opportunity to guide our economy toward safer, more sustainable actions than ever before. Combined, these laws are projected to lower economy-wide emissions more than 40% by 2030, relative to 2005 levels, positioning us to achieve the goal of a 50-52% emissions reduction by the end of the decade REF, REF. In the transportation sector, these investments include historic levels of funding for transit, rail, and active transportation, buildouts of EV charging and sustainable fuel infrastructure, new and improved clean vehicle and fuels tax credits, sustainable aviation fuel tax credits, rebates for clean school buses and trucks, clean ports, investments along the EV and battery supply chains, and more. While BIL and IRA equip us with many of the appropriate tools for decarbonizing the transportation sector, implementation will be critical.

By 2030, BIL and IRA will drive substantial adoption of new zero-emission vehicles and sustainable fuels and support large-scale GHG emissions reductions. The degree of impact will also depend on choices made by regional, state, local, and Tribal recipients of BIL funding, as well as market evolution and technology development and deployment by the private sector. We intend to closely collaborate with the entities involved. Achieving our climate goals will not only require implementing the BIL and IRA to maximize their decarbonization, equity, and other benefits, but also taking action beyond these pieces of legislation, as identified in the MOU and this Blueprint.

1. INTRODUCTION

"In the United States and around the world, we are already feeling the impacts of a changing climate. Here at home, in 2021 alone we have seen historic droughts and wildfires in the West, unprecedented storms and flooding in the Southeast, and record heatwaves across the country. We see the same devastating evidence around the world in places like the fire-ravaged Amazon, the sweltering urban center of Delhi, and the shrinking coastlines of island nations like Tuvalu. The science is clear: we are headed toward climate disaster unless we achieve net-zero global emissions by midcentury. We also know this crisis presents vast opportunities to build a better economy, create millions of good-paying jobs, clean our waters and air, and ensure all Americans can live healthier, safer, stronger lives."

The Long-Term Strategy of the United States, November 2021

A. CONTEXT & VISION

In November 2021, the Biden-Harris administration published *The Long-Term Strategy (LTS) of the United States*, a visionary climate strategy that outlines a plan to tackle the growing climate crisis by decarbonizing our national economy. The LTS established a goal of net-zero GHG emissions by no later than 2050 with an interim, near-term milestone of a 50–52% reduction from 2005 levels in economy-wide net GHGs by 2030. Addressing the climate crisis is critical for the long-term health and well-being of every resident of the United States and will require rapid, widespread, and major transformations of many complex systems that are closely intertwined with our economy and way of life. Achieving a net-zero-emissions economy by 2050 involves aggressive curbing of emissions from all sectors (see Figure 1), including transportation, which is now the largest source of U.S. GHGs—about a third of all domestic emissions. In the LTS, transportation emissions are projected to reduce by 80–100% by 2050.

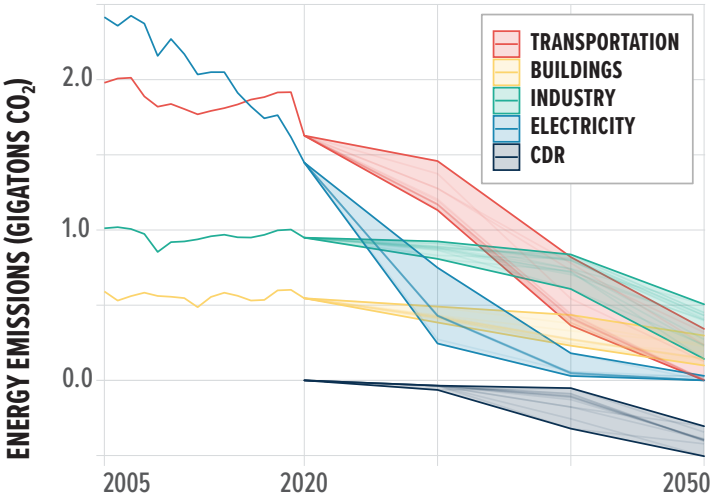


Figure 1. The path to economy-wide decarbonization entails electricity emissions and emissions from transportation, buildings, and industry falling dramatically in all scenarios, with the greatest reductions coming from electricity, followed by transportation, and growth in non-land sink carbon dioxide removals (Source: LTS).

The rising temperatures and increases in wildfires, droughts, and severe weather that are the direct impacts of climate change are already stressing the nation's transportation system. The results over the past few years are evident, for example, in the sections of California's Highway 1 that collapsed into the ocean

and forced officials to close the highway for more than a year and in the increased flooding in the New York City subway system. In Alaska, melting permafrost has buckled roads and bridges in areas that were previously frozen year-round. Flooding in the Gulf Coast halted rail service after Hurricane Harvey, and floods in Michigan shut down metropolitan highways for days. In Texas, a deadly ice storm led to several fatalities on I-35, while wildfires in California burned nearly 4,000 structures and mudslides in Colorado stranded more than 100 motorists overnight. Heat waves in the Pacific Northwest melted streetcar power cables in Portland. Deadly floods have occurred in eastern Kentucky, and hurricane winds knocked out power in all of Puerto Rico. Florida experienced its deadliest hurricane since the 1930s.

Without successfully decarbonizing the economy and fortifying the nation's infrastructure, impacts of climate change are projected to worsen and yield a substantial cost of *in*action, potentially up to $2 trillion annually or 10% of gross domestic product (GDP) by the end of the century [REF]. The urgency is high, and the time to act is now. Transforming our transportation system, while challenging, is possible with a dedicated, coordinated effort. Doing so provides an unprecedented opportunity to tackle climate change, while improving quality of life; making mobility safer and more affordable; and creating vibrant, sustainable, healthy, resilient, and equitable communities.

In response to the urgency of the moment, the Department of Energy (DOE), the Department of Transportation (DOT), the Environmental Protection Agency (EPA), and the Department of Housing and Urban Development (HUD) are coordinating actions toward a decarbonized sustainable transportation future, starting with a memorandum of understanding (MOU) and this Blueprint. These agencies directly influence transportation decisions through policy, regulation, collaboration, and investments in innovation

The urgency is high, and the time to act is now. Transforming our transportation system, while challenging, is possible with a dedicated, coordinated effort.

and RD&D of new technologies and infrastructure. **This Blueprint is the first comprehensive, whole-of-government approach to decarbonizing the transportation sector that aligns decision-making among agencies and identifies new and innovative opportunities for collaboration that are critical to achieving our shared vision of a future decarbonized transportation system**. The agencies provide guiding principles and strategies described here to shape future federal policies and actions direct the development and implementation of practical and effective pathways for all four agencies and our partners. This document will serve as a guide for other stakeholders, including other government agencies, local communities, the private sector, and philanthropic organizations, providing a united and consistent message on decarbonizing the transportation sector.

The Blueprint builds on and complements the LTS, which serves as a guidepost to determine the pathways for transportation, as part of a broader, U.S. economy-wide solution to the climate crisis. Following the Blueprint's release, the agencies will publish addenda detailing specific actions that each agency can take to enable and accelerate decarbonization across all transport modes and fuels. This Blueprint, and the addenda that will follow, are the beginning of a process that will continue to evolve over time. Consumer decisions, business actions, and evolving macroeconomic trends will shape the implementation of these strategies. To effectively address the climate crisis, we must be able to adjust course and act quickly to meet our goals through the decarbonization pathways outlined here.

B. PLAN & STRATEGY

The emissions from transportation are the result of three interrelated factors, all of which must be addressed to achieve significant emissions reductions, while yielding significant co-benefits and advancing equity:

1. **Transportation system design and land use** – Homes, workplaces, and services are often located far apart from one another. When people have limited transportation choices, or less accessible and efficient options, it can take them even more time to address their daily needs. The spatial mismatch between jobs, housing, and services is especially pronounced in disadvantaged communities.
2. **Vehicle and engine efficiency** – While vehicle efficiency has improved greatly over the last several decades, further improvements are needed to meet decarbonization goals.
3. **High-GHG fuels** – Petroleum provides nearly all energy used in transportation today. This reliance on petroleum is a major energy security concern and driver of transportation emissions.

Decarbonizing the transportation sector will require strategies and actions that approach the problem from all angles. Working with local partners to enhance land-use planning and coordinate public and private sector investments will tackle the problem at the root and make it possible for people to take fewer or shorter trips, or make it easier to walk and bike on those trips. This will both improve equity and provide better access to goods and services with less travel required for rural, suburban, and urban communities. Investments in passenger rail, public transportation, and active transportation infrastructure will give people the option to use more energy-efficient forms of transportation. And, thanks to significant strides in research and innovation, the technologies to decarbonize most transportation systems are within sight and offer realistic and viable pathways to replace fossil fuels with sustainable solutions.

This Blueprint focuses on continued, coordinated RD&D and deployment efforts from multiple stakeholders to enable widespread and equitable deployment of solutions that are viable, affordable, and that have sufficient resources to scale. It also allows for the development of missing solutions via innovation and demonstration. We identify several enabling catalysts, such as policies that encourage increased convenience in our communities, transit and efficient mobility, vehicle

Achieving meaningful reductions in emissions this decade is essential in reaching the near-term emissions reductions goals and enabling a pathway to reach net-zero emissions economy-wide by 2050.

electrification, and availability of sustainable fuels. We can pair these actions with continued growth in research and technology deployment and coordination with the wide-ranging community to shape our transportation future. This will allow the United States to achieve our ambitious climate goals and improve lives. **We envision a future mobility system that is clean, safe, secure, accessible, affordable, and equitable, and provides decarbonized transportation options for people and goods.**

Achieving this vision will require actionable strategies that result in a major transformation of how people and goods move in the United States, including the modes of travel chosen and the fuels used. **This transformation is already underway, and consumers and businesses have started to adopt new clean technologies, but the trend needs to accelerate dramatically both in scale and scope. It is essential to make meaningful reductions in emissions this decade to reach near-term emissions reductions goals and enable a pathway to reach net-zero-emissions economy-wide by 2050.**

The strategies outlined in this Blueprint emphasize existing commercially available solutions or technologies that are currently under advanced development and can be deployed in the near term. Additional RD&D will be needed to further improve certain solutions and reduce costs, but progress and demonstration are well underway. Some of these solutions will result in immediate emissions reductions while others will require a longer time to implement, with impacts that will be observed over the decades to come. We must act now to implement near-term and longer-term solutions that reduce GHG emissions from transportation.

Accordingly, this Blueprint's vision will guide and inform agencies' policy and decision-making across a wide range of activities, including regulatory standard development, infrastructure investments, grants and technical assistance, research and innovation, evaluation, and deployment. This Blueprint can also serve to guide other decision-makers, including federal, regional, state, local, and Tribal governments; the private sector, academia, and community-based organizations; and non-profit, grassroots, and philanthropic organizations toward decarbonized transportation solutions. Our vision for a transformed transportation sector not only minimizes GHG and pollutant emissions but also ensures improvements towards a safe, affordable, and equitable system that provides better access to clean transportation options for all communities. Transportation systems must support resilience to the impacts of climate change, create new domestic jobs and economic opportunities, bring co-benefits to communities, and position the United States to lead the global race to clean energy and transportation technologies adoption.

ENVIRONMENTAL JUSTICE AND EQUITY

The benefits and costs of transportation systems in the United States have historically been unequally distributed. American transportation systems have disproportionally impacted underserved or overburdened communities REF, REF. Low- and medium-income and minority households tend to have less access to personal vehicles and fewer transportation options that connect them to housing, employment centers and other services and amenities. Historical underfunding of public transportation has deprioritized or neglected enhancements in public transportation quality in the communities that need it most, leading to longer travel times and constrained mobility options. These communities are often underfunded in other infrastructure areas, including sidewalks, bike lanes, and EV chargers, further constraining residents' transportation options.

Communities that are overburdened and historically underserved are also exposed to a disproportionate amount of air pollution and environmental hazards, including the release of toxic pollutants from petroleum refineries and petrochemical facilities, which exacerbates existing health and economic inequities. Additionally, **the financial burden of transportation as a percentage of income is almost three-times higher for households in the bottom income quintile compared to the top quintile** REF.

These disproportionate impacts are reinforced by a long history of federal, state, and local policies that have shaped our transportation system. In many cities and towns, exclusionary practices such as redlining and other discriminatory housing policies led to racially segregated neighborhoods, with areas with predominantly minority populations tending to suffer from chronic underinvestment. While investments in amenities were disproportionately directed to wealthier areas, highways were in many cases intentionally routed through existing neighborhoods, damaging the character and economies of those communities, and affecting the wellbeing of residents due to long-lasting effects from worsened air quality, increased heat and noise pollution, and physical barriers to opportunity and mobility.

In some places, housing policies and land-use decisions have reinforced the transportation barriers.[4] For example, disjointed housing and transportation policies over the past decades have impeded access to safe and reliable transportation options and hindered travel to critical destinations—including work, schools, grocery stores, and health care facilities—leading to increased transportation and housing cost burdens.[5] Further, many communities' land-use codes or development processes have failed to provide sufficient affordable housing, thereby excluding low-income and moderate-income residents. In many instances, these communities can lift exclusionary barriers, invest more in affordable housing, and link those investments to enhancements in public transportation and a viable mix of travel options.[6] Additionally, communities of color have often been passed over for infrastructure wealth-creation opportunities such as jobs, careers, and the use of minority-owned contractors.

The federal government is committed to the Justice40 initiative, which establishes the goal that at least 40% of the benefits of certain federal investments flow to disadvantaged communities REF. As investments in cleaner transportation solutions increase, it will be important to ensure that disadvantaged communities reap the benefit of those investments, including jobs and business opportunities. It will be necessary to balance community priorities as potential federal investments are considered. Strategies should avoid resident displacement and address the need for quality affordable housing near transit or other affordable and convenient transportation options. Federal investments in the clean energy economy can lead to decreased consumer costs, increased access to clean transportation, improved public health, new business and workforce opportunities, and enhanced community resiliency REF. Meaningful public involvement is critical to realize these goals, including early and proactive discussions with communities to develop plans and programs. Decarbonizing the transportation sector while addressing equity will be key to ensuring our future transportation infrastructure results in better outcomes for everyone, particularly residents of disadvantaged communities.

[4] Ewing, Reid, Rolf Pendall, and Don Chen. "Measuring sprawl and its transportation impacts." *Transportation research record* 1831.1 (2003): 175-183.
Howell, Amanda, et al. "Transportation impacts of affordable housing." *Journal of Transport and Land Use* 11.1 (2018): 103-118.

[5] Rothstein, R. (2018). *The color of law*. Liveright Publishing Corporation.

[6] Van Wee, Bert. "Land use and transport: research and policy challenges." *Journal of transport geography* 10.4 (2002): 259-271.; Litman, Todd. "Evaluating transportation land use impacts." (2008).

Achieving a net-zero economy by 2050 will require major transformations across all sectors and effective integration between them. The *Inventory of U.S. Greenhouse Gas Emissions and Sinks*, which EPA publishes annually, provides detailed accounting of GHG emissions across the U.S. economy [REF]. The sources of GHG emissions for 2019 are shown in Figure 2, along with additional detail for the transportation sector.[7] This Blueprint focuses on reducing emissions from the use phase of the transportation sector (the blue slice in Figure 2). Analyses throughout this Blueprint will use 2019 as a baseline, as impacts due to the COVID-19 pandemic complicate the use of later data.

2019 U.S. GHG EMISSIONS

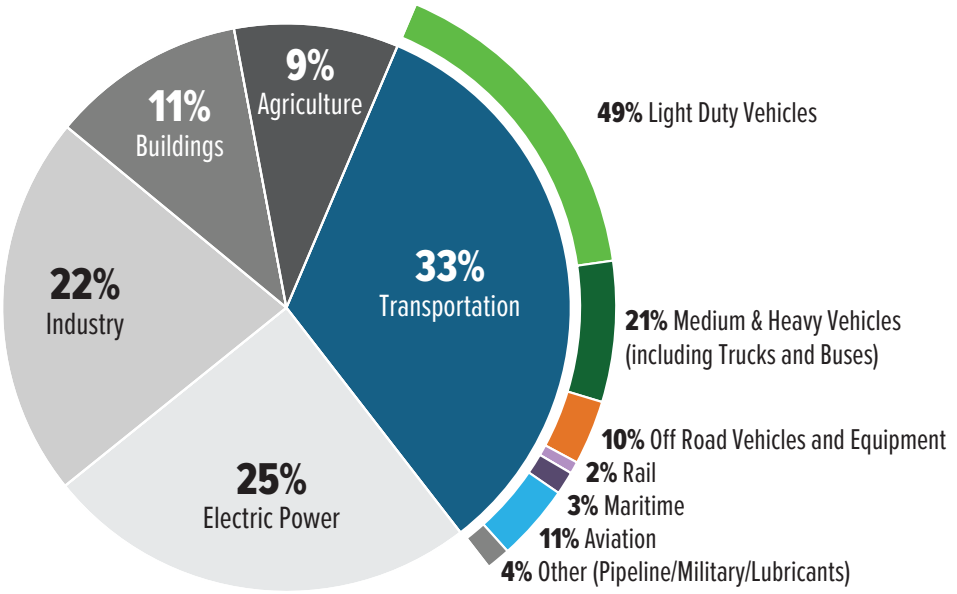


Figure 2. Total 2019 U.S. GHG emissions with transportation and mobile sources breakdown. Data derived from the EPA Inventory of U.S. Greenhouse Gas Emissions and Sinks [REF].[8] This Blueprint uses 2019 as a baseline since impacts due to COVID-19 complicate the use of later data.

Transportation is closely interconnected with other sectors of the economy. For example, EVs rely on electricity generation and will have different implications for manufacturing relative to manufacturing of internal combustion engine vehicles. Specific strategies to reduce full life-cycle emissions associated with transportation activities are not addressed in this document, but they are needed to achieve a decarbonized economy. They are the focus of other government-wide initiatives that will affect this Blueprint's implementation.

[7] The U.S. Greenhouse Gas Emissions and Sinks report shows transportation as responsible for 29% of all U.S. emissions in 2019. Figure 2 includes mobile source emissions in the off-road category and fuels for international travel which are included elsewhere in the GHG Inventory report. For further discussion of what is included in each specific sector, see the Inventory of U.S. Greenhouse Gas Emissions and Sinks report, and section 3 of this report.

[8] The off-road vehicles and equipment category in Figure 2 includes some mobile source emissions that are reported in the U.S. GHG Inventory report as part of the Commercial and Industrial sectors. Figure 2 also includes international maritime and aviation fuels.

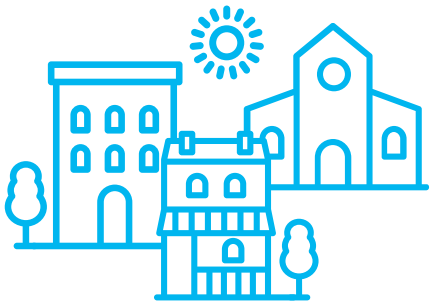
LIFE-CYCLE EMISSIONS AND EMBODIED CARBON

This Blueprint focuses on the direct transportation emissions from the use phase of transportation vehicles and systems, but our vision considers full life-cycle emissions reductions and recognizes that the transportation sector also induces additional GHG emissions from the production and end-of-life phases. These include GHG emissions from fuel production and processing; vehicle manufacturing and disposal; and construction, maintenance, and disposal of transportation infrastructure. Transportation systems contribute to climate pollution at a variety of points and full life-cycle transportation GHG emissions need to be considered and addressed. The carbon emissions from the full life-cycle of a product or service—often referred to as "embodied carbon"—are significant, although they are not included in the 33% of economy-wide emissions attributed to the transportation sector in Figure 2. Decarbonizing those sectors of our economy is the focus of other government-wide initiatives that complement this Blueprint. In particular, many transportation decarbonization solutions rely on electricity directly or indirectly (such as the production of hydrogen or certain sustainable fuels). Achieving 100% clean electricity by 2035, largely through new solar and wind energy development, will be a critical co-strategy to support transportation decarbonization REF.

For example, according to America's Cement Manufacturers, over the next five years, spending from the BIL alone will result in the use of 18.63 million metric tons (MMT) of cement for roads and bridges, 5.78 MMT for airports, 2.99 MMT for ports and waterways, and 0.31 MMT for rail and transit. About 0.5-0.6 tons of carbon dioxide (CO_2) is emitted per ton of cement produced, so cement used in projects funded by the BIL will result in about 15.2 MMT of CO_2 emissions REF, REF. This is equivalent to the emissions from about 3.3 million gasoline-powered vehicles driving for a year. Reaching the goal of net-zero GHG emissions by 2050 requires addressing the GHG emissions associated with the production and end-of-life phases of fuels, vehicles, and transportation infrastructure and systems, both directly through procuring lower-carbon materials and indirectly by employing more sustainable construction practices, including leveraging digitalization and e-construction.

This Blueprint provides a comprehensive, system-level perspective covering the entire transportation sector across all passenger and freight travel modes and fuels, and lays out a three-pronged strategy for a transition to a sustainable transportation future, all centered around providing better options to **increase convenience, improve efficiency, and transition to clean options:**

1

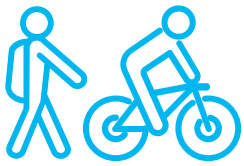


INCREASE CONVENIENCE

by supporting community design and land-use planning at the local or regional level that ensure that job centers, shopping, schools, entertainment, and essential services are strategically located near where people live to reduce commute burdens, improve walkability and bikeability, and improve quality of life…

…Because every hour we don't spend sitting in traffic is an hour we can spend focused on the things and the people we love, all while reducing GHG emissions.

2

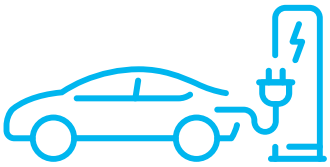


IMPROVE EFFICIENCY

by expanding affordable, accessible, efficient, and reliable options like public transportation and rail, and improving the efficiency of all vehicles…

…Because everyone deserves efficient transportation options that will allow them to move around affordably and safely, and because consuming less energy as we move saves money, strengthens our national security, and reduces GHG emissions.

3



TRANSITION TO CLEAN OPTIONS

by deploying zero-emission vehicles and fuels for cars, commercial trucks, transit, boats, airplanes, and more…

…Because no one should be exposed to air pollution in their community or on their ride to school or work and eliminating GHG emissions from transportation is imperative to tackle the climate crisis.

Coordination of effort across all three of these areas will be necessary to achieve our long-term goals.

It is essential to implement design solutions that increase convenience, provide better access to clean modes of travel, and support demand management policies that make it easier and more convenient to choose more efficient travel options.

These solutions, which may take time to implement, will provide critical co-benefits such as improved safety and quality of life, and while they are not sufficient to reach our net-zero goals, they are essential to offsetting expected increase in travel demand driven by population and economic growth. It will also be important to improve system and vehicle efficiency, while supporting greater use of more efficient travel modes such as rail and transit. Absent solutions to increase convenience and improve efficiency, we will see the undesirable outcomes of travel amplified—more and longer trips needed to support day-to-day activities; long hours spent sitting in traffic on the daily commute; and higher expenses for gasoline, vehicle maintenance, and other costs.

A transition to clean options that involves the rapid and widespread deployment of clean vehicle and fuel technologies is critical to achieving deep emissions reductions by mid-century. Agency-led efforts are crucial to tying these strategies to necessary policies and partnerships and to further incentivize innovation where it is most needed to accelerate the pace of deployment. Collaboratively focusing on solutions ranging from system-level design integrations to investments in new technologies will allow all Americans to benefit from improved mobility options in the equitable and decarbonized transportation sector of the future.

2. A WHOLE-OF-GOVERNMENT APPROACH

The MOU between DOE, DOT, EPA, and HUD represents a historic step toward a collaborative approach to decarbonizing transportation. Each of the agencies has access to a unique set of tools, knowledge, and partnerships.

This Blueprint recognizes these proficiencies and evaluates how they can be applied collectively to achieve transportation decarbonization goals faster and more efficiently than any agency could alone. This collaboration can serve as the basis for further cooperation on decarbonization with other federal agencies; regional, state, local, and Tribal governments; private industry; academia; community-based organizations; non-profits; and philanthropic groups. This section highlights how the four agencies will work together and with our external partners to ensure these ambitious but attainable decarbonization goals are achieved.

A. THE AGENCIES

Each of the four agencies engages in extensive efforts related to transportation, and our fundamentally distinct missions shape our actions:

DOE: The Department of Energy, in partnership with our National Laboratories, strengthens the nation's prosperity and security by addressing energy, environmental, climate, and nuclear challenges through transformative science, technology, and infrastructure solutions. This includes RD&D and deployment of a wide array of sustainable technologies and solutions to make transportation and other sectors cleaner and more efficient.

DOT: The Department of Transportation seeks to transform the nation's transportation system to make it safer, more accessible, more reliable, and multimodal; to increase economic strength; improve climate and equity outcomes; and build global competitiveness for the American people. To achieve these goals, DOT provides funding to regional, state, local, and Tribal governments and other entities to invest in transportation infrastructure, accelerate electric vehicle deployment, and support mobility options across all modes of transportation. DOT has a number of regulatory and policy levers, such as fuel economy standards, that it can use to help reduce emissions in the transportation sector. DOT also supports extensive RD&D deployment and innovation initiatives.

EPA: The Environmental Protection Agency's mission is to protect human health and the environment. As part of this mission, EPA is responsible for numerous regulatory, partnership, and funding programs that seek to reduce air pollutants, air toxics, and GHG emissions from across the transportation sector. EPA provides modeling tools, policy analysis, technical assistance, and public information—such as the fuel economy and emissions labels on all new vehicles. EPA has a strong focus on environmental justice and equity and supports community-led action to clean up environmental hazards, create new economic opportunities, and support equitable revitalization.

HUD: The Department of Housing and Urban Development's mission is to create strong, sustainable, inclusive communities and quality affordable homes for all. Central to this mission is supporting location-efficient housing investments that increase mobility options for low- and moderate-income households; promote economic development; lower combined housing-transportation as well as utility expenditures; increase access to employment, schools, services, and amenities; and encourage equitable transit-oriented development.

As articulated in the MOU, the four agencies are committed to building a clean, safe, secure, accessible, affordable, equitable, and decarbonized transportation system for all. These goals are integral to the mission of our agencies and are aligned with the agencies' initiatives and strategic goals REF. The agencies will each be critical to reducing transportation emissions at the pace climate science demands, and our work cannot take place in silos. For decarbonization to be successful, close collaboration and sharing of best practices, research, policy ideas, and other resources are necessary. For example, the BIL created the Joint Office of Energy and Transportation (Joint Office), which combines expertise from DOE and DOT to tackle issues of mutual concern, including EV charging infrastructure deployment and technical assistance for programs such as EPA's Clean School Bus initiative.

Additionally, DOE, DOT, EPA, and HUD work with other federal agencies and regional, state, local, and Tribal entities to provide modeling tools, data, technical assistance, and public information. These and related efforts aim to ensure resources are being used efficiently and effectively to maximize impact and accelerate the transition to a sustainable, decarbonized transportation future.

B. GUIDING PRINCIPLES

The Blueprint's strategies are based on a set of **five guiding principles:**

- **Implement Bold Actions to Achieve Measurable Results:** Act upon the urgency of the climate crisis and seize the critical opportunity to improve lives by prioritizing efforts that measurably and rapidly reduce GHG emissions and improve health outcomes, especially for overburdened communities.
- **Embrace Creative Solutions Across the Entire Transportation System:** Evaluate a broad set of solutions to reduce emissions, including improved land-use planning; infrastructure investments; and new policies, technologies, and business models that support clean modes of travel and zero-emission vehicles (including battery electric, plug-in hybrid electric, and hydrogen fuel cell EVs) for both passengers and freight.
- **Ensure Safety, Equity, and Access:** Focus on approaches that prioritize safety; include community engagement; address consumer needs and reduce emissions; expand accessibility and affordability of travel; distribute benefits more equitably and address disproportionate burdens; enhance infrastructure resiliency to a changing climate; and improve quality of life, health outcomes, and economic opportunity, particularly in overburdened and historically underserved communities.
- **Increase Collaboration:** Create and support collaborative programs that leverage the combined expertise of DOE, DOT, EPA, HUD, and other federal partners, and expand the federal government's partnerships with regional, state, local, and Tribal governments; private industry; community-based organizations; and other stakeholders.

As articulated in the MOU, the four agencies are committed to building a clean, safe, secure, accessible, affordable, equitable, and decarbonized transportation system for all. These goals are integral to the mission of our agencies and are aligned with the agencies' initiatives and strategic goals.

- **Establish U.S. Leadership:** Position the U.S. to lead the global race to clean transportation solutions, creating well-paying domestic jobs, strengthening U.S. energy independence and security, and developing robust and sustainable new domestic and international supply chains for clean transportation technologies.

C. THE LEVERS

The agencies intend to work collaboratively and with external partners to ensure we are using all tools at our disposal to decarbonize the transportation sector. These tools include numerous levers that the agencies can jointly pursue to enable and support a transition to a sustainable transportation future consistent with the Biden-Harris administration's 2030 and 2050 GHG reduction goals, thus avoiding the worst climate outcomes. These levers fall into the six general categories described below. By defining these levers, the agencies will identify potential for new research, collaboration, and opportunities to reduce GHG emissions from transportation.

Achieving meaningful reductions in emissions this decade is essential in reaching the near-term emissions reductions goals by 2050.

- **Policy and Regulation:** The federal government, along with regional, state, local, and Tribal governments, can use a variety of policy and regulatory levers to help enable transportation sector decarbonization. These levers can support the transition to zero-emission vehicles and fuels, enable access to clean transportation options, improve the efficiency of systems and vehicles, and support increased production of sustainable fuels. Policies and regulations may include, but are not limited to: market incentives (e.g., vehicle purchase credits or production tax credits for sustainable fuels); GHG and fuel economy standards; infrastructure compatibility standards; prioritization of zero-emission transportation projects in discretionary grant programs; transit-oriented development policies to support reliable, frequent, and affordable public transportation services; transportation-demand management programs (e.g., rideshare and vanpool programs, employer-based trip reduction programs); investments in walking and biking infrastructure; transportation planning; and programming processes and procurement. Economy-wide policies, such as carbon pricing, sustainable fuel standards, or renewable fuel standards, would also affect carbon reduction efforts.

- **Infrastructure, Industrial Investments, and Financing:** Investments in infrastructure are critical to enable decarbonization, including supporting a transition to zero-emission vehicles, the production and delivery of sustainable fuels, and operational improvements through travel demand management. Investments in these areas are crucial and will encompass projects that help spur

mode shift and all its benefits, including increasing the share of trips made using low- to no-carbon travel options. Example areas for financing are:

- Battery EV charging infrastructure for all on-road vehicles and other applications of battery technologies and other zero-emission fueling infrastructure for rail, off-road, maritime, and aviation, as well as grid transformation and upgrades to enable transportation electrification.
- Manufacturing of zero-emission vehicles, batteries, fuel cells, and production of sustainable fuels such as hydrogen and sustainable biofuels, including industrial investments to strengthen supply chains and improve access to critical minerals.
- Transit and rail, for building new systems and expanding service on existing systems.
- Safe infrastructure for active transportation options like walking and biking and shared micromobility options such as scooters and e-bikes.
- A fix-it-first-and-fix-it-right approach to road and bridge investments, that prioritizes repairing and modernizing existing roadways before expanding capacity.
- Smart planning and improved system operations, innovative uses of the transportation right-of-way, such as siting renewable energy technologies on highway or rail properties), and other cross-sector strategies.
- Accelerating the transition to zero-emissions vehicle and engine technologies.

The BIL and the IRA's historic investments in clean transportation options and infrastructure demonstrate the role of the federal government and how those investments can be used to enable a path toward deep decarbonization economy-wide, especially in transportation (see textbox on page 11).

Achieving meaningful reductions in emissions this decade is essential in reaching the near-term emissions reductions goals and enabling a pathway to reach net-zero emissions economy-wide by 2050.

- **Research and Innovation:** Innovation in clean technologies is critical to achieve our climate goals and will support both economic growth and the creation of well-paying jobs. Markets alone will not accelerate the energy transition at a sufficient pace or scale to address the climate crisis, and the federal government has an integral role to play to catalyze the private sector into actions to ensure that the U.S. economy is competitive [REF]. Reducing the cost of clean transportation options will be required to drive the scale of adoption needed for sector-wide decarbonization, as well as to achieve market pull to accelerate adoption. In particular, our agencies—in close collaboration with DOE National Laboratories—should strategically advance RD&D and deployment to improve performance and reduce costs of clean energy solutions and support the development of new and higher-risk (but potentially higher-reward) technologies collaboratively with the private sector while also leveraging universities, non-profits, and philanthropic organizations.

The interagency Climate Innovation Working Group launched in February of 2021 will also help drive innovation. It works to identify, prioritize, and accelerate innovation in game-changing net-zero technologies. The working group has identified 37 net-zero RD&D and deployment opportunities and prioritized five areas to launch the Net-Zero Game Changers initiative, including net-zero aviation and net-zero power grid and electrification [REF].

The private sector, with incentives from the BIL and IRA, can focus resources on scaling and commercializing technology solutions that drive decarbonization. RD&D and deployment should focus on all stages of the innovation spectrum and support a wide array of solutions. Although some aspects of our future transportation systems, mobility needs, and available technologies remain uncertain, the federal government, regional, state, local, and Tribal governments, the private sector, and other stakeholders are investing to develop the talents and solutions necessary to ensure a sustainable transportation future. Alignment of research and policy workstreams across our agencies will be critical to ensure research and innovation efforts inform commercially deployable technologies and that research efforts can target and address identified gaps.

- **Data and Analytic Tools:** The public and decision-makers need accurate and accessible information to understand the benefits of clean mobility options, such as improvements to air quality, heath, and quality of life, and their implications for the rest of the energy systems and the economy. Timely and reliable data and analytic tools are critical to inform and guide decisions by consumers and others, ensure equitable outcomes, and adjust course during this monumental transition.

- **Workforce Education, and Training:** As the country transitions to a clean energy economy, there are tremendous opportunities to create new, well-paying jobs. These jobs can provide meaningful economic prospects for all people, including former fossil fuel industry workers and residents of disadvantaged communities. Building a diverse and well-trained clean energy workforce is critical to developing a successful clean energy economy, including in the transportation sector. To create that workforce, all levels of government and the private sector should invest in high-quality training and education programs connected to well-paying jobs. Such programs may include pre-apprenticeships and apprenticeships. A strong clean energy and transportation workforce can help create an economy that benefits everyone.

- **Stakeholder Engagement and Public-Private Partnerships:** Engagement and partnerships with local and international governments, the private sector, and other stakeholders is critical to

achieving decarbonization. All levels of government and the private sector should align their efforts to enact solutions through technical assistance and collaborative work. Partnering with the private sector to accelerate climate-focused research and innovation is also critical. Further, it will be essential to work alongside labor unions and other community stakeholders to ensure the transition to a decarbonized transportation sector empowers and improves the lives of everyone. The federal government must provide leadership, set the course, and provide long-term confidence and stability during the global transition from fossil fuels. Achieving near- and long-term energy and climate goals will require building consensus among different stakeholders and coordinated action.

The goal of this Blueprint is to illustrate how domestic actions within the above levers can be catalyzed. However, many of the same actors and solutions that have a role in decarbonizing the U.S. transportation sector are also critical in supporting decarbonization abroad. Many of the companies that will deploy decarbonization solutions are global. It is therefore vital to share and seek best practices with stakeholders abroad and to consider other available levers internationally to support global decarbonization.

3. TRANSPORTATION CHALLENGES TODAY

A. CURRENT STATUS

In 2017, the transportation sector surpassed the electric power sector to become the largest direct source of U.S. GHG emissions. Transportation emissions increased 22% between 1990 and 2019, largely due to increased vehicle miles traveled REF. After a reduction in transportation emissions during the COVID-19 pandemic, transportation demand has returned to near pre-pandemic levels and is projected to continue growing REF, REF. While U.S. transportation emissions increased between 1990 and 2019, emissions from the electric power sector fell by more than 12% over the same period and by more than 30% between 2007 and 2019 REF. Emissions from the electric power sector continue to fall as power generation has rapidly moved toward wind, solar, and natural gas sources, and away from coal REF.

As shown in Figure 2, light-duty vehicles, including passenger cars, SUVs, pickup trucks, and motorcycles, are responsible for about half of all U.S. transportation GHG emissions, as reported in the *Inventory of U.S. Greenhouse Gas Emissions and Sinks*. The evolution of vehicle design and use over the last decades has shaped light-duty vehicle (LDV) emissions. Between the late 1980s and 2004, technology progress allowed for increase in vehicle weight and power, while fuel economy remained essentially flat. Since 2004, average new vehicle fuel economy has increased 32%, but horsepower has also increased 20%, and weight has increased 4%, which has offset some of the potential fuel economy gains. The percentage of all new vehicles classified as trucks under DOT and EPA regulations used to be less than 40%, but has steadily grown, reaching 63% in model year 2021 driven mostly by the adoption of SUVs REF, REF. Increasing annual miles traveled and the preference for larger, less fuel-efficient vehicles are two long-running trends that have significantly contributed to light-duty vehicles emissions and will make decarbonization more challenging.

Medium- and heavy-duty vehicles (MHDVs) are the second-largest contributor to transportation GHG emissions, at 21% of all emissions. This diverse category of vehicles includes larger pickup trucks, delivery and work vans, refuse collection vehicles, buses, and heavy trucks. Aviation is the third largest contributor to transportation GHG emissions, at 11%. Aviation emissions include fuel used for all domestic flights and for aircraft taking off from the U.S. on international flights. Emissions from off-road vehicles and equipment are responsible for an additional 10% of U.S. transportation GHG emissions, including vehicles used for agricultural, mining, construction, and other mobile sources of emissions.[9] Maritime activities, including shipping and recreational boating, account for 3% of transportation GHG emissions, and rail transport is responsible for 2%. The final 4% of U.S. transportation sector GHG emissions is from the operation of pipelines, emissions created from the use of lubricants (due to combustion during use or disposal), and domestic military aviation activities.[10] The impacts of lubricants and domestic military activity are not further explored in this Blueprint.

GHGs emitted from transportation sources during vehicle use are predominantly (more than 97%) in the form of CO_2 released as a byproduct of combusting

[9] The off-road vehicles and equipment category in Figure 2 includes some mobile source emissions that are reported in the U.S. GHG Inventory report as part of the Commercial and Industrial sectors.
[10] For more detailed definitions of what is included in each specific sector, see the *Inventory of U.S. Greenhouse Gas Emissions and Sinks* reports.

fossil fuels and biofuels. Combustion processes also create smaller amounts of methane and nitrogen oxides (NOx), which are potent GHGs. Additionally, various hydrofluorocarbons used in vehicle air conditioners contribute to the overall GHG emissions from transportation. Aviation emits soot and induces cirrus cloudiness, which also contribute to aviation's global warming impact and is an active area of study.

The transportation sector depends heavily on petroleum fuels, and is responsible for more than 70% of the total U.S. petroleum consumption. More than 95% of transportation energy use comes from petroleum-based fuels, making it the least energy-diverse sector and subjecting the American economy to the volatility of global markets.

AIR QUALITY

In addition to GHG emissions, the transportation sector is responsible for other emissions that impact our environment and public health and that disproportionately affect disadvantaged communities. Transportation is responsible for about half of all U.S. emissions of NOx, as well as emissions of volatile organic compounds (VOCs), particulate matter, sulfur dioxide (SO_2), and various air toxics REF, REF. Air toxics are compounds such as benzene and formaldehyde that are known or suspected to cause cancer or other serious health and environmental effects. Most emissions from transportation are due to the combustion and evaporation of fossil fuels. Brake and tire wear are also significant sources of particulate emissions.

The health effects of air pollution affect millions of people, especially those who live near highways; ports; rail yards; or petroleum extraction, refinery, storage or transport infrastructure. These effects can include asthma, decreased lung function, cancer, and premature death. Children, older adults, people with preexisting cardiopulmonary disease, people of low socioeconomic status, and racial and ethnic minorities are among those at higher risk for health impacts from air pollution due to disproportionate exposure. Nationally, these impacts affect people of color disproportionately. For example, Black Americans are 40% more likely to have asthma and almost three times more likely to die from asthma-related causes than non-Hispanic white Americans REF.

Reducing emissions from the transportation system creates significant benefits to public health and welfare REF. On December 20, 2022, EPA adopted a final rule, "Control of Air Pollution from New Motor Vehicles: Heavy-Duty Engine and Vehicle Standards," that sets stronger emissions standards to further reduce air pollution from heavy-duty vehicles and engines. That rule alone is projected by 2045 to reduce up to 2,900 premature deaths and 18,000 fewer cases of asthma in children annually REF, REF. Decarbonizing the transportation system will reduce air pollution and its associated health impacts. For example, transitioning to electric vehicles powered by clean electricity will eliminate tailpipe emissions and the associated air quality and health impacts.

B. CHANGING MOBILITY NEEDS

An effective strategy to reduce emissions from transportation must consider current and future mobility needs for both people and goods. Population and economic growth are fundamental forces shaping future mobility needs, as are the trends in personal travel and housing choices and opportunities, goods movement and delivery business models, and available transportation options.

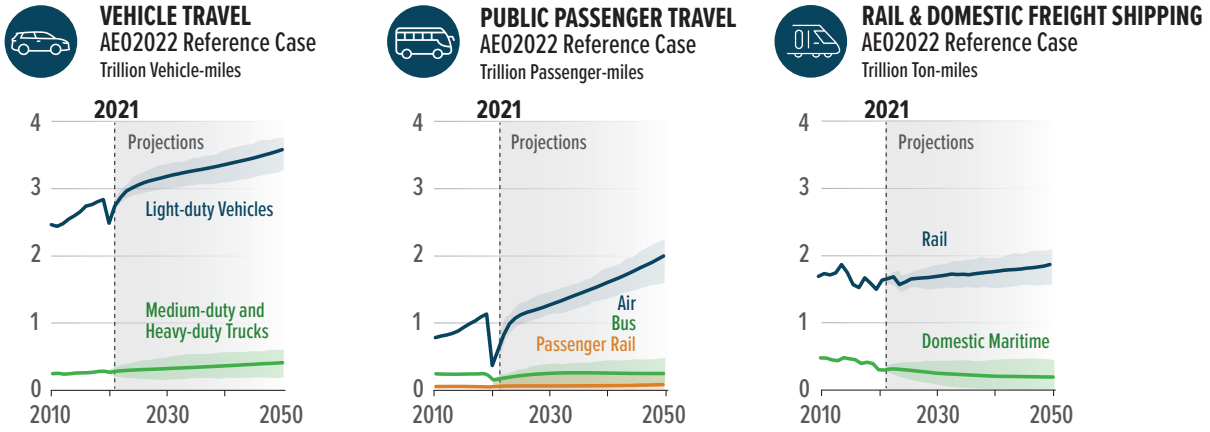


Figure 3. Passenger and freight demand projections from AEO 2022 with additional illustrative uncertainty bounds.

Projections for a business-as-usual reference scenario from the *Annual Energy Outlook 2022* (AEO), published by the U.S. Energy Information Administration, show a rebound in mobility demand to pre-pandemic levels and subsequent steady increase in vehicle miles traveled from light-duty and heavy-duty vehicles. This projection in light-duty vehicle travel demand is primarily driven by population growth, with per-capita miles traveled remaining relatively flat. Growth in heavy-duty vehicle travel demand is projected to be more significant, increasing by about 50% by 2050, mostly driven by projected economic growth and assumed relationships between GDP and freight demand. The AEO reference case also projects a significant increase in air travel, which is expected to almost double by 2050. Freight rail demand is also projected to grow, while domestic maritime operations are expected to decline slightly over time. These projections are based on assumed population growth of 0.4% per year and GDP growth of 2.2% per year from 2021 to 2050 [REF].

The AEO reference case is not intended to reflect a transformative future and does not account for major regulatory, policy, or technology changes. Instead, the AEO reference case represents a business-as-usual perspective with limited changes from the current systems and no behavioral, technological, or policy changes.

There is uncertainty regarding the extent to which travel demand is expected to grow in the future. The COVID-19 pandemic altered mobility and behavioral patterns related to how people travel and obtain goods and services. While the duration and long-term effects of these impacts are unknown, and travel has largely returned to pre-pandemic levels for most travel modes already, the pandemic has shown that rapid change can occur both in total transportation demand and how that demand is met. New services and transportation options have also been introduced into the marketplace in recent years. There has been explosive growth in e-commerce, for example, and options such as ride hailing services, scooters, and

Projections for a business-as-usual reference scenario from the *Annual Energy Outlook 2022* (AEO), published by the U.S. Energy Information Administration, show a rebound in mobility demand to pre-pandemic levels and subsequent steady increase in vehicle miles traveled from light-duty and heavy-duty vehicles.

e-bikes on shared platforms have all become part of the mobility fabric in a very short time. These disruptions of the status quo could cause, among other things, long-term shifts in mobility needs, commerce, and travel choices that will profoundly impact transportation systems and associated emissions. However, several other transportation energy sector issues have emerged since the economic recovery post-COVID-19, including a decline in the use of public transportation, congested freight transportation due to near record-high demands, and energy supply constraints due to the Russian invasion of Ukraine. These challenges in transitioning away from fossil fuels illustrate that aggressively decarbonizing transportation will serve the dual purpose of insulating the nation from the global energy and climate crises that America faces today.

Changing mobility needs and preferences create both challenges and opportunities looking forward. Policy and infrastructure investments at the federal, regional, state local, and Tribal levels, as well as other macroeconomic changes, new technologies, and behavioral drivers will influence future passenger and freight travel in major ways. While there is uncertainty in demand growth for future passenger and freight mobility, there is also an opportunity to help shape that future to provide more options to reduce vehicle miles traveled while increasing mobility options and accessibility, improving quality of life, and reducing emissions. Leveraging these opportunities can influence future travel demand and contribute to a more sustainable transportation future.

C. MOBILITY COSTS AND IMPACT OF FUEL PRICES

Transportation is currently the second-largest household expense in the U.S., with the average family spending more than $10,000 a year on transportation costs—almost 20% of the $60,574 average annual household expenditures [REF]. In 2019, owning and operating private vehicles accounted for more than 70% of the total transportation costs, and gasoline expenses represented another 21% (see Figure 4). In the same year, public transportation accounted for 7% of total transportation costs [REF]. The cost of transportation is a significant expense for many families, particularly for those in overburdened communities. In addition, the price volatility of gasoline and diesel fuels has contributed to economic uncertainty for families and businesses alike.

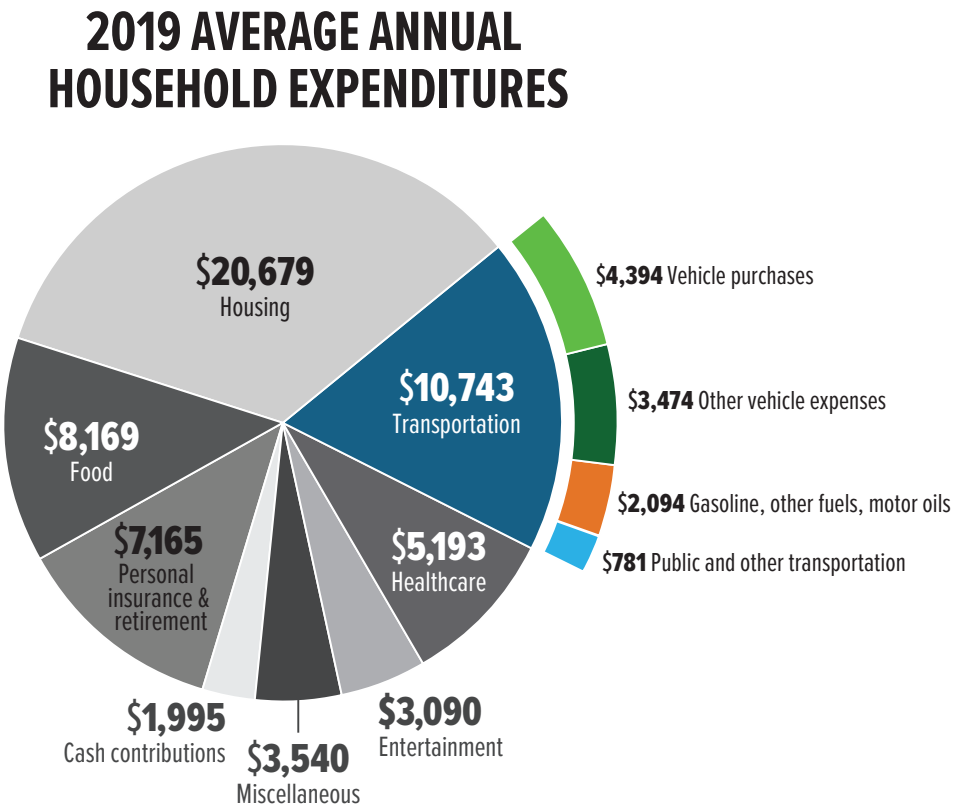


Figure 4. Consumers expenditures highlight the burden of transportation, the second-largest expenditure after housing, at over $10,000 per year on average. Data source: Bureau of Labor Statistics [REF]. This Blueprint uses 2019 as a baseline since impacts due to COVID-19 complicate the use of later data.

Fuel prices are on average 80% LOWER for EVs compared to gasoline.

Alternative transportation options represent an opportunity to reduce transportation costs while simultaneously reducing emissions and improving access and quality of life for many people. For example, EVs are already cheaper to drive than gasoline vehicles: fuel prices are on average 80% lower for EVs compared to gasoline vehicles [REF] and maintenance costs for light-duty EVs are about 40% lower than for internal combustion engine vehicles [REF]. Additionally, while electricity costs have risen, they have not increased as much as petroleum fuel costs and do not experience the same large price swings that regularly occur in the petroleum sector. The increasing supply, diversity of available models, and technological improvement of EVs are increasing their cost competitiveness with internal combustion engine vehicles. We will continue to support efforts that improve access to EV ownership and EV infrastructure, particularly for disadvantaged communities. The transportation future envisioned in this Blueprint represents an opportunity to achieve our GHG emission goals while reducing the burden of transportation on many families and businesses and making travel more accessible for all.

CONNECTIVITY, AUTOMATION, AND SHARING COULD RADICALLY CHANGE FUTURE MOBILITY

Technologies, including connectivity and automation systems, are transforming transportation in many ways. These developments can radically change how mobility needs are met, as well as consumer choices and options. New tools give people trip planning, booking, and payment options at their fingertips, improving efficiency and convenience, opening up seamless integration of travel modes, offering more options for ride and vehicle sharing, and responding to consumer preferences by increasing transparency around travel emissions.

- **SHARING RIDES –** including car/vanpooling and ride hailing—impacts emissions per passenger mile traveled. Transportation systems become more efficient when passengers and cargo can move to their destinations with fewer or no vehicle miles, which can also lower transportation costs. When passengers traveling in the same direction share a ride, they are helping to reduce energy use and emissions. However, shared vehicles often travel empty or "deadhead" between rides, increasing emissions. When vehicles take circuitous routes to pick up and drop off multiple passengers, assessing the net emissions impact can be challenging. Additionally, the pandemic has reduced the desire for sharing trips and rides, impacting travel mode choices, while increasing travel to alternative locations.

- **CONNECTED MOBILITY SOLUTIONS** enable unprecedented system-level improvements—better communication among vehicles and with infrastructure can smooth traffic flow and reduce congestion. Connectivity and automation, such as eco-approach and departure at traffic lights and platooning, enable reductions in energy consumption. Technologies that link vehicle controls with traffic control infrastructure, for example, have been demonstrated to reduce energy use by almost 20% on a test track.[11]

- **AUTOMATED DRIVING SYSTEMS** could offer convenient and safe travel options, enhancing efficiency, accessibility, and productivity. These systems are becoming increasingly available. Nine out of 10 currently available new cars are equipped with adaptive cruise control, for example, and 50% of those can control both speed and steering (e.g., lane assist) REF. It will be important to carefully plan for these systems to avoid unanticipated consequences such as increased travel demand and congestion.

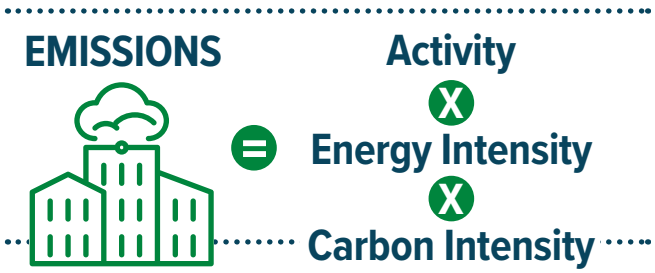
- **REMOTE WORK AND VIRTUAL INTERACTIONS** can provide a viable alternative to daily commute requirements for some people, as the COVID-19 pandemic demonstrated. An increase in remote work and virtual engagements has the potential to change travel patterns, including shifting peak commute times, reducing commuting miles, and/or increasing off-peak miles. However, overall passenger car travel has already returned to pre-pandemic levels.

Overall, widescale use of connectivity and automation will dramatically change future mobility in ways that are hard to forecast. Policies and technology solutions can harness these changes to improve safety, convenience, and affordability, and enable more efficient mobility while helping to avoid the risk of increased travel these technologies could pose if not properly managed. Our transportation systems need to be flexible enough to accommodate unforeseen new technology and societal changes that will cause mobility shifts.

[11] J. Han, D. Shen, J. Jeong, M. D. Russo, N. Kim, J. J. Grave, D. Karbowski, A. Rousseau, and K. M. Stutenberg, "Energy Impact of Connecting Multiple Signalized Intersections to Energy-Efficient Driving: Simulation and Experimental Results," to be submitted to IEEE *Vehicular Technology Magazine*

4. STRATEGIES TO DECARBONIZE TRANSPORTATION

Emissions reductions throughout the entire transportation sector will be necessary to achieve full decarbonization. All sources of transportation emissions will need to be addressed considering the projected growth and changes in mobility needs discussed above. Transportation use-phase emissions are the result of three main drivers or categories: the total amount of activity, (i.e., the distance and volume of passenger and goods travel); the energy intensity of the transportation options used to meet the activity demand, (i.e., the energy used per mile traveled); and the carbon intensity of the fuels used to provide that energy, specifically the amount of GHG emitted per unit of energy consumed:



These three categories have been widely used in scientific studies to evaluate decarbonization challenges and provide a useful framework for developing holistic decarbonization strategies [REF]. The three strategies proposed in this Blueprint directly address each of the categories and must be implemented in concert to achieve the full vision of a **clean, safe, secure, accessible, affordable, equitable, and decarbonized** transportation system for everyone. The strategies will empower people and businesses to:

- **Increase convenience** by implementing system-level design solutions that prioritize access and proximity to work opportunities, community services, and entertainment options to reduce unnecessary or excess movement of people and goods while still meeting all mobility needs. Local and regional **land-use decisions and the design of our communities and mobility systems are major drivers of travel behavior, and in turn, transportation emissions.** Improving mobility systems to reduce emissions and provide improvements in safety, traffic, and quality of life requires careful local or regional land-use planning, improved freight logistics, and harnessing emerging trends like telework and the sharing economy. Collectively, these approaches can

also help improve connections and access in communities that are historically disadvantaged and underserved.

- **Improve efficiency** by providing options to enable shifts to more efficient vehicles and transport modes like transit, rail, walking/biking, or new mobility solutions. **Coupled with system-level design solutions, more efficient mobility options offer people and businesses better access to services and reduce reliance on energy-intensive modes of transport.** Transportation efficiency can also be improved by introducing and scaling innovative technologies and services that can better connect people with mobility options, especially better first-mile/last-mile solutions. The benefits of these efforts include reduced congestion, vehicle miles traveled, parking requirements, total energy use, and GHG emissions, as well as enhanced energy security, and overall improved quality of life. Moreover, policies and technology solutions can be used to adapt to changes in future mobility. For example, the wide-scale use of connectivity and automation technologies can improve safety, convenience, and affordability, and enable more efficient travel. Properly designed policies and technology solutions can help communities avoid the risk of increased travel that could occur if these technologies and related systems are not properly managed. Achieving these goals will require proper management of mobility at the transportation systems-level rather than at mode-specific or technology-specific levels. Finally, in addition to system-level efficiency improvements, vehicle efficiency can be improved for all vehicle types.

- **Transition to clean options** by deploying zero-emission vehicles and fuels for all passenger and freight travel modes. This includes light-duty vehicles, commercial trucks, buses, off-road vehicles (such as agricultural and construction equipment), aircraft, locomotives, maritime vessels, and pipelines. This strategy involves adopting highly efficient zero-emission battery vehicles, hydrogen fuel cell vehicles, and sustainable fuels for vehicles and applications that are more challenging to electrify. Reducing the carbon intensity of the fuels that power our vehicles, airplanes, trains, and ships is essential to reducing transportation GHG emissions. **Achieving a net-zero economy by 2050 will require transitioning new vehicle sales to zero-emission technologies across all modes of transportation by the mid-2030s**, and rapidly converting older and higher-polluting fossil fuel-powered vehicles. This transition will require addressing EV charging and clean fuel infrastructure needs to enable every person and business to meet their mobility requirements.

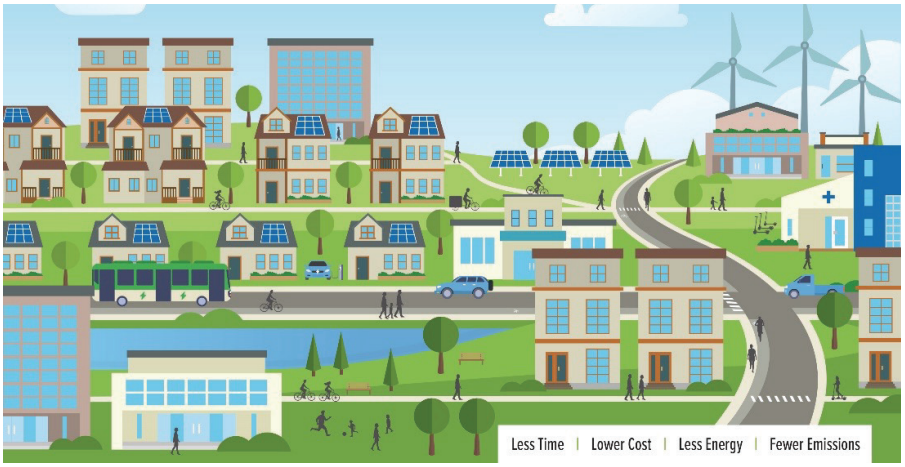
Figure 5. Three strategies to address all sources of transportation emissions and achieve the full vision of a clean, safe, secure, accessible, affordable, equitable, and decarbonized transportation system for everyone.

A. INCREASING CONVENIENCE BY IMPLEMENTING SYSTEM-LEVEL AND DESIGN SOLUTIONS

Increasing convenience by implementing system-level and design solutions will be critical to achieving sustainable mobility, especially in light of expected population and economic growth that could otherwise significantly increase demand for passenger and freight travel. Increased convenience entails supporting community designs and land-use planning that ensure job centers, shopping, schools, entertainment, and essential services are strategically located near where people live to reduce commute times, improve walkability and bikeability, and improve quality of life. It is also important to recognize the different transportation needs and opportunities for rural communities, which are often separated by large distances, have little or no public transit options, and present unique infrastructure challenges. Reducing transportation emissions starts with understanding and addressing the factors influencing travel demand and optimizing the amount of travel needed to reliably access services and distribute freight to ensure the mobility needs of all Americans are fully met.

The design of our cities, towns, suburbs, and neighborhoods, and investments in transportation infrastructure like highways, streets, bike lanes, and railways, heavily influence travel behavior and mode choices, which in turn impacts total miles traveled and resulting emissions. Decisions that federal, regional, state, local, and Tribal governments have made—including ones made decades ago—have shaped our current transportation landscape, where reliance on driving, increased traffic, congestion, and associated emissions are accepted as norms. These decisions have also often caused disproportionate environmental and health impacts on low-income, minority, and underserved communities and deprived them of investments in affordable, low-carbon transportation options, which has been exacerbated by dispersed development. These communities have higher housing and transportation cost burdens that further exacerbate inequities. Local and regional land-use policies and infrastructure investments need to deliberately support these communities and help them address transportation disparities. Similarly, land-use practices have moved logistics facilities away from urban centers, which has resulted in increased emissions. Infrastructure investments and policy decisions made today will shape land-use development patterns for

Significant emission reductions can be achieved by 2050 by supporting regional, state, local, and Tribal governments' development and land-use policies that prioritize investments in efficient transportation options and by leveraging new technologies. Together, these system-level design and technological solutions can increase accessibility and mobility options and enhance freight efficiency while decreasing GHG emissions.



decades, setting the stage for future mobility demand and creating the opportunity to improve transportation systems. While land-use decisions are made at the regional, state, local, and Tribal levels, federal policy and investments can guide and inform those decisions.

It is important to plan for redevelopment and new development that take into account future mobility patterns and support equitable, clean, and convenient transportation systems. Robust partnerships with regional, state, local, and Tribal communities can enable and incentivize land-use decisions—promoting equitable redevelopment of existing neighborhoods, retrofitting dispersed development to create a mix of uses and improve transportation options, and planning for new development—that will lessen environmental and health harms, reduce travel times, make it easier to choose less-polluting transportation options, improve quality of life, and mitigate longer-term climate change impacts. Supporting land-use strategies and planning practices that enable clean transportation solutions will improve mobility for people and goods; give people easier access to work and housing opportunities, community services, and entertainment options; and bring other environmental, health, economic, and community benefits.

New technologies could also improve convenience through better mobility and access. For example, telework, the shared economy, and e-commerce are transforming our lives and changing the way we access goods and services. Mobile applications can more seamlessly integrate multiple travel options, including transit, e-bike and scooter options, multimodal freight, and others on a single platform. Additionally, mobile technologies have allowed digital service offerings to replace some trips. Telework is now commonplace, and remote access to services like healthcare and education has grown. E-commerce is widespread.

These trends and how they continue to evolve will be key determinants of future travel demand (see textbox on page 33). However, increased automation and connectivity will not necessarily decrease emissions and might instead induce increases in travel demand if not properly managed. For example, there could be an increase in miles traveled without a passenger for autonomous vehicles, reflecting the need to carefully consider the full effects of design solutions and new solutions. Forward-looking policy and management at the transportation system-level are needed for emerging technologies to improve quality of life and reduce emissions. This reliance on digital technologies will also require efforts to ensure that everyone has access to these platforms and the opportunities they offer.

Achieving the benefits of system-level and design solutions to reduce transportation emissions requires coordination across federal, regional, state, local, and Tribal governments and engagement with community-based organizations, businesses, and residents. Pursuant to state-enabling legislation, towns, cities, or counties have jurisdiction over regulations and zoning laws that shape land use. This positions them to use policy and planning tools to curb GHG emissions over time with future development patterns [REF]. For example, changes in local zoning regulations to allow for multifamily and affordable housing, work, and play to be close to public transportation will reduce the need for longer trips to meet daily needs.

Complementary actions that support decarbonization of the transportation sector can include integrating land-use, transportation, and freight planning to reduce vehicle miles traveled, and increasing investments in first-mile/last-mile solutions to broaden access to public transportation. Federal resources and efforts can amplify actions at all levels of government:

Fix Existing Assets Before Building New Assets

One key system-level planning solution is to prioritize investments that fix assets and modernization projects that enhance existing infrastructure, avoiding more costly expansions in roadway capacity. Investments in expanding roadway capacity increase maintenance expenditures and induce additional travel, resulting in increased emissions. Additionally, capacity expansion generally provides limited-to-no congestion reduction benefits over the long-term REF, REF, REF, REF. In 2018, 22.9% of spending on highways receiving federal aid went to system expansion REF. A recent analysis by the Georgetown Climate Center found that whether the investments in the BIL lead to an increase or a decrease in emissions depends on how effectively the federal government and regional, state, local, and Tribal entities can use the available funds to support climate-friendly infrastructure projects and prioritize system maintenance and multimodal options over expanding roadway capacity REF. The BIL and IRA funding present an opportunity to encourage locally driven land-use changes and reinvest in existing communities, including rural main street revitalizations, and transit-oriented and walkable development.

Eighty-seven percent of federal highway funding is distributed to states via a congressionally established formula, and states have discretion in how those funds are spent REF. In order to meet our climate goals by prioritizing repairing and modernizing existing

infrastructure, DOT's Federal Highway Administration (FHWA) released guidance in December 2021 to encourage states and other funding recipients to use newly available resources to prioritize repair, rehabilitation, and modernization of existing roads and bridges over expanding capacity, and to be mindful of their abilities to deploy resources in support of multimodal projects REF. Several states have already shown leadership in this space and have goals for reducing VMT, including California, Minnesota, Massachusetts, Pennsylvania, Washington, and Colorado REF.

Changes in Land-Use Planning and Transportation Systems Design

More compact cities and towns with a mix of commercial, residential, and civic uses close to each other reduce the distances between where people live, work, and recreate, which makes active modes of transportation and transit even more viable and allows people to spend less time sitting in traffic.

A compact urban form can also help reduce distance traveled at various supply chain stages, thereby making light modes, such as cargo-bikes and smaller EVs, more practical for freight delivery. Planning for all transportation system users, including pedestrians, bicyclists, transit riders, motorists, and delivery drivers, can also improve roadway safety for all users, encouraging more people to choose active transportation.

Planning must also be centered around improving access for people with disabilities to ensure that all transportation system users are able to choose from clean mobility options. The combination of mixed-use development, increased density, and improved transportation systems could also lead to more efficient distribution of goods. For example, mixed-use development could reduce the travel distance between stores or distribution centers and their customers, and also allow for different vehicle choices like delivery e-bikes. Public and private players in the last-mile ecosystem of freight delivery have a key role to play in reducing emissions because of the significant rise in e-commerce.

The federal government, with regional, state, local, and Tribal governments, stakeholder groups and partners from private industry, can play a role in the following areas:

- **Equitable Transit-Oriented Development (eTOD)**. Improved land-use planning and transportation systems design can also support transit-oriented development, making active travel modes (e.g., walking and biking) and public transportation even more viable. As these modes become more attractive, drivers also benefit from reduced congestion.[12] ETOD supports a walkable, mixed-use development and transit lifestyle and meets the needs of existing businesses and consumers, while avoiding displacement of local residents and ensuring an adequate mix of affordable and market-rate housing. A cornerstone of TOD is the inclusion of affordable housing, to be achieved through new construction, preservation of existing stock, and tenant protection efforts to minimize displacement caused by increased land values that often accompany TOD. The federal government can work with local transit agencies and the private sector to incentivize development that protects existing residents from displacement, as well as support small business and economic development. For example, under the Federal Transit Administration's (FTA) Joint Development Guidance, local transit agencies can use land purchased with FTA funds to support eTOD through joint development partnerships or joint development.

Decision-makers at the regional, state, local, and Tribal levels can also leverage federal funding opportunities to support first-mile/last-mile solutions and equitable transit-oriented and walkable development. For example, localities can apply for DOT RAISE planning grants to develop integrated corridor plans that encompass improvements to bike/pedestrian infrastructure and transit along with affordable housing strategies, or seek federal financing opportunities such as DOT's loans programs, HUD's Community Development Block Grants and the associated Section 108 Loan Guarantee program—along with formula affordable housing grants through the Home Investment Partnership Program (HOME)—to support transit-oriented development REF, REF.

In addition to funding, federal agencies can coordinate and align technical assistance, as is being done through the Thriving Communities Network, which provides a whole-of-government approach to place-based technical assistance from seven federal agencies, including DOE, DOT, EPA, and HUD.[13] For example, HUD and DOT are partnering to provide assistance to local governments to identify and use vacant land on or

[12] U.S. Government Accountability Office, *Public Transportation: Multiple Factors Influence Extent of Transit Oriented Development*, GAO –15-70, 2014. Cited in Mariia V. Zimmerman et al, National Academies, *Coordination of Public Transit Services and Investments with Affordable Housing Policies* (2022).

[13] DOT, Federal Interagency Thriving Communities Network

near transportation investments that is suitable for housing development, and identify unnecessary barriers to location-efficient housing REF.

- **Location Affordability and Efficiency.** Combining transit-oriented development with affordable housing strategies is an effective way to reduce GHG emissions, while supporting other co-benefits. Location efficiency is the siting of housing and commercial development in proximity to transit and other amenities. Past suburban and exurban development resulted in families moving further and further from downtowns and urban centers to find affordable housing. In doing so, they often incurred higher transportation costs associated with the location of that housing. HUD and DOT created the Location Affordability Index (LAI) in 2015 to increase public access to data about transportation, housing, and land use REF, REF. The LAI provides a combined index of household housing and transportation expenditures, taking into account proximity to transit, car ownership, access to amenities and services, and other factors.[14] Similarly, EPA developed a Smart Location Database that includes more than 90 attributes summarizing characteristics such as housing density, diversity of land use, neighborhood design, destination accessibility, transit service, employment, and demographics REF. Federal agencies can encourage or incentivize location-efficient housing with federal financing, as HUD does through the Green Mortgage Insurance Premium for multifamily affordable housing, and some states do in Qualified Allocation Plans for the federal Low Income Housing Tax Credit.

- **Local Zoning Reform.** States and localities can craft local regulations and zoning policies to encourage more housing supply in walkable, transit-oriented areas. The president's Housing Supply Action Plan REF identifies local zoning and land-use policies as a significant constraint on affordable housing production: "One of the most significant issues constraining housing supply and production is the lack of available and affordable land, which is in large part driven by state and local zoning and land-use laws and regulations that limit housing density." Local zoning reform can address the critical need to both expand housing supply, and simultaneously enable a wider range of transportation choices in local communities. Localities may also reset minimum and maximum parking requirements. Recognizing that zoning is a local responsibility, the Housing Supply Action Plan includes proposals for rewarding jurisdictions that have implemented forward-looking local land-use policies with higher scores in certain federal grant processes, and leverage BIL funding to encourage state and local governments to boost housing supply. As outlined in the Housing Supply Action Plan, DOT will continue to include language encouraging locally driven land-use reform, density, rural main street revitalization, and transit-oriented development in BIL and other transportation discretionary grant programs.

- **Supporting Safe Active Transportation.** Regional, state, local, and Tribal governments can invest in safe active transportation, including through opportunities in the BIL, such as the new Safe Streets and Roads for All program and the Transportation Alternatives Program to support

[14] Location affordability refers to the fact that most of the benefit occurs because of the attributes of a neighborhood or location, holding income and household size constant; makes it possible to identify bundles of discrete actions (those that increase local convenience and regional accessibility) that can lower transportation costs.

pedestrian and bike infrastructure, recreational trails, safe routes to school and more. Additionally, curbside management strategies and complete streets, or streets designed to enable safe use and support mobility for all users, can enhance safety and convenience in communities and support a shift to active transportation. As more people use clean travel options and personal light-duty travel decreases, road lanes can further accommodate shared and active modes of transportation REF.

- **Coordinated Transportation Planning.** Transportation planners and researchers have long recognized the importance of coordinating transportation, transit, and land-use planning near higher-capacity transit services to help build ridership, reduce congestion, and shape community development REF. The BIL includes several changes in the metropolitan planning process that provide new opportunities to align investments in transportation and housing.[15] These include provisions for Metropolitan Planning Organizations to consider projects and strategies that promote consistency between transportation improvements and state and local housing patterns; to increase consultation with housing officials and opportunities for comment by affordable housing organizations; and to address the integration of housing, transportation, and economic development strategies through a housing coordination plan.

Digital Solutions and Teleworking

Telework and other components of a digital economy that allow consumers to access information and services remotely can improve convenience by reducing travel demand, especially for work commuting. The COVID-19 pandemic has highlighted major opportunities for telework, with some studies showing the possibility of 10% long-term reduction in annual VMT REF. However, for most travel modes, total travel activity has already returned to near pre-pandemic levels. Ultimately the impact of telework depends on the specific travel displaced and whether additional travel is induced due to vehicle use by other household members, possible relocation decisions, impacts to commercial centers, and other complex factors. Overall, the transportation implications of telework are not yet fully understood REF, REF.

Transportation Demand Management (TDM)

Transportation demand management is the use of strategies and policies to reduce travel demand, which in turn reduces traffic, energy use, and GHG emissions. TDM initiatives are multimodal in nature and include strategies like congestion pricing and parking pricing paired with affordable transit options, car free zones with accessible and safe bike and pedestrian infrastructure, ride sharing promotions, safe walking, biking, and rolling routes to school, transit fare discounts, off-peak goods delivery incentives, and more. An understanding of local mobility needs and optimizing existing transportation assets are essential for implementing effective TDM strategies REF. The federal government can support TDM efforts at the regional, state, local, and Tribal levels by sharing best practices, data, and tools to support decision-maker efforts to effectively manage transportation demand.

Supply Chain Management and Freight Efficiency

Supply chain management and logistics planning is the practice of optimizing the movement of goods from one place to another. Improvements to supply chain management, which could reduce VMT and associated emissions, involve strategies to improve

[15] Bipartisan Infrastructure Law, Section 11201(d), 23 USC 134.

vehicle and infrastructure utilization, such as enabling vehicles to travel with full loads as often as possible (reducing empty or "deadhead" miles) and optimizing vehicle travel routes. For example, just-in-time queuing at ports can enable ships to optimize their speed, thus reducing fuel consumption and emissions REF. Strategies to increase freight efficiency could also include using emerging technologies like improved packaging and materials, distributed manufacturing, and dematerialization. Advanced computing and data analytics (e.g., sensors, big data analytics, blockchain) have the potential to improve supply chains by optimizing truck routing and freight logistics. EPA's SmartWay program helps companies improve freight transportation sustainability by selecting more efficient modes, carriers, equipment, and operational strategies and fuel-saving technologies REF. The continuing growth of e-commerce creates new opportunities for improvement—as increasing direct delivery of goods to consumers can offset personal travel—but fast-delivery demands and returns present new challenges.

These system-level and design solutions to increase convenience have the potential to deliver total reductions in GHG emissions of an estimated 5-15% by 2050, and also offer significant additional co-benefits (see textbox on page 48) REF, REF. Near-term benefits are expected to be modest due to the long service lives of residential and commercial buildings and transportation infrastructure, but benefits can compound over time and managing demand is critical to avoid increased emissions from population growth or induced demand from clean technologies and solutions. Implementing system-level and design solutions will require coordination across multiple levels of government, especially local governments and planning organizations. DOE, DOT, EPA, and HUD encourage these approaches in partnership with other federal agencies, regional, state, local, and Tribal governments, and private stakeholders. States and cities have taken the lead on many of these solutions, however there is a federal role in aligning and supporting these efforts.

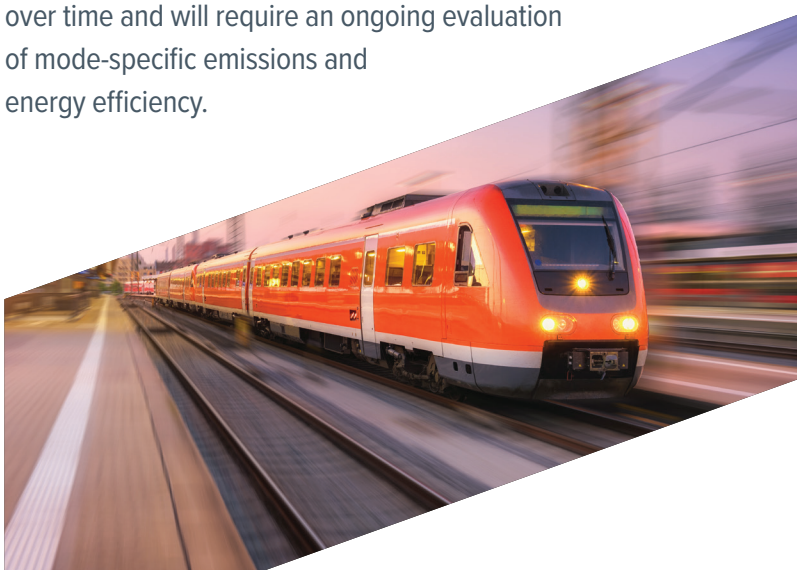
USING THE TRANSPORTATION RIGHT-OF-WAY FOR CLIMATE BENEFITS

The transportation right-of-way (ROW) offers an opportunity to support decarbonization and enhance energy system resilience. Specifically, transportation agencies can leverage pre-existing sites to host critical infrastructure, such as electric vehicle charging infrastructure, electricity transmission lines and renewable energy systems with lower approval barriers. For example, more than 52,000 acres of empty roadside land is available at interstate exits and suitable for solar energy development, offering the potential to generate up to 36 terawatt hours (tWh) a year, which is enough energy to power roughly 10 million passenger EVs REF. The ROW also offers a pathway to deploy electric transmission lines that will be critical to connect renewable electricity to end users, increasing resiliency for the benefit of all Americans REF. Other potential resilience benefits of using transportation ROW in innovative ways include sequestering carbon and reducing air pollution through the strategic planting of trees and bushes REF; combating heat island effects with native vegetation; and capturing, filtering, and absorbing rainfall to protect water quality and reduce localized flooding. This green infrastructure—trees and planted areas along streets, parking lots, and other paved areas—also beautifies neighborhoods, makes walking and biking more appealing, and can manage stormwater runoff more cost-effectively than conventional infrastructure REF. While working in the right-of-way can entail a high degree of coordination and approvals from property owners, easement holders, and the travelling public, we understand the benefits of these applications, and DOT released a memorandum to further encourage and allow for state transportation agencies to expand the productivity of existing highway ROW REF.

B. IMPROVING EFFICIENCY THROUGH MODE SHIFT AND MORE EFFICIENT VEHICLES

The second key strategy to reduce transportation emissions is to improve efficiency by increasing the availability of highly efficient travel options, while also improving the energy efficiency (or fuel economy) of all vehicles, especially passenger vehicles, which often have low occupancy. Road freight vehicles such as trucks and vans are the largest contributor to freight emissions, and heavy road freight vehicles in particular can be difficult to decarbonize. This energy- and emissions-intensive paradigm is a significant reason why transportation has become the largest GHG emissions source in the United States. Using more efficient modes and vehicles is essential to reduce overall transportation emissions and energy use. The use of more efficient modes could also reduce the number of vehicles on the road and reduce congestion, improving travel time and traffic flow thereby further reducing GHG emissions and other harmful air pollutants.

The choice of which transport mode is best for any given trip is complex and depends on available mobility options, as well as cost, speed, safety, convenience, and other factors. Generally, transportation options that move greater numbers of people or volumes of goods (buses, trains, large ships, carpooling, etc.) result in lower GHG emissions per mile traveled. Figure 6 provides a snapshot of the current emissions from various travel modes in the United States (note that these results are based on current vehicles on the road powered by petroleum fuels). For local passenger travel, large personal vehicles with low occupancy have the highest emissions, while buses and transit rail offer the cleanest options other than walking or biking. For longer passenger trips, buses and cars with multiple occupants offer the lowest emissions option, followed by rail, aviation, and large passenger vehicles with low occupancy. For freight, maritime and rail offer the cleanest options, followed by trucks and aviation, which results in the highest emissions. New first/last mile transportation services and infrastructure, such as shared electric scooters and e-bikes, shared mobility apps, mobility hubs where multiple personal transportation options are available, and intermodal freight terminals that can help optimize freight movement, are all transportation developments that can enable and support a shift to more efficient transportation modes and help reduce GHG emissions [REF]. Additionally, emerging vehicle technologies and fuels will reduce emissions for many of these travel modes over time and will require an ongoing evaluation of mode-specific emissions and energy efficiency.



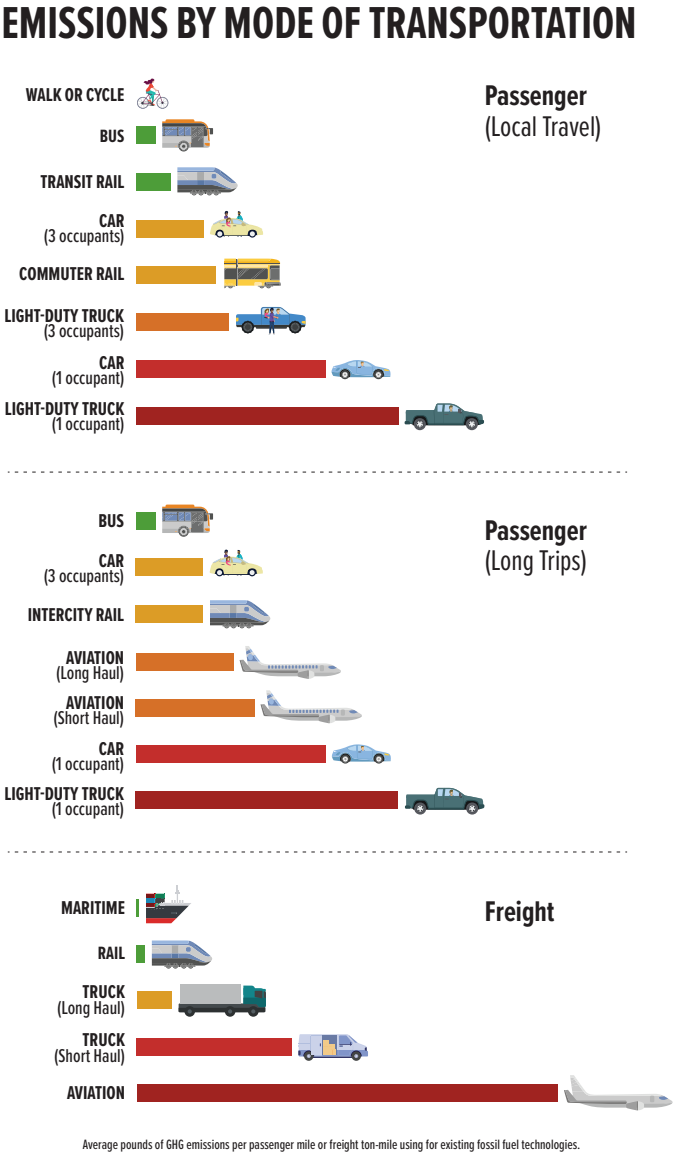


Figure 6. Different modes of transportation have different carbon intensities per passenger mile or per ton mile, and a system that prioritizes low-carbon-intensity options has fewer emissions overall. Note: emissions vary significantly based occupancy, fuel type, and other factors, so the scale in this figure is meant to be illustrative and represent the current fuel mix. For example, transit rail is fully electrified, while most other modes rely on fossil fuels. Illustrative data informed by GREET modeling [REF] and EPA data [REF].

By increasing clean and efficient transportation options and improving vehicle efficiency, we can reduce harmful climate change impacts and air pollution; ensure a more equitable, accessible, and affordable transportation system that improves quality of life for all users; reduce reliance on fossil fuels; and improve energy security. In 2018, public transportation in the United States saved 63 MMT of carbon dioxide equivalent.[16] Building on this success, an effort to continue expanding transit, intercity rail, and active transportation options and use will further reduce emissions. In addition, clean and efficient freight solutions can help address negative impacts associated with freight delivery, such as traffic and air pollution, while ensuring that consumer expectations are met. Combined with enhanced travel convenience, improving efficiency can significantly reduce energy needs and GHG emissions.

Multiple **solutions and actions** can improve mobility options and offer all Americans more affordable, energy-efficient, and cleaner alternatives, including:

- **More investments in efficient passenger and freight transportation**
  Regional, state, local, and Tribal governments can encourage greater use of transit by leveraging federal funding and financing opportunities to expand existing transit and intercity rail systems and invest in new service. Ensuring that transit service is equitable and fully accessible for people with disabilities will make it easier and more appealing for all users to choose less carbon-intensive options. Strategies to increase convenience that were highlighted in the previous chapter will also improve mobility options, as transit-oriented development and complete streets will allow more people to choose lower-carbon modes of transportation such as walking, biking, and public transportation. Investment in protected

[16] Transit Cooperative Research Program (Research Report 226)

bike lines, accessible sidewalks, and other roadway safety improvements will further encourage people to choose active modes of transportation. Timely and impartial data collection and analysis will also help inform decisions and guide investments, especially on behavioral responses and impacts of innovative technologies and solutions. Equitable access to rail, pedestrian, and bicycle infrastructure can also help reduce emissions from freight. Well-maintained, wide sidewalks, for example, could support delivery robot movement in addition to pedestrian access, and bicycle infrastructure can support the use of cargo bikes for freight delivery.

- **Incentives for less carbon-intensive options and shared mobility**
  All levels of government should guide and incentivize development and use of efficient passenger travel systems, including vehicle sharing solutions. This could include a diverse set of policies, including local zoning and permitting and incentive programs. Additionally, investing in infrastructure for more efficient modes of freight transport will enable and encourage businesses to use less carbon-intensive options. Jurisdictions can consider options like dynamic parking pricing, removing minimum parking space requirements, and congestion pricing to encourage people to consider alternative travel modes or solutions to enable ride pooling and vehicle sharing. In doing so, they should also consider equity implications and ensure that these policies do not disproportionately burden disadvantaged communities. Employers can also provide incentives for employees to choose less carbon-intensive commuting options, including public transportation, active transportation, carpooling, and telework. The federal government can support these efforts by sharing best practices and providing funding. Educational materials that highlight the benefits of mode shift, such as financial savings, increased exercise, less stressful commutes, or more convenient travel options, can encourage the general public to consider less carbon-intensive mobility options. Industry can prioritize shifting parts of shipment journeys away from trucks to rail and water shipping when feasible. Additionally, light modes of freight delivery, such as cargo bikes, delivery robots, and small EVs can be encouraged for local/last-mile deliveries in more compact areas. Incentives can be offered to encourage the use of freight-efficiency practices, such as minimizing empty miles, off-peak deliveries, and freight vehicle load optimization.

- **Improvements in the operation of transportation systems**
  Transportation systems operations can be improved and optimized to reduce energy use and emissions. For example, better logistics could increase vehicle routing and load factors, improving efficiency while also reducing fuel costs. New technologies can help improve multimodal freight transport and logistics and enable the use of shared transport assets and services, and more effectively respond to changes or unexpected delays using real-time data. Also, new connectivity and automation solutions can enable additional system-level efficiency improvements to alleviate traffic congestion and significantly reduce emissions. For example, cooperative driving automation (e.g., platooning, intersection eco-approach) could reduce congestion and improve energy efficiency by up to 20% REF. Additionally, new air traffic management methods such as Trajectory Based Operations

can increase system efficiency by optimizing flights using time-based management, improving information exchange between air and ground systems, and fully leveraging an aircraft's ability to fly a precise path REF. Importantly, automation and other operational improvements could result in additional travel demand, offsetting efficiency improvement benefits. This paradox highlights the importance of properly managing new technology to achieve positive results.

In 2018, public transportation in the United States saved

63 MILLION METRIC TONS

of carbon dioxide equivalent.

- **Improvements in the energy efficiency of vehicles**
  While achieving long-term climate goals requires transitioning to cleaner vehicles and fuels (see Section 4C), conventional vehicles will continue to be sold over the next decade and many legacy vehicles are likely to still be operating in 2050. Therefore, it is critical to continue to improve system- and vehicle-level efficiency through improved engines and vehicles; light-weighting and use of better materials; reduction of non-combustion emissions (e.g., pipeline leakage); and optimizing vehicle use to minimize emissions (e.g., better freight logistics to improve fuel economy). Vehicle-level efficiency improvements such as hybridization or mixed use of fuels (e.g., oceangoing vessels using electricity generated on shore while in ports) will also be important. Vehicle energy efficiency improvements will also benefit consumers and businesses through lower operating costs. These improvements will help reduce the cost of future EVs while increasing energy security. Government policies have played a key role in improving the energy efficiency of new passenger vehicles and medium/heavy-duty trucks. These policies will continue to be critical as clean vehicles are adopted.

- **Innovative business models and solutions**
  Emerging business models and technologies will shape the future of the transportation sector. The public and private sectors should work together to explore and test technologies that enable mode shifts and multimodal solutions that include high-efficient modes for passenger and freight travel. For example, rideshare companies can encourage pooled rides and partnerships with transit agencies so the public can easily incorporate micromobility, transit, and additional forms of shared mobility when planning trips. The California Integrated Travel Program (Cal-ITP) is a seamless trip planning and payment program across California rail and bus providers that brings together the principles of "sustainability, equity, and optimizing the rider experience" by eliminating barriers related to fare payment, verification of transit discounts, and accessible real-time data REF. Overall, public support can help reduce investment risks and encourage innovative solutions to test market effects and consumer response.

The federal government can support regional, state, local, and Tribal governments in facilitating a shift toward more efficient travel through funding and financing opportunities for transit, rail, and active transportation. DOT can also work with stakeholders to help facilitate this shift through improvements in roadway safety. The department's *National Roadway Safety Strategy* outlines a comprehensive approach to improve safety on our nation's highways, roads, and streets, which will encourage more people to walk, bike, and roll. Working with stakeholders, the federal government can improve mobility options for everyone, but ultimately the general public and businesses make decisions based on what travel choices are most affordable, accessible, and convenient. Cleaner, more affordable, and more convenient travel options will encourage people to explore transportation options besides single-occupancy vehicles and help people become more comfortable with new, efficient transportation choices. The federal government, partners, and stakeholders will need to build a transportation system that ensures these efficient travel modes are the most reliable, affordable, and convenient solutions for both freight and passenger movement.

CO-BENEFITS OF DECARBONIZING TRANSPORTATION SYSTEMS

In addition to beneficial climate impact, improved transportation systems and mobility options offer a variety of co-benefits.

- **Safety and Quality of Life –** Investments in active transportation infrastructure can ensure that those walking, biking, and rolling can travel safely and improve access to public transportation. In addition to reducing air pollution, these investments will generate health benefits by encouraging people to exercise in the course of their daily lives and avoid the stress of driving in traffic. Transportation systems that rely more on walking, biking, and transit require a smaller physical footprint, which reduces impacts on the natural and human environment, frees up space used for parking, and lowers noise and pollution in communities, greatly improving quality of life in our neighborhoods.
- **Equity –** Today's transportation system does not serve all communities equitably. For example, 20% of American families below the poverty line do not have access to a car, with a disproportionate percentage of those families being Black (33%) and Latino (25%) REF. Limited transportation options mean limited access to jobs, culture, recreation, and even friends and family. Investments in reliable, frequent, and affordable transit service, along with safe sidewalks and bike lanes, provide much-needed mobility for households without access to personal vehicles and offer outsized benefit for people of color, residents of low-income communities, and Americans with limited mobility. Increasing access to low-carbon travel infrastructure by improving bicycle and pedestrian safety will benefit all roadway users and bring significant benefits to vulnerable roadway users, including seniors, people with disabilities, and people in lower income communities. In addition, investments in infrastructure can increase wealth creation opportunities for underserved communities. DOT's Disadvantaged Business Enterprise program is helping ensure that small businesses owned by people of color and women get a fair chance to compete for infrastructure contracts.
- **Air Quality –** Decarbonizing the transportation sector will reduce air pollutants that are harmful to the environment and to public health, such as NOx, volatile organic compounds, particulate matter, sulfur dioxide, and others (also see air quality textbox on page 29).
- **Economic Growth –** Investment in public transportation, rail, and active transportation infrastructure generates large economic returns. Every $1 invested in public transportation generates an estimated $5 in long-term annual economic returns, and every $1 billion invested in public transportation supports about 20,000 jobs REF. Fuel savings from walking and biking instead of driving are estimated to be $3.3 billion annually in the U.S. REF. A study on Georgia's Silver Comet Trail expansion found that people gain an estimated $4.64 in direct and indirect economic benefits from every $1 invested in the expansion REF. In 2017, Class I railroads alone generated $219 billion in economic activity and yielded around $26 billion in tax revenues, while supporting 1.1 million jobs across the nation REF. Additionally, the compact, mixed-use development patterns that support a cleaner transportation system also generate greater revenue per acre of land, spur more economic productivity, and support job creation REF.
- **Energy Security –** Transportation is currently heavily dependent on petroleum fuels, and the sector accounts for over 70% of all petroleum used in the United States. Improving mobility options and the efficiency of the transportation sector will reduce our dependence on petroleum, limit the impacts of petroleum price volatility and inflation, and lower our total energy use. Lower and more diversified energy demand—when accompanied by enhanced domestic supply chains or clean technologies—will improve the nation's security, decrease vulnerability to supply interruptions or price changes, and increase the reliability and affordability of mobility for all Americans. Incentives in the BIL and IRA combined with other federal investments and the National Blueprint for Lithium-Batteries REF are actively expanding sources of battery components, increasing diversification and energy security.

C. TRANSITIONING TO CLEAN OPTIONS BY DEPLOYING ZERO-EMISSION VEHICLES AND FUELS

The third strategy to reduce transportation emissions is to transition to clean options by deploying zero-emission vehicles and fuels as rapidly as possible for all viable vehicles and fuels. Improving the transportation system by increasing convenience and improving efficiency is the foundation upon which we can deploy clean vehicles and fuels. Successfully implementing the first two emissions reduction strategies will ease the challenges associated with rapidly deploying clean vehicles and fuels and replacing fossil fuels with clean alternatives.

Achieving a net-zero-emissions economy by 2050 requires aggressively curbing transportation emissions through a suite of technology solutions across all passenger and freight travel modes, vehicle types, and fuels. Today's transportation system relies on petroleum fuels for more than 95% of its energy use. With renewable electricity and sustainable fuels becoming increasingly available and affordable, there are more viable pathways to transition to low- or zero-carbon technologies by 2050.

The cornerstone of this new transportation paradigm will be highly efficient zero-emission EVs that can leverage clean electricity while also supporting the decarbonization of the power sector (see textbox on page 55). The specific requirements of different modes and applications will require multiple targeted technology solutions across all passenger and freight travel modes, including direct electrification, use of hydrogen, and low-carbon sustainable liquid fuels. Progress in battery and electric drive technologies has already made zero-emission battery EVs a viable alternative to fossil fuel-powered vehicles in many applications. EVs are rapidly becoming a practical alternative for most on-road vehicle applications, with potential opportunities in other modes as well [REF]. Hydrogen fuel cell vehicles can complement battery EVs for applications requiring longer ranges and faster refueling times, like long-haul trucking. To achieve net-zero targets, sustainable fuels produced from biomass and waste feedstocks can be used to decarbonize hard-to-electrify forms of transportation such as air transport and long-haul shipping that require more energy-dense fuels. Widespread electrification of on-road vehicles will ensure that sufficient amounts of sustainable fuels are available for these harder-to-electrify applications (see textbox on page 54). Even with accelerated fleet turnover, combustion engine vehicles will still be in use after 2040, so sustainable fuels can help decarbonize legacy vehicles during the transition toward zero-emissions technologies. The transition to clean fuels will also have a profound effect on the source of this energy—the electric grid. The grid itself is decarbonizing, and the electricity needs of new transportation systems will require innovations in design and operation of the grid.

These clean technologies will also have benefits outside the transportation sector—such as use of hydrogen or batteries to decarbonize industry or the electricity sector and use of bio-products to replace fossil fuel

1 icon represents limited long-term opportunity 2 icons represents large long-term opportunity 3 icons represents greatest long-term opportunity	BATTERY/ELECTRIC	HYDROGEN	SUSTAINABLE LIQUID FUELS
Light Duty Vehicles (49%)*		—	TBD
Medium, Short-Haul Heavy Trucks & Buses (~14%)			
Long-Haul Heavy Trucks (~7%)			
Off-road (10%)			
Rail (2%)			
Maritime (3%)		†	
Aviation (11%)			
Pipelines (4%)		TBD	TBD
Additional Opportunities	• Stationary battery use • Grid support (managed EV charging)	• Heavy industries • Grid support • Feedstock for chemicals and fuels	• Decarbonize plastics/chemicals • Bio-products
RD&D Priorities	• National battery strategy • Charging infrastructure • Grid integration • Battery recycling	• Electrolyzer costs • Fuel cell durability and cost • Clean hydrogen infrastructure	• Multiple cost-effective drop-in sustainable fuels • Reduce ethanol carbon intensity • Bioenergy scale-up

* All emissions shares are for 2019

† Includes hydrogen for ammonia and methanol

Figure 7. Summary of vehicle improvement strategies and technology solutions for different travel modes that are needed to reach a net-zero economy in 2050 (more details provided in Section 5).

feedstocks—but will require targeted investments in RD&D, infrastructure deployment, supply chains for materials and minerals, and comprehensive policy support that varies by travel mode as described in more detail in Chapter 5.

Reducing transportation emissions to a level consistent with a net-zero economy in 2050 will require a full fleet transition, as well as a large scale-up of sustainable fuels to replace petroleum that will take decades. To achieve 2050 goals, most new vehicle sales will need to be zero-emissions by the mid-2030s, and the legacy stock of fossil-based vehicles must be simultaneously transitioned to EVs. Multiple **solutions and actions** are needed to enable such a transition:

- **Support Adoption of Zero-Emission Vehicles** Zero-emission EVs offer a pathway to transition away from fossil fuel vehicles and decarbonize a large portion of the transportation sector. This transition will help reduce air pollution and improve health, especially in communities near highways or heavy traffic zones. To achieve this transition, numerous coordinated actions across multiple stakeholders will be required. These actions include continued support for technology development and cost reduction; financial incentives to support market growth; and regulation to support the broad adoption of EVs and to require safe, efficient vehicles and infrastructure. Stakeholders will need to support consumer education on these new technologies, work to deploy the required fueling and recharging infrastructure, and develop tools and signage that enable drivers to locate and easily use new infrastructure. Particular attention and investment will be needed at the federal,

state, and local levels to plan, fund, and install infrastructure in advance of zero-emission vehicles deployments and to ensure these benefits extend to disadvantaged communities. These actions will be critical for overburdened communities looking to increase access to and adoption of EVs. The federal government and other stakeholders should also ensure safe and reliable supply chains and ensure that a trained workforce is available. Finally, the federal government should adopt policies that account for the full set of externalities associated with fossil fuels.

The federal government is already leading the transition to EVs. In his Executive Order on Catalyzing Clean Energy Industries and Jobs Through Federal Sustainability, President Biden directed the federal government to use its scale and procurement power to achieve ambitious goals, including 100% zero-emission vehicle acquisitions by 2035 and 100% zero-emission light-duty vehicle acquisitions by 2027 REF. Moreover, President Biden set a target of 50% EV sales share in 2030 and kicked off the development of long-term fuel efficiency and emissions standards to save consumers money, cut pollution, boost public health, advance environmental justice, and address the climate crisis REF.

Importantly, the IRA is already providing consumer incentives and investments supporting the expansion of zero-emission transportation industries, which will help support the industrial transition to clean energy technologies and secure the production of EVs in the United States. Building upon investments from the BIL, including $2.8 billion in the sustainable sourcing of critical minerals, battery production, and recycling, and the CHIPS and Science Act which will bolster the supply of automotive microchips, the IRA supports the commercialization of advanced vehicle technology components, conversion of domestic automotive manufacturing facilities, production tax credits for batteries and critical minerals, and more. For example, $3 billion from IRA will enable the United State Postal Service to purchase 66,000 battery electric delivery vehicles by 2028, with acquisitions delivered in 2026 and thereafter expected to be 100% electric REF. Timely and impartial data collection and analysis from federal agencies will inform decisions and guide investments during the transition, allowing for course adjustment as more information is collected, especially on impacts of innovative technologies and solutions. Additionally, education highlighting the benefits of EV ownership and dispelling misinformation will accelerate the adoption of personal EVs.

- **Accelerate Replacement of Older Vehicles**
  At current vehicle turnover rates, replacing the more than 300 million fossil fuel vehicles in operation today will take decades. Fleet turnover rate varies by transportation mode, but in nearly all cases it requires that almost all new vehicles purchased by the mid-2030s are zero emission. Even at that rate, without acceleration in legacy vehicle replacement, a share of the vehicles in use in 2050 may still rely on fossil fuels. Funding programs in both BIL and IRA will help bring new zero-emission vehicles and engines to market sooner than would be otherwise expected. It is also possible that vehicle turnover rates will accelerate as the technology and costs of zero-emission vehicles continue to improve. If, for example, EVs become cheaper than internal combustion engine vehicles and dominate new vehicle sales, the cost to operate fueling and maintenance infrastructure and services for internal combustion engines could increase, further accelerating the replacement of legacy fossil fuel-powered vehicles. However, higher up-front costs continue to serve as a barrier to adoption for lower-income consumers. Incentives or other policies

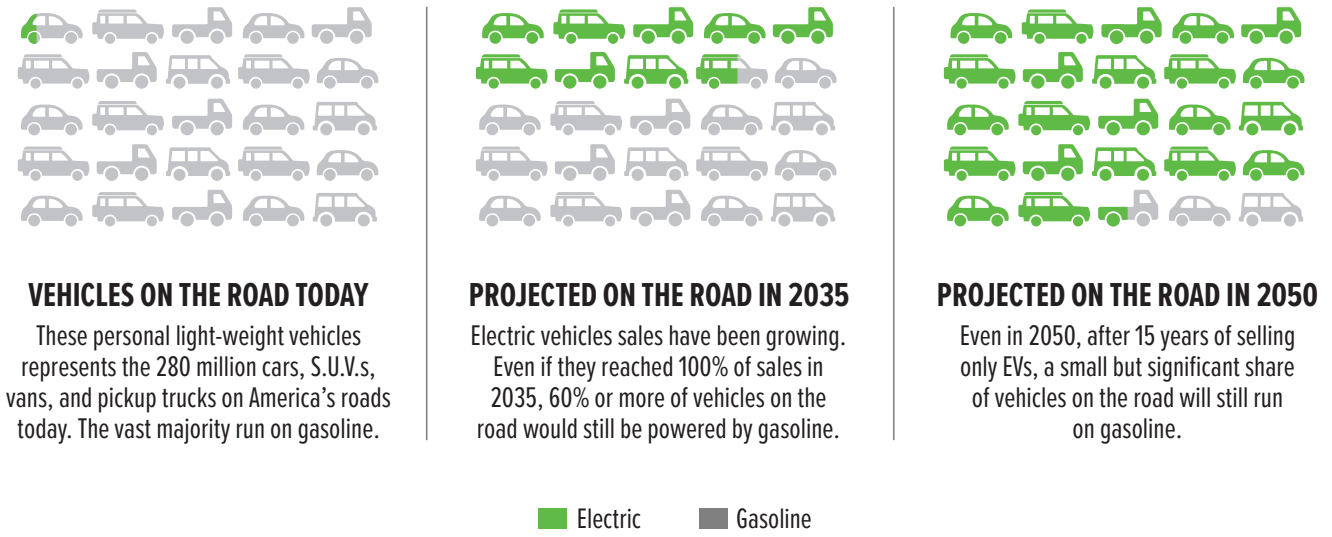


Figure 8. Illustrative example of fleet turnover evolution in a scenario achieving 100% light-duty EV sales in 2035 based on modeling framework documented in Muratori et al.

may be required to increase the rate of adoption of zero- or low-emission vehicles or to replace fossil fuels with cleaner energy alternatives. This is particularly true for transportation modes such as maritime and rail that have vehicles with very long lifespans. Additionally, educational materials and data on the benefits of zero-emission vehicles (e.g., lower maintenance and fueling costs) can support the acceleration of the transition.

- **Support Development of Drop-in Sustainable Fuels and Related Infrastructure**
  Not all transportation applications are prime candidates for electrification. Some applications, such as long-haul aviation, have range and power requirements that are beyond the limits of current and expected electric technologies. Drop-in, energy-dense sustainable fuels will be needed for these applications. These sustainable fuels can also help decarbonize legacy vehicles across other modes and applications during the transition period. While some initial production is already in place, these fuels require targeted support to continue technology progress, including policies and incentives to support market growth in early phases. Ideally, the deployment of these fuels would utilize existing infrastructure, leverage streamlined regulation to ensure interoperability of systems, and support the development of safe and reliable supply chains and a properly trained workforce. Renewable diesel and sustainable aviation fuels are already being developed using standards to ensure they are safe for use and are fully compatible with existing vehicle fleets and fueling infrastructure and minimize emissions in their full life-cycles. As a result, these fuel alternatives are already capitalizing on our existing supply chains and workforce, with even greater opportunities ahead to leverage existing industrial infrastructure by converting petroleum refineries and other facilities for sustainable fuel production.

- **Develop a Robust Supply Chains and Workforce to Produce Zero-Emission Vehicles and Fuels**
  A robust domestic supply chain for batteries, charging infrastructure, hydrogen, and sustainable fuels will be critical to support the transition to zero-emission vehicles and fuels. Major advancements in

oil and gas technologies allowed the United States to reduce its dependence on foreign fossil fuels and their volatile global markets. As we transition to new clean technologies, it is imperative to support a comprehensive industrial strategy that maintains this energy independence and strengthens our national security by supporting diverse energy sources, by building reliable supply chains, and by developing secure manufacturing solutions. Such a strategy will help ensure reliable access to strategic materials and address potentially stranded assets REF, REF. The Federal Consortium for Advanced Batteries (FCAB) is bringing together federal agencies to ensure a domestic supply of lithium batteries and to accelerate the development of a robust and secure domestic industrial base REF. Similarly, the Sustainable Aviation Fuel (SAF) Grand Challenge and the *National Clean Hydrogen Strategy and Roadmap* articulate steps needed to secure domestic industrial bases for those sustainable fuels, including mitigating safety and environmental risks and developing the necessary codes, standards, and workforce to enable this transition REF. As we transition from fossil fuels and internal combustion engine vehicles, it is important to create opportunities for workforce development that lead to well-paying jobs, including in manufacturing, vehicle fuel supply, and vehicle maintenance. A strong workforce will be critical to enable the transition and can be supported through training and education programs, including pre-apprenticeships, apprenticeships, and on-the-job training programs to create well-paying careers. Many of these types of programs can be targeted to ensure no one is left behind in the transition to a clean energy economy.

Improving vehicle efficiency and rapidly transitioning to zero-emission vehicles and fuels will be critical to achieving near- and long-term emission reduction goals and will require coordinated and sustainable actions from multiple stakeholders: the federal government, local governments, industry, and the general public. Multiple technology solutions will be needed for various travel modes and applications (see Section 5), and some technologies are not yet commercially viable. **Declaring clear cross-agency goals now, with support from industry, federal, and local planners, labor, and other stakeholders, will enable targeted investments in RD&D and deployment and infrastructure and the design of effective policies. It will also provide the lead time needed to complete this transformation and succeed in achieving a net-zero-emissions economy by 2050.**

SUSTAINABLE FUELS SUPPLY

Sustainable fuels offer an opportunity to replace petroleum and reduce GHG emissions. They provide the same advantages and flexibility of petroleum fuels, making them well-positioned to decarbonize applications like long-haul aviation and international maritime shipping that require energy-dense liquid fuels. Sustainable fuels can also be used with existing infrastructure and vehicles, helping to reduce emissions of legacy vehicles. Multiple production pathways exist to create sustainable fuels using renewable resources including corn, vegetable oils and animal fats, forestry and agriculture residues, wastes, and purpose-grown energy crops and algae, as well as from renewable electricity. However, the full environmental impact from scaling up feedstocks for sustainable fuels must be part of the full life-cycle emissions analysis, and the amount of available biomass, its geographic distribution, and technologies to sustainably convert that waste carbon into fuel are limited [REF]. The scale-up of sustainable fuel production requires developing and deploying advanced technologies to reduce cost and improve performance, while ensuring that life-cycle emissions and overall environmental and societal impacts are minimal. DOE's Bioenergy Technologies Office (BETO) estimates that over 50 billion gallons of sustainable biofuels (80% or more GHG emissions reduction) can be cost-effectively produced domestically by leveraging multiple production pathways [REF]. In a future in which on-road transportation will largely rely on EVs, 50 billion gallons of sustainable fuels would be enough to fully supply aviation, maritime, and rail demand in 2050, as shown in Figure 9. Although it is uncertain if all pathways will become cost effective, there is a significant effort to demonstrate that SAF can fully replace fossil fuels in aviation. Moreover, synthetic e-fuels (liquid fuels produced using captured carbon and hydrogen produced by electrolysis of water with renewable electricity) could also provide a viable pathway to produce sustainable fuels and increase supply. Depending on the final fuel product, sustainable fuels could address some local air pollution issues and offer a solution for transportation applications that lack other clean alternatives. Moreover, some sustainable fuel production pathways offer the opportunity to leverage carbon capture and storage (CCS) to further reduce GHGs and even achieve carbon-negative emissions [REF]. Finally, a robust bioenergy industry could also produce chemicals and products for the petroleum industry with significantly lower emissions. Sustainable fuels must be produced in a way that considers climate change, land use, water, and ecosystems implications, and planning will require cross-sectoral expertise and broad collaborations.

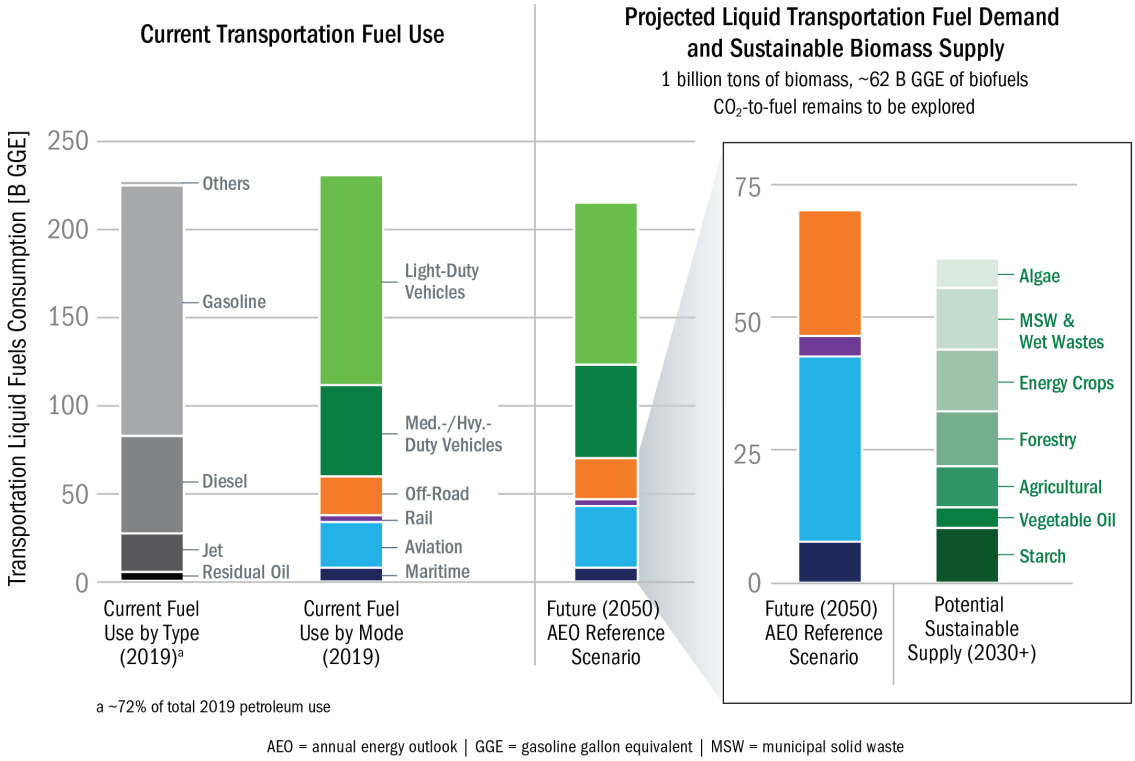


Figure 9. Current and projected liquid transportation fuel demand and sustainable biofuel supply. Note that the AEO reference case represents a business-as-usual perspective with limited changes from the current systems and does not reflect the transformative changes this Blueprint envisions. Data sources: EIA AEO Ref case [REF] and DOE BETO assessments [REF].

MODERNIZING AND CLEANING THE ELECTRICITY GRID

Future transportation systems must leverage affordable and abundant clean electricity to power battery EVs and produce clean hydrogen and sustainable fuels. While the exact mechanisms for creating a clean and resilient grid are out of scope for this document, clean electricity will be critical to decarbonizing transportation. Widespread transition away from fossil fuels for transportation will have far-reaching consequences for energy and electricity systems, including new opportunities for significant electricity load growth, while also requiring greater coordination for planning and operation between the transportation and electricity sectors. EVs are projected to become the largest source of load growth in the U.S. and could represent more than 25% of total electricity demand in 2050, up from <1% today [REF]. There are many aspects of our generation transmission and electricity distribution systems that are not yet ready to accommodate such load growth, requiring new analysis and solutions to plan and operate a reliable and affordable decarbonized grid. Effective integration of EVs with the power system—driven by interoperability standards, transparent electricity markets, and coordinated long-term planning among fleet operators and utilities—is necessary to ensure this growing demand for electricity can be supplied reliably and that grid planning fully considers the rapidly evolving transportation electricity demand. The impact on the grid is exacerbated for hydrogen and e-fuels, which require approximately twice and four times, respectively, the amount of clean electricity per mile of travel compared to direct use of electricity in EVs. New transportation loads can support the decarbonization of the grid, especially by complementing variable renewable energy sources with managed EV charging and other solutions [REF]. Similarly, flexible electrolyzer operation for hydrogen production and use of hydrogen as a long-duration energy storage solution could provide major benefits to the power grid [REF, REF]. EVs can also act as distributed energy storage devices, providing electricity back to the grid (V2G) or to other loads (V2X) to further support the power system and increase resiliency, especially during extreme events.

5. APPLYING THE STRATEGIES BY TRANSPORTATION MODE

Decarbonizing the transportation sector in the United States will require increasing convenience, improving efficiency, and transitioning to clean transportation options.

These strategies will need to be applied broadly and must consider all of the many interconnections between transportation systems, vehicles and technology, and the lives of people across a large and diverse country. This chapter provides an overview of solutions that can facilitate the transition to clean vehicles and fuels for all passenger and freight transportation modes.

The transportation sector includes a broad array of travel options for passenger and freight and is generally broken-down into seven specific sub-sectors or travel modes: light-duty vehicles, medium and heavy-duty trucks and buses, off-road vehicles and mobile equipment, rail, maritime vessels, aviation, and pipelines. Emissions from off-road vehicles and mobile equipment are often considered part of the industrial and agricultural sectors, but the solutions to decarbonize those vehicles will leverage and be aligned with solutions for other transportation vehicles. Therefore, for the purposes of this Blueprint, off-road vehicles and mobile equipment are considered part of the transportation sector. Similarly, while pipelines are not always considered part of the transportation sector, they carry the second largest quantity of freight (liquid and gaseous commodities) by tonnage in the United States of any of the seven modes and thus play a significant role in our transportation system [REF].

Each of these travel modes, or sub-sectors, presents unique technological challenges to transition to clean technologies, yet each also offers major opportunities to reduce emissions. The U.S. government has defined clear decarbonization paths for some, but not all, of the transportation subsectors. For example, the *2021 United States Aviation Climate Action Plan*, which was coordinated across multiple federal agencies, provides a strategy to help the federal government and industry achieve net-zero GHG aviation emissions by 2050. Other travel modes have less established pathways or partial goals and require additional research and policy coordination to establish viable routes to full decarbonization. Additionally, in some sub-sectors there are well-identified zero-emission technologies that are already transforming industries. For example, battery EVs, which have widespread global support, are successfully helping to decarbonize the light-duty vehicle sector. Their sales are rising, manufacturers are investing heavily in them, and consumer demand is rapidly growing. Other sectors will need to prioritize research in the near-term to identify the best technologies for decarbonization. The table on the next page summarizes current transportation emissions by mode and established federal emissions reduction goals and associated measures.

Transportation Mode	Share of Current Transportation Emissions	Federal GHG Emissions Reduction Goals
Light-Duty Vehicles	49%	• Achieve 50% of new vehicle sales being zero-emission by 2030 supporting a pathway for full adoption, and ensure that new internal combustion engine vehicles are as efficient as possible • Deploy 500,000 EV chargers by 2030 REF • Ensure 100% federal fleet procurement be zero-emission by 2027 REF
Medium and Heavy-Duty Trucks and Buses	21%	• Aim to have 30% of new vehicle sales be zero-emission by 2030 and 100% by 2040 REF • Ensure 100% federal fleet procurement is zero-emission by 2035 REF
Off-road	10%	• Work to establish specific targets • Focus resources to develop technology pathways and set efficiency and zero-emissions vehicle and equipment targets
Rail	2%	• Work to establish specific targets • Focus resources to develop technology pathways and set efficiency and zero-emissions vehicle targets • Encourage greater use for passenger and freight travel to reduce emissions from road vehicles
Maritime	3%	• Continue to support the Zero-Emission Shipping Mission (ZESM) goals to ensure that 5% of the global deep-sea fleet are capable of using zero-emission fuels by 2030, at least 200 of these ships primarily use these fuels across the main deep sea shipping route, and 10 large trade ports covering at least three continents can supply zero-emission fuels by 2030 REF • Support the U.S. domestic maritime sector by performing more RD&D into sustainable fuels and technologies and incentivize U.S. commercial vessel operators to move towards lower GHG emissions • Work with countries in the International Maritime Organization to adopt a goal of achieving zero emissions from international shipping by 2050 REF
Aviation	11%	• Reduce aviation emissions by 20% by 2030 when compared to a business-as-usual scenario • Achieve net-zero GHG emissions from the U.S. aviation sector by 2050 • Catalyze the production of at least three billion gallons of SAF per year by 2030 and ~35 billion gallons by 2050, enough to supply the entire sector REF

Pipelines	**4%**	• Work to establish specific targets • By 2036, repair or replace 1,000 miles of high-risk, leak-prone, community-owned legacy gas distribution pipeline infrastructure, as well as an estimated reduction of 1,000 metric tons of methane emissions REF • Eliminate leakages and enable use of pipelines for clean sustainable fuels
Total Sector	**100%**	• 80–100% Emissions Reductions by 2050 (**in line with the U.S. LTS**)

A. LIGHT-DUTY VEHICLES

With more than 280 million vehicles on the road, light-duty passenger vehicles—cars, SUVs, and pick-up trucks—are the primary mode of passenger travel in the country and account for over 75% of total U.S. passenger miles traveled REF, REF. LDVs are responsible for about 50% of total transportation energy use and emissions: over 120 billion gallons of gasoline consumed and over 1,000 MMT CO_2 emitted each year REF. Light-duty passenger vehicles are also major contributors to air pollution, which especially impacts people who live near highways. The fuel economy of new LDVs has improved by about 30% over the past 15 years, driven largely by regulations, including EPA GHG emissions standards and the Corporate Average Fuel Economy (CAFE) standards established by the National Highway Traffic Safety Administration. This improved fuel economy has translated into significant per-vehicle energy and emissions savings REF. However, sales trends toward larger and less-efficient vehicles have led to lower overall emission reductions than would have been achieved without these market shifts REF.

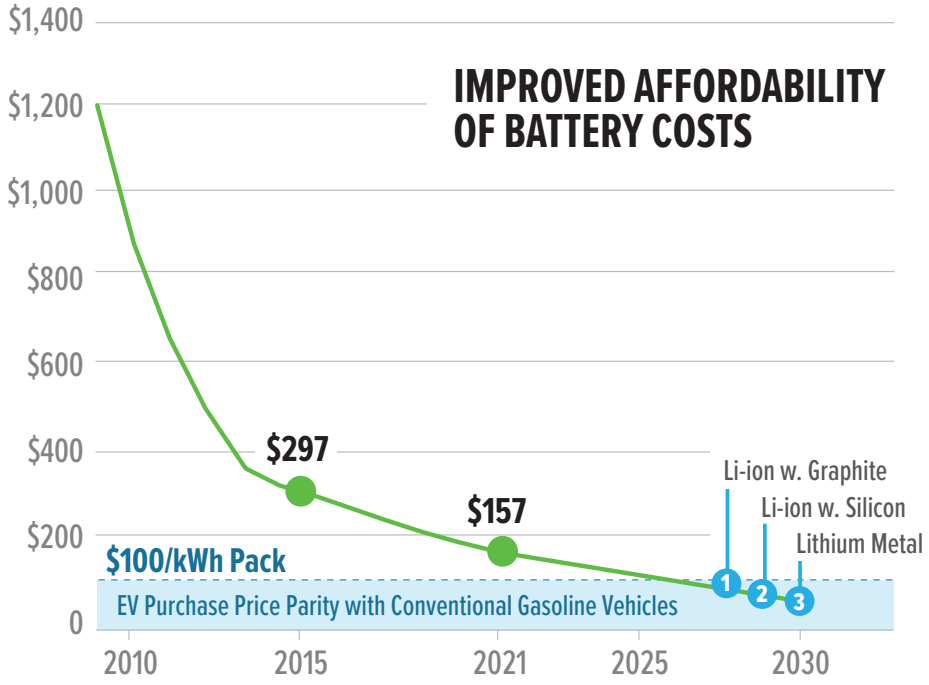
Achieving 2050 net-zero-emissions goals will require **transitioning new LDV sales to zero-emission EVs by the mid-2030s, and then rapidly replacing the legacy stock of higher-polluting fossil-based vehicles with zero-emission EVs**. Ensuring that fossil fuel vehicles sold in the interim are as efficient as possible will further reduce energy needs and emissions during the transition. The rate of EV adoption and speed of vehicle replacement will affect the degree to which LDVs use liquid fuels in the decades to come. Thus, sustainable fuels provide an additional opportunity to reduce the emissions of legacy internal combustion engine vehicles still on the road in 2050 and beyond.

Sales of plug-in battery EVs have been rapidly increasing in recent years thanks to technology improvements and lower costs (especially for batteries, as shown in Figure 10), supporting policies, and increased availability of charging infrastructure REF. In 2021, U.S. EV sales more than doubled to over half a million vehicles sold, reaching 4.5% of the total market share. Globally, EVs accounted for 9% of new vehicle sales in 2021, with Europe and China representing the two largest EV markets REF. In California, where support for EVs has been substantial, EVs accounted for about 18% of vehicle sales in the first half of 2022 REF. Despite this progress, more than 99% of LDVs on the road in America today still rely on gasoline[17] or diesel fuels, since only a small fraction of vehicles are replaced each year. A rapid acceleration of new EV sales will be critical to achieving decarbonization goals.

[17] *Motor gasoline is a blend of 90% fossil gasoline and 10% ethanol.*

With sales increasing globally and manufacturers planning to spend more than half a trillion dollars on EV and battery development through 2030 [REF], it is clear that EVs are a viable technology to dramatically reduce GHG emissions from LDVs by 2050. The number of EV models available is also rapidly increasing, with more than 100 models currently or soon-to-be available across multiple vehicle classes, including larger SUVs and pick-up trucks [REF].

The outlook for EV growth for personal and commercial vehicles is increasingly positive, and over time the environmental benefits of zero-emission vehicles combined with progressive grid decarbonization are expected to compound [REF]. Further technological progress will accelerate EV competitiveness for additional applications and increase affordability for all consumers. Batteries are projected to continue to improve and become cheaper, especially as domestic minerals processing and cell production capacity increases, enabling further competitiveness over the next decade. Still, significant challenges remain to achieving high market penetration of EVs over the next decades, and multiple actions are needed to achieve 2030 and 2050 goals:



Vehicle battery costs dropped 90% over the ten-year period ending in 2020, creating less expensive overall electric vehicle costs. Studies indicate that when battery costs reach an average of $100/kWh (or $60/kWh per cell), EV purchase prices (MSRP) will reach parity with gasoline-powered vehicles. Multiple technology pathways exist to achieve this cost threshold, including lithium-ion with graphite, lithium-ion with silicon, and lithium metal.

Figure 10. Battery cost evolution and projections (2021 USD per pack-level usable kilowatt-hour (kWh)) Data source: DOE Vehicle Technologies Office [REF]. Investments, including from the BIL, IRA, and the CHIPS and Science Acts, are ensuring battery costs continue to decline and that reliable and secure supply chains and manufacturing are available.

1. **Implement policy and regulation** to expand the market share and use of EVs. Government, industry, and labor set a target of 50% new light-duty EV sales share by 2030 [REF]. The actions needed to achieve this goal will demonstrate the viability and underlying benefits of EVs, including lower costs, and put us on a pathway for 100% EV adoption. EPA and DOT are currently evaluating future GHG emissions and fuel economy policies that will support this transition while ensuring that new internal

combustion engine vehicles sold in the interim are as efficient as is feasible. At the same time, tax credits and manufacturing incentives established by the IRA are designed to reduce the costs of new and used EVs and strengthen supply chains and domestic manufacturing. The federal government is also leveraging its scale and procurement power to transition the federal fleet to EVs, with the goal of having 100% of its vehicle acquisitions for its fleet of more than 600,000 vehicles be zero-emission vehicles by 2035 (2027 for LDVs) REF. Regional, state, local, and Tribal actions can also enable more rapid zero-emission vehicle transitions. For example, 13 states—California, Colorado, Connecticut, Maine, Maryland, Massachusetts, Minnesota, New Jersey, New York, Oregon, Rhode Island, Vermont, and Washington—have adopted mandates on automakers' sales of zero-emission vehicles, charting a course toward 100% EV sales REF. Additional policy and vehicle incentives may also be needed to encourage legacy fleet turnover to EVs, at least until the additional purchase cost of EVs is sufficiently lowered to achieve widespread adoption. EVs generally have much lower operating costs, so educating consumers on the total cost of EV ownership relative to conventional vehicles (rather than simply comparing purchase prices) could also speed adoption.

2. **Continue EV charging infrastructure investments and planning** to ensure every individual and business has access to convenient and affordable charging whenever needed. These actions will entail an equitable expansion of access to charging, including widespread public charging solutions for those without access to home charging (workplace, curbside, multi-unit buildings with shared parking), and ubiquitous fast charging networks. A major expansion of the U.S. charging ecosystem will offer opportunities to rapidly charge EVs during long trips, ensure consistent and convenient access to charging, and provide charging assurance for all individuals, including those without personal access to vehicle chargers. Moreover, investments must support network maintenance to ensure that a well-functioning and reliable charging system is available at all times.

   The Joint Office of Energy and Transportation will be a critical part of this effort. Created through the BIL to coordinate efforts between DOE and DOT, the Joint Office supports the president's goal of deploying 500,000 EV chargers by 2030. Combining the expertise of both agencies, the Joint Office is helping to implement BIL programs that will jumpstart a national network of EV charging along our highways and throughout our communities. In collaboration with regional, state, local, and Tribal jurisdictions, the Joint Office can help ensure that all Americans have full access to charging infrastructure. EPA is working with the Joint Office to help communities plan for investments in EV charging infrastructure and to ensure chargers are distributed equitably and in ways that will bring additional co-benefits. Local

and state governments can update ordinances to encourage or require vehicle chargers, particularly at multi-unit dwellings or commercial buildings that also support interoperability. Additionally, it is imperative to develop and implement solutions for effective vehicle-grid integration, as EVs are expected to become one of the largest electricity load categories by 2050. Managed charging and incentivizing charging at times that are beneficial for the grid can provide valuable demand-side flexibility to better design and operate the power system, reducing electricity costs for all and increasing resiliency.

3. **Fund research and innovation** that will continue to improve vehicle, battery, and charger performance and reduce costs, and leverage large investments from BIL, IRA, and the CHIPS and Science Act to develop a domestic EV manufacturing supply chain that is reliable, secure, and creates equitable clean-energy manufacturing jobs, as articulated in the *National Blueprint for Lithium Batteries* REF. Based on its research and development activities, DOE projects that new technologies under development will reduce battery costs to $80–100/kWh over the next decade, which is expected to allow EVs to achieve purchase price parity with conventional vehicles REF. Moreover, EVs offer lower operational (fuel and maintenance) costs by being more efficient and having fewer moving parts than conventional vehicles. These benefits offer significant cost savings, especially for consumers who own older vehicles REF. DOE estimates the maintenance cost of EVs is 40% cheaper than for internal combustion engine vehicles, which can amount to thousands of dollars of savings over the course of a vehicle's lifetime REF. Additional research and innovation will be required to accelerate these trends in efficiency and performance, and to continue developing future generations of battery technology.

B. MEDIUM AND HEAVY-DUTY ON-ROAD TRUCKS AND BUSES

Medium duty and heavy-duty vehicles include a wide range of vehicles that vary in size, from heavy-duty pickup trucks to long-haul semi-trucks. The use of these vehicles is correspondingly diverse, as this category encompasses vehicles used for local delivery, refuse collection, public transportation, long-haul goods delivery, and many other purposes. While MHDVs represent only 5% of total vehicles on the road, they are responsible for an outsized 21% of transportation emissions, making them the second-largest emissions contributor behind only light-duty vehicles. And within MHDVs, a small portion—about 10% of heavy trucks with high utilization—is responsible for approximately 50% of total MHDV emissions REF. MHDVs are also a major source of criteria pollutant emissions, particularly along busy corridors that are close to disadvantaged communities. These emissions cause increased asthma and lung disease rates among these populations and have been linked to thousands of premature deaths. They also contribute to the inability of some areas to achieve compliance with federal ambient area quality standards REF, REF, putting residents at disproportionate risk for additional health impacts.

Although nearly all MHDVs on the road today rely on internal combustion engines fueled with diesel (81%), gasoline (17%), or natural gas (1%) REF, many manufacturers are investing heavily in zero-emission

Virtually all MHDVs on the road today rely on internal combustion engines fueled with

DIESEL (81%)

GASOLINE (17%)

NATURAL GAS (1%)

MHDVs that use battery electric or hydrogen fuel cell electric powertrains. At COP27 on November 16, 2022, the United States joined the Global Memorandum of Understanding on Zero-Emission Medium- and Heavy-Duty Vehicles REF. First introduced at COP26, the Global MOU puts countries on a path to 100% new zero-emission MHDV sales by 2040 at the latest, with an interim goal of at least 30% new sales by 2030 REF.

Since MHDVs are used for a variety of purposes, there will likely be a suite of zero-emission technology solutions in the future to cover various use cases. Based on expectations of current technological progress, smaller vehicles with lower utilization will likely be EVs REF. Other manufacturers are investing in hydrogen powertrains using fuel cells. While not currently commercially viable for freight applications, hydrogen vehicles are appealing for future long-haul operations requiring greater vehicle range and faster refueling times. There is also ongoing RD&D and deployment focused on hydrogen use in internal combustion engines, which could improve deployment and support the build out of hydrogen fueling infrastructure. Research and development are also improving durability and reducing costs of fuel cells, which will enable major efficiency improvements. Fleet operators are sensitive to fuel and maintenance costs, which could make efficient EVs even more appealing and result in a more rapid shift toward EVs. With continued improvements in vehicle and fuel technologies (in line with DOE targets for zero-emission vehicle technologies and fuels costs and performance vetted with industry), zero-emission vehicles in all MHDV classes can reach total-cost-of-driving parity with conventional diesel vehicles by 2035 REF.

Sustainable fuels may also be an option for some MHDVs, particularly for remote applications and for legacy vehicles relying on internal combustion engines. The historically slow turnover rate for many MHDVs means that new technologies may not replace diesel engines for several decades and that disseminating new technology across the MHDV fleet will be a slow process if market forces or policy decisions do not accelerate vehicle turnover. Sustainable fuels could help alleviate this turnover challenge by providing low-carbon solutions that are compatible with existing vehicles. To achieve 2030 and 2050 goals, the current MHDV reliance on diesel and gasoline must shift to zero-emission vehicles and sustainable fuels. This shift can be achieved in part through decisive and coordinated actions, including:

1. **Fund research and innovation** to develop viable technologies to replace fossil-fuel vehicles for all MHDV applications. It is vital to continue to support research, design, and development toward lower-cost and higher-energy-density batteries and fuel cell applications, as well as the use of clean hydrogen and sustainable fuels to fully decarbonize

the MHDV sector. For example, DOE is investing hundreds of millions of dollars to support the next stage of the SuperTruck initiative aimed at electrifying freight trucking [REF]. The department is also collaborating with industry through the 21st Century Truck Partnership, which is shaping a national vision for trucks and buses that safely and cost-effectively move larger volumes of freight and greater numbers of passengers while emitting little or no pollution and dramatically reducing dependency on petroleum [REF]. DOE is also coordinating with partners internationally on the development of the new Megawatt Charging System standard, which will enable compatibility between automakers and charging equipment installed in the United States. Research can also help improve access to big data, such as information collected from GPS navigation services and user mobile phone applications, to inform strategies to reduce GHG emissions.

2. **Implement policy and regulation** to reduce new vehicle GHG and criteria emissions and set ambitious targets for transitioning to zero-emissions vehicles on a timeline consistent with achieving economy-wide 2030 and 2050 emissions reduction goals. This effort should account for the wide range of MHDV vehicles and applications. One example of such regulatory action is EPA's Clean Trucks Plan, which will reduce the emissions of GHGs and other harmful pollutants through a series of rulemakings [REF]. Another example is the fuel efficiency standards for MHDVs, which DOT issued jointly with EPA. Additionally, the government will continue to provide grants and other incentives for low-emission or zero-emission vehicles (e.g., the Congestion Mitigation and Air Quality Program, the Low or No Emission Vehicle Program, the Diesel Emission Reduction ACT (DERA), SmartWay, and the Clean School Bus Program [REF]). Regional, state, local, and Tribal actions to enable more rapid zero-emission MHDV transitions can further support these programs. For example, 17 states and the District of Columbia and the Canadian province of Quebec are working collaboratively through the Zero Emission Vehicle (ZEV) Task Force to advance and accelerate the market for electric MHDVs [REF]. The committed signatories have stressed the need for market-enabled adoptions, including innovative financing models and additional funding sources and actions to encourage fleet purchases. Together, they have emphasized accelerating deployments of zero-emission trucks and buses in disadvantaged communities. In addition to multi-state actions, strategies can be further identified through regional, state, local, and Tribal climate action plans that consider freight planning, and state freight plans should include GHG emissions-reduction strategies. Regional coordination formalized in such planning documents will also help support this transition by reflecting multi-jurisdictional capacities. Additionally, fleet transition plans can accelerate the shift to zero-emission vehicles. The IRA directs EPA to award grants and rebates for zero-emissions heavy duty vehicles. And under the BIL, zero-emission vehicle project grant applications for the Buses and Bus Facilities Program and the Low or No Emission Vehicle Program must include a Zero-Emission Fleet Transition Plan. Innovative freight strategies, such as green loading zones, zero- or low-emissions delivery zones, and restricted multi-use lanes, can also incentivize the use of zero- or low-carbon freight options in urban areas.

The government will continue to provide grants and other incentives for low-emission or zero-emission vehicles.

3. **Invest in strategic demonstration and deployment** to support the build-out of interoperable EV charging and refueling infrastructure through coordinated planning, policy, and funding opportunities. An unprecedented level of collaboration is needed among fleet operators, facilities throughout the freight transportation network, infrastructure providers, and electric utilities to ensure energy systems can accommodate the charging demands associated with the rollout of zero-emission MHDVs during the latter half of this decade. The Joint Office is offering technical assistance to school districts and transit operators for deployment of electric school and transit buses under BIL programs. For freight applications, vehicles can leverage central fueling facilities, and accordingly there will need to be an initial focus on large truck depots and key truck corridors that carry high volumes of freight from ports. These centrally located fueling facilities and focused uses will have the strongest business cases, particularly since they can help reduce the emissions and noise impacts in urban areas that disproportionately burden disadvantaged communities. The BIL created a new Reduction of Truck Emissions at Port Facilities grant program, which will support electrification at ports. For long-haul freight, long-term strategies may involve multi-state considerations for on-the-road charging stations and other infrastructure needs to support zero-emission fueling applications of long-haul freight. An accelerated decarbonization transition will require advancing the adoption of EVs and the deployment of a supporting charging and fueling infrastructure concurrently, so the growth of each component complements the other. Sustainable fuel readiness planning can help local and regional governments identify and address barriers to adoption, such as insufficient supporting infrastructure.

C. OFF-ROAD VEHICLES AND MOBILE EQUIPMENT

Off-road vehicles are primarily designed to operate away from existing roadways. This category contains a disparate and very diverse set of vehicles and use cases, including construction and mining equipment (36% of off-road energy use), industrial equipment (23%), agriculture equipment (21%), lawn and garden equipment (15%), and recreational vehicles (4%) [REF]. Diesel provides the majority (79%) of the total fuel that off-road vehicles consume today, especially for agricultural, construction and mining and industrial equipment, with gasoline (8%), liquified petroleum gas (11%) and compressed natural gas (2%) making up the remaining fuel consumption. Recreational vehicles, in contrast, are primarily fueled by gasoline [REF]. Combined, off-road vehicles are responsible for 10% of transportation GHG emissions. Due to the nature of these vehicles and the work they do, the emissions from these vehicles are often mapped to the industrial and agriculture sectors in emissions accounting. **Off-road vehicle and mobile equipment are included with transportation in this Blueprint since the technology solutions required to decarbonize them are well-aligned with solutions used for other transportation modes.**

There are a wide range of engine sizes, power requirements, duty cycles, and vehicle applications

to be considered in the pathways for decarbonizing off-road vehicles. Unlike most on-road vehicles, an off-road vehicle's engine typically provides power to propel the vehicle and to perform auxiliary work, such as digging or harvesting. As a result, different applications in the off-road sector have specific requirements for ruggedness, durability, and other operational constraints. Strategies for decarbonizing the off-road sector will leverage technologies similar to other sectors, including battery electric and fuel cell EVs and sustainable fuels. However, the exact roles of different technologies and solutions across these use cases have many nuances. A deeper understanding of real-world operations and requirements is needed to enable comprehensive data-driven analysis that can identify viable pathways at the vehicle and system level. Hybridization can also help optimize engine operation, allow for engine downsizing support auxiliary power needs, and increase overall efficiency. Finally, automation could offer opportunities to optimize vehicle design and use to reduce emissions.

Electrification is already taking place across parts of the off-road sector, particularly household lawn and garden equipment. As battery technology progresses, more opportunities for electrification in this wide category of vehicles will emerge. Large vehicles that run continuously or operate in remote areas far from refueling infrastructure might require hydrogen or sustainable liquid fuels. Building infrastructure that brings sustainable fuel and/or electricity to work sites (or produces it there) will be a key strategy for decarbonizing the off-road sector.

Significant challenges remain to develop, demonstrate, and deploy off-road vehicle decarbonization solutions aligned with overall 2030 and 2050 goals. Strategies for addressing those challenges include:

1. **Increase targeted research and innovation efforts** to better understand the spectrum of available technologies and collect real-world operational data to enable a deeper understanding of off-road vehicle and mobile equipment requirements. New analytical tools must also be developed to perform technical analyses that identify viable pathways for zero-emission vehicles to replace fossil fuel vehicles or to find opportunities to improve efficiency for off-road applications in which zero-emissions technologies are not viable. Targets for future zero-emission technologies—such as batteries and fuel cells performance to match off-road vehicle and mobile equipment requirements—also need to be identified. Finally, solutions will be needed to increase efficiency, reduce operational costs, and promote electrification (including by leveraging vehicle automation) in complex work settings. Research efforts should also focus on demonstrating the viability of zero-emission off-road and mobile equipment applications during early market phases by leveraging available on-road vehicle and infrastructure technologies.

2. **Implement policy and regulations**, including establishing GHG and efficiency standards for off-road vehicles and mobile equipment and setting ambitious targets for transitioning to zero- or low-emissions technologies. These efforts will help drive down emissions and accelerate the transition to clean vehicles and equipment. Standards must be comprehensive and cover the entire range of vehicles, manufacturers, and applications. New mechanisms to ensure compliance and a framework to assess life-cycle emissions may also be required. Federal and local-level policy are necessary, especially for areas that do not meet national ambient air quality standards, as is funding to incentivize and support early adoption and infrastructure deployment and to encourage turnover of existing fossil fuel-powered vehicles, which might otherwise remain in use for decades.

3. **Invest in strategic demonstration** to understand EV charging and clean fuel refueling infrastructure needs, and support deployment through coordinated planning, policy, and funding opportunities. Providing reliable access to electricity and clean fuels for off-road vehicles and mobile equipment will require addressing varied and unique usage challenges, especially in remote locations, extreme conditions, and temporary sites. Electrification will be easier for applications that can leverage existing electricity access, such as applications at residential or commercial buildings. Some off-road vehicles may be able to leverage refueling facilities for other transportation applications at or near places such as ports or along highways. In contrast, providing charging and access to clean fuels in remote locations, temporary sites, or for equipment intended to provide back-up power and resilience will require new and innovative solutions that need to be developed and demonstrated. Developing and demonstrating reliable and effective charging and refueling solutions for the varied off-road vehicles and mobile equipment is critical to enable the decarbonization of the sector.

D. RAIL

The United States has the largest rail network in the world, and it is used primarily to support freight movement. Although passenger rail does not currently account for a relatively large proportion of passenger miles traveled relative to other modes, it is critical to addressing traffic congestion in and between cities and can play an important role in decarbonizing both freight and passenger movements REF. Passenger rail services include local passenger travel on commuter and transit rail services in cities where it is available, and some intercity travel. In the U.S., there are very limited higher-speed rail options. Freight accounted for 91% of all domestic rail-use energy in 2019. Rail makes up approximately 28% of U.S. freight movement by ton-miles but only accounts for about 2% of total U.S. transportation emissions thanks to its significantly higher efficiency than freight trucking. Rail is also an energy-efficient mode of passenger transportation, offering a cleaner option than single-occupancy vehicles and air travel REF.

Identifying transformation pathways can also help to set ambitious goals and inform development of regulation to reduce rail emissions.

While electric rail technologies are widely used worldwide, in the U.S., freight rail carriers almost exclusively use diesel locomotives. Intercity passenger and commuter carriers also heavily rely on diesel, though there are some partially or fully electrified

lines. Most rail systems that provide local public transportation, such as light rail and streetcars, are electrified but represent less than 5% of rail energy use [REF]. The rail industry is currently exploring opportunities to maintain its comparative energy-use advantage on a ton-mile basis by transitioning to direct use of electricity (e.g., overhead catenary charging, third-rail systems), batteries, hydrogen fuels, sustainable fuels, or hybrid solutions. Full electrification via catenary systems used in other countries has been hindered by the long distances and relatively low traffic on U.S. railways. Diesel alternatives for use in the U.S. freight rail industry are primarily in demonstration stages and not yet widely available, although there are interim opportunities to advance fleet technologies by retrofitting locomotives and using modular hybridization. For example, there are battery-powered locomotives in use (primarily in switch yards), and additional pilot projects using battery-powered locomotives or hydrogen fuel cells are underway [REF]. Sustainable fuels can play a key role in reducing rail emissions, especially in the near and medium terms, but they are currently not cost competitive.

While electrification is more common in the U.S. for passenger rail than for freight rail, commuter rail is not fully electrified. As such, the electrification of commuter rail fleets offers promising opportunities for further emissions reduction. Longer-distance rail for passengers and freight may require fuel technologies in addition to electric batteries and fuel cells to achieve emissions reductions goals, and pathways to total decarbonization still need to be determined. Priority actions and levers to decarbonize rail include:

1. **Infrastructure investments** in electric locomotives and the expansion of electrification corridors to help to accelerate the zero-emission transition. Interoperability and infrastructure for clean fuel technology adoption will facilitate efforts. Federal funding may be used to purchase more efficient and cleaner trains and to implement solutions that improve system-level efficiency. Other investments that will maximize emissions reductions include building strong domestic rail equipment supply chains for electric and alternatively fueled locomotives and railcars and supporting the development and deployment of sustainable fuels.

2. **Multi-stakeholder collaborations** to accelerate the deployment of rail technologies that reduce emissions and increase efficiency. Ambitious and shared targets and regulation for the rail sector can help minimize investment risk and catalyze decarbonization actions. Existing industry partnerships such as EPA's SmartWay Program are designed to improve efficiency and reduce emissions in the freight network. State freight advisory committees and rail and freight plans present opportunities for stakeholders to help

identify pathways to transition fleets and modernize rail systems.

3. **Research and innovation** to advance technology through pilot projects, greater infrastructure investments, and continued policy and regulation support that helps accelerate the growth of electrification of the U.S. passenger rail system. Freight rail research should be prioritized to determine the most promising paths to decarbonization, including a focus on sustainable fuels and the design and manufacture of new locomotive propulsion and fueling systems. The four agencies and partners should identify transformative pathways that can help inform the development of ambitious goals and regulation to reduce rail emissions. The continued collection of real-world operational data to better understand vehicle requirements and develop models and tools to perform technical analyses can help to identify the most viable pathways for clean technology solutions to replace diesel locomotives.

E. MARITIME VESSELS

Maritime transportation moves people and freight via waterways. The U.S. maritime fleet is comprised of numerous vessel types across its domestic shipping, international shipping, and recreational boat segments. While the fleet of U.S.-flagged ocean-going vessels is relatively small, the fleet of vessels that operate under U.S. registry along our coasts and inland waterways is significantly larger. There are approximately 12 million privately owned recreational boats (USCG Office of Auxiliary and Boating Safety 2019) and 38,000 commercial vessels, such as tugboats, containerships, and ferries (USCG Maritime Information Exchange 2021), in the U.S. maritime sector. Recreational boats usually burn gasoline, while larger vessels rely on an almost equal share of diesel and residual oil, the latter of which is generally used for international voyages. A small fraction of maritime energy use comes from liquified natural gas. According to EPA estimates, half of U.S. marine vessel carbon emissions are from international shipping (including from fuel purchased in the U.S. for international voyages), roughly 30% is from domestic shipping, and the remaining 20% is from recreational boats. Although these numbers reflect the best available information, accurate accounting of maritime emissions is challenging due to the complex international nature of vessel operations and ownership. Emissions from multimodal equipment at ports largely contribute to poor air quality and environmental justice issues for millions of people living in near-port communities, many of which often consist of disadvantaged and underserved populations.

The maritime industry is international in scope, with the largest share of GHG emissions originating from international voyages. Therefore, effective decarbonization will require intergovernmental collaboration that aligns with industry and community needs. During the 2021 Leaders Summit on Climate, President Biden pledged to work with countries in the International Maritime Organization to revise the organization's current decarbonization strategy and adopt a new goal of zero emissions (on a life-cycle basis) from the sector by 2050 REF.

Despite the variety of potential decarbonization fuels, technologies, and policies under development, the best pathway for decarbonizing the maritime sector is unclear. New maritime technologies can be slow to be adopted, particularly when safety and operational standards still need to be established. Vessels have a long fleet turnover time—30 years or more—so understanding the costs, standards, and requirements is critical for long-term investment planning. Decarbonizing the sector by 2050 will require innovative practices, targeted regulations, and a strong and immediate commitment to innovation and deployment of new and emerging technologies.

Efforts are underway globally to significantly reduce the GHG emissions of vessels and port activities, while considering vessel types and size, routes, and other operational constraints. Accordingly, a variety of approaches are likely necessary to decarbonize the maritime sector. There are currently several viable energy-efficient technologies, including battery electrification options for smaller vessels and recreational boats, and in-port shore power or "cold ironing" using clean, onshore energy sources. There are also a select few clean and affordable fuels that can be deployed now for limited vessel types. Once alternative fuels and technologies have been demonstrated, a significant effort will be needed to support deployment, adoption, and the roll-out of required infrastructure.

Decarbonizing the sector by 2050 will require innovative practices and a strong, immediate commitment to innovation and deployment of new and emerging technologies.

Priority actions and levers to decarbonize maritime include:

1. **Research and innovation** on viable alternative fuels and new technologies to determine the most promising paths to decarbonizing the maritime sector. Additional research can identify and expedite effective solutions for different vessel types and applications. Extensive performance and operations data on the total life-cycle emissions from new shipping technologies and alternative fuels should be collected from real-world settings and shared widely with stakeholders. New models and tools need to be developed to characterize and forecast critical aspects of the maritime industry, including emissions, energy use, costs, or other impacts and externalities to inform decisions and investments. Promising fuels and technologies that can support maritime decarbonization include:
    a. **Sustainable liquid and gaseous fuels**. These include certain types of biofuels, ammonia, hydrogen, and methanol. Some biofuels and biofuel blends are drop-in replacements for traditional fossil fuels and offer the most substantial immediate GHG emissions reductions, as well as the opportunity to complement sustainable aviation fuel production and associated investments. Hydrogen, ammonia, and methanol are other promising fuel alternatives, but more research is needed to use and supply these fuels, ensure that they have low life-cycle emissions, and verify that they do not increase criteria pollutant emissions.
    b. **Electric vessels.** Electric powertrains and batteries can be used to augment power on certain ships, especially smaller boats, offering high efficiency and zero stack emissions.

c. **Cold-ironing.** Cold-ironing of larger vessels ("plugging-in" while at port to utilize clean electricity generated onshore) can reduce emissions and greatly improve local air quality at ports.
d. **Energy efficiency and hybridization:** There are a number of existing technologies that can help improve overall vessel efficiency, including electric powertrain hybridization, waste heat recovery, improved hull design or coatings, higher-efficiency HVAC, and power management systems. Vessel speed reduction and other operational strategies can also help.
e. **Renewable energy:** Renewable energy from solar, wind, and nuclear power is being investigated for onboard use to provide supplemental propulsion or auxiliary electrical power generation to offset fuel consumption.
f. **Exhaust treatment and carbon capture:** Post-combustion exhaust treatment measures can limit emissions of criteria pollutants, and CO_2 capture can potentially capture some or all CO_2 emissions; however, there are challenges with capture technologies, onboard storage, and portside supply chain logistics that must be resolved.

2. **International and domestic stakeholder engagement** to develop and implement effective decarbonization strategies and regulation. Coordination between the federal government and key outside stakeholders, such as vessel owner/operators, ports, terminal operators, and energy providers, is necessary. Given the international nature of the maritime sector, it is essential to build well-functioning domestic and international stakeholder collaborations to better understand industry challenges and needs and to enable the investments necessary to transition to low-carbon maritime operations. The federal government is engaging with international stakeholders through DOT's Maritime Administration, which collaborates with the International Maritime Organization and the Quad Shipping Task Force, and through the government's participation in the Clydebank Declaration REF, REF, REF. DOE is co-leading the Mission Innovation Zero-Emission Shipping Mission, which aims to transition at least 5% of the global deep-sea fleet to zero-emission fuels and ensure that at least 10 ports on three continents can supply zero-emission fuels by 2030 REF.

3. **Infrastructure investments and improved design and planning** in clean technologies and fuels for maritime applications funded through new and existing federal programs. Resources are necessary for activities including clean vessel upgrades, retrofits, or conversions, and essential charging and refueling infrastructure. For example, the Inflation Reduction Act allocates funding for ports to develop climate action plans and purchase zero-emission equipment. Similarly, the Port Infrastructure Development Program (PIDP) offers grants for port and terminal infrastructure improvements REF. Federal agencies can also provide technical assistance to interested applicants and coordinated planning across the maritime industry to ensure resources are used as efficiently and effectively as possible.

F. AVIATION

The combustion of jet fuel from domestic and international aviation is responsible for more than 10% of total transportation GHG emissions in the U.S. REF, REF. The CO_2 emissions from domestic commercial flights are roughly comparable to the CO_2 emissions of international commercial flights coming to and leaving from the U.S. REF.

1. The *2021 United States Aviation Climate Action Plan* REF describes a whole-of-government approach to achieve net-zero emissions in the U.S. aviation sector by 2050. The plan builds on individual and sector-wide commitments announced by the U.S. aviation industry and highlights specific actions and policy measures to foster innovation and drive change across the entire domestic aviation sector. The plan identifies key measures required to meet this challenging goal, including sector growth rate management, new aircraft and engine technologies to reduce fuel requirements, operational efficiency improvements, and switching to sustainable aviation fuels that would result in significant life-cycle emissions reductions and that are expected to account for the majority of aviation emissions reductions.

As aviation demand continues to grow, the development and introduction of new aircraft and engines by manufacturers will be critical to reducing future CO_2 emissions (see Section 3b). With investments by industry and the federal government, new, more fuel-efficient aircraft could be introduced. Through the Sustainable Flight National Partnership (SFNP), the government will work with industry to demonstrate a suite of aircraft technologies by 2030 that achieve a 30% improvement in fuel efficiency compared to today's best-in-class aircraft.

An increase in aviation demand could also lead to additional congestion and inefficient air traffic management-related fuel usage. Without continued investment in operational improvements, excess per-flight fuel usage is expected to increase. Even though the National Airspace System is already highly efficient, there are areas for improvement in all operational phases of flight to reduce fuel usage. Further optimization of surface, takeoff, cruise, and landing operations is possible with continued infrastructure investments and the development of improved operational concepts. As with any changes to the aviation system, operational procedure upgrades would need to ensure the safety of all aircraft operations and account for local environmental factors, such as noise and pollutants affecting air quality.

Sustainable aviation fuels will be critical to the long-term decarbonization of aviation. SAFs are fully interchangeable, drop-in liquid hydrocarbon fuels with the same performance and safety as conventional jet fuels produced from petroleum. They can be deployed in existing infrastructure, engines, and aircraft. SAF can be created from renewable or waste materials and have been shown to reduce life-cycle GHG emissions by at least 50% relative to conventional jet fuel and

The combustion of jet fuel from domestic and international aviation is responsible for more than 10% of total transportation GHG emissions in the U.S.

potentially 100% if low-carbon technologies such as climate-smart agricultural practices, low-carbon electricity and hydrogen usage, or CCS are used REF (see textbox on page 54). Efforts are ongoing to approve the use of 100% SAF in today's fleet of aircraft, thus enabling the decarbonization of aviation without a change in its underlying infrastructure.

The SAF production industry is still developing, a trend spurred on by the SAF Grand Challenge. That partnership among the federal government, the airline industry, and partners established a goal of increasing U.S. SAF production to at least 3 billion gallons per year by 2030. This would put the U.S. on a path to produce and use about 35 billion gallons of SAF by 2050, which would decarbonize the aviation sector almost entirely REF. SAF production will also be aided by the new tax credits and a competitive grant program the IRA established.

In addition to SAF, battery electrification and hydrogen fuel are also potential options for replacing petroleum-based aviation fuels. These technologies can play an important role in the coming decades by decarbonizing short-distance flights and dedicated regional cargo routes. However, they are not expected to provide a solution by 2050 for the medium- and long-haul flights that generate most of the aviation sector's carbon emissions. At present, flights less than 500 nautical miles represent 50% of operations but only 15% of total fuel usage. Conversely, flights greater than 1,000 nautical miles represent 20% of operations and 65% of total fuel usage. An analysis conducted by the United Nations' International Civil Aviation Organization (ICAO) on global aviation showed that even if a short-range hydrogen aircraft were to enter the fleet in the mid-2030s, hydrogen aircraft as a whole would not have a measurable effect on aviation CO_2 emissions before 2050 REF. Since the majority of aviation CO_2 emissions stem from long-haul operations and fleet turnover is slow—an average of 30 years for most aircraft—drop-in SAF is the most viable pathway for rapid decarbonization of the aviation sector.

Finally, aviation contributes to climate impacts beyond GHG emissions. It also creates high-altitude emissions and aviation-induced cloudiness that can affect the climate. Additional research is needed to quantify the GHG impact from these factors and to understand how SAF, improved technologies, and operational procedure changes might mitigate climate impact without increasing CO_2 emissions from added fuel usage.

The *Sustainable Aviation Fuel Grand Challenge Roadmap*, developed by DOE, EPA, the U.S. Department of Agriculture and DOT's Federal Aviation Administration, is a multi-agency blueprint that identifies key actions to realize SAF Grand Challenge goals, including policy support to cut costs and support rapid scale-up of domestic production of SAF REF. The roadmap articulates how federal agencies will coordinate RD&D and

deployment activities to catalyze technology innovation, public–private partnerships, policy frameworks, and investments needed to address barriers to achieving the SAF Grand Challenge goals.

Key priorities to enable a transition to a sustainable aviation industry by 2050 include:

1. **Policy and regulation** to incentivize low-emission aviation innovations through new and breakthrough technologies, and to reduce emissions by providing access to and use of proven technologies from other transportation sectors. Rulemaking can accelerate the implementation of strategies within the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) to the greatest extent possible and will also spur decarbonization efforts. CORSIA requires aircraft operators purchase emissions offsets or use CORSIA eligible fuels (CEF) to reduce international CO_2 emissions above a defined baseline. As an international program, CORSIA enables the development of harmonized standards for emissions offsets and CEF to ensure their robustness and sustainability and creates a marketplace for their use. This harmonization establishes global certainty for all stakeholders involved. The federal government has led the development of all aspects of CORSIA and continues to work to ensure CORSIA's environmental integrity.

2. **Research and innovation** to advance technological, operational, and sustainable aviation fuels solutions to reduce emissions. Research on aircraft and engine technologies can deliver improvements in efficiency and reductions in emissions. The SFNP will conduct ground and flight tests to demonstrate technologies with step-change improvements in environmental performance. The legacy infrastructure in use across the National Airspace System must continue to be modernized to support improved and emerging technologies. Enhanced data quality and information distribution can enable operators to fly more fuel-efficient trajectories in U.S.-controlled airspace, especially during the cruise phases of flights. Continued federal support for RD&D and deployment focused on feedstock systems, conversion, testing, analysis, and coordination—as well as ongoing industry collaboration through direct partnerships and the Commercial Aviation Alternative Fuels Initiative (CAAFI)—will be essential to a successful transition to SAF. In addition, decision support tools must be developed for industry to cost-effectively address the overall climate impacts of aviation via contrail mitigation.

3. **Expand stakeholder engagement and partnerships** around the world to address the challenges and opportunities inherent in the international nature of aviation. Pursuing ambitious international standards that incentivize the most effective technologies is essential to safely limit the growth of, and ensure reductions in, aircraft emissions. The federal government can continue to provide technical leadership to the ICAO Committee on Aviation Environmental Protection (CAEP) and its working groups. Government leadership must also negotiate internationally to maintain the environmental integrity of CORSIA and its mission, strengthen ICAO's aircraft CO_2 emissions standard, and support the implementation of the medium- and long-term goals adopted by ICAO in 2022 to ensure they realize their potential to drive aviation climate action globally. The U.S. must also work toward mutually beneficial climate protection provisions in aviation bilateral and multi-lateral agreements.

G. PIPELINES

Although freight is typically thought of as commercial goods hauled by trucks, ships, or rail, petroleum fuels, natural gas, and other commodities primarily transported by pipelines are also considered freight. In fact, pipelines carried 18% of all freight by tonnage in the U.S. in 2015, second only to trucks [REF]. Approximately 3.3 million miles of pipelines transport natural gas and petroleum (crude oil and refined products) throughout the country. Natural gas and petroleum represent 32% and 37% of total U.S. energy usage today, respectively. Liquid fuels such as gasoline are pushed through pipelines by pump stations, which are typically powered by electricity, diesel, or natural gas-powered engines. Gaseous fuels such as natural gas are pushed through pipelines by compressor stations, which are usually powered by natural gas or electricity.

Generally, these pipeline systems offer an efficient method of transportation; however, the fossil fuels they move are a major source of U.S. GHG emissions. The energy used to move products through pipelines is responsible for approximately 4 MMT of CO_2 emissions per year (plus emissions associated with generation of electricity). These emissions come from several sources, including the combustion of fuels to drive pumps and compressors, intentional pipeline blowdowns and venting, and equipment malfunctions or human error resulting in unintentional releases. Moreover, pipeline leaks and failures can release methane, a potent GHG, into the environment. Methane leaks resulted in an estimated 57 MMT of CO_2-equivalent emissions in 2019 (methane emissions during hydrocarbon production was responsible for an additional 134 MMT of CO_2-equivalent emissions in 2019)—a much higher amount of emissions than generated by pump and compressor stations.

Reducing methane emissions while energy systems transition to cleaner fuels will require more accurate leak detection and quantification, as well as adjustments to pipeline operation and maintenance procedures. Similarly, emissions from pipeline energy use can be reduced by using cleaner energy to operate pumps, compressor stations, and other support equipment, and by reducing the use and transportation of fossil fuels.

The federal government and pipeline owners and operators have a variety of tools at their disposal to mitigate methane leaks, reduce emissions from pipeline operations, and positively impact environmental justice communities. Priority levers include:

1. **Policy and regulation** that continue to increase the stringency of methane emissions limits, tackle emissions associated with pipeline operations (e.g., pumping and compressor stations), and promote the viable use of electricity or other clean energy sources. The bipartisan Protecting our Infrastructure of Pipelines and Enhancing Safety Act of 2020 (PIPES Act) directed DOT's Pipeline and Hazardous Materials Safety Administration (PHMSA) to minimize methane emissions from pipeline facilities. PHMSA has issued a number of regulations focused on pipeline safety and methane emission reduction, as outlined in the *U.S. Methane Emissions Reduction Action Plan* (including the Gas Gathering Pipeline Safety Rule, Valve Rule, and Gas Transmission Safety Rule). In addition, PHMSA has initiated rulemaking on

several other rules (including Leak Detection Rule, Gas Distribution Rule, and Liquified Natural Gas (LNG) Facilities Rule, as well as a new rule for carbon dioxide pipelines) to enhance pipeline safety and methane and carbon emissions reductions from pipeline facilities.

2. **Infrastructure investments and improved design and planning** for pipelines as made possible through provisions in the BIL. The new Natural Gas Distribution Infrastructure Safety and Modernization grant program will support the repair, rehabilitation, or replacement of leaking or failure-prone natural gas distribution pipeline facilities in community-owned systems. Those efforts will decrease leakage, thus reducing pipeline-related methane emissions [REF].

Additionally, investments focused on shifting toward electrifying pumps and compressor stations can reduce emissions associated with operations.

3. **Research and innovation** to continue to develop tools and reporting systems for accurate disclosure of methane emissions, including direct measurement and remote sensing technologies; performance-based risk reduction for design, construction, operations, maintenance, and fire protection of LNG facilities; improved safety systems for underground natural gas storage facilities; and new technologies to mitigate risk posed by excavation damage to pipelines. Additional research efforts should focus on safety and environmental mitigation improvements associated with an increase in the transport of sustainable fuels, hydrogen, and CO_2 for CCS via pipelines. It will be critical to focus on the safety, reliability, resiliency, and emissions associated with pipelines used for sustainable fuel and CO_2 as we transition to a decarbonized economy.

FUTURE OF PIPELINES

As we transition to a net-zero economy, the role of pipelines will also transform. While pipelines primarily transport fossil fuels today, in a future sustainable energy system pipelines could also transport CO_2 to injection wells for carbon capture and sequestration and to other end users. They could also be used to transport hydrogen and other sustainable liquid fuels like SAF. There are several risks and barriers associated with the transportation of alternative fuels by pipeline and potential integrity threats posed by different fuels must be fully examined and understood.

6. CONCLUSION – A CALL TO ACTION

"The benefits of a net-zero future will not only be felt by future generations. Mobilizing to achieve net-zero will also deliver strong net benefits for all Americans starting today. Driving down greenhouse gases will create high-quality jobs, improve public health in every community, and spur investments that modernize the American economy while reducing costs and risks from climate change. Reducing air pollution through clean energy will alone help avoid 300,000 premature deaths in the United States—alleviating these and other severe impacts that also fall disproportionately on communities of color and low-income communities. Investments in emerging clean industries will enhance our competitiveness and propel sustained economic growth. Modernizing the American economy to achieve net-zero can fundamentally improve the way we live, creating more connected, more accessible, and healthier communities.

That does not mean it will happen quickly or without hard work. There will be many challenges on our path to net-zero that will require us to marshal all our ingenuity and dedication. But it can, and must, be done. And even as we invest at home, the new technologies and investments outlined in this strategy will also help scale up low-cost, carbon-free solutions for the world. We can create a healthy, vibrant, and abundant world for our children. This plan is our promise to them—and it is one we must keep."

The Long-Term Strategy of the United States, November 2021

The Long-Term Strategy of the United States highlights the urgency of tackling the climate crisis and decarbonizing the U.S. economy. Transportation is the largest source of GHGs emissions and the second largest household expense. **Decarbonizing the transportation sector is integral to achieving a net-zero-emissions economy that benefits all communities.** Moving toward zero transportation GHG emissions is not only critical to tackling the climate crisis, but the accompanying transformation of passenger and freight mobility system toward sustainable solutions and technologies will save lives and improve quality of life. It will reduce pollution, increase U.S. competitiveness, decrease household costs, and increase accessibility for all communities, particularly those that have traditionally been overburdened and underserved.

To confront this challenge, in September 15 of 2022, DOE, DOT, EPA, and HUD signed a historic MOU to collaborate on rapidly decarbonizing transportation. The agreement recognized the unique expertise, resources, and responsibilities of each agency, setting the foundation for solutions that are more innovative and far-reaching than any of the agencies could achieve independently. The first step in this collaboration was to create a national vision for a decarbonized transportation system that will guide the four agencies and our partners as we move toward a better transportation future. This Blueprint offers that shared

The Blueprint's Five Principles

Initiate bold action

Embrace creative solutions across the entire transportation system

Ensure safety, equity, and access

Increase collaboration

Establish U.S. leadership

vision, giving direction to our future policymaking and research, development, demonstration, and deployment in the public and private sectors.

This Blueprint is based on five principles: initiate bold action; embrace creative solutions across the entire transportation system; ensure safety, equity, and access; increase collaboration; and establish U.S. leadership. It presents a three-pronged approach to realizing a clean, safe, secure, accessible, affordable, equitable, and decarbonized transportation system for all:

1. **INCREASING CONVENIENCE** by supporting community design and land-use planning that ensure services are located near where people live to reduce commute times, improve walkability and bikeability, and enhance quality of life and access to jobs and services;
2. **IMPROVING EFFICIENCY** by expanding affordable, accessible, and efficient options like public transportation and rail, and improving the efficiency of our systems and vehicles; and
3. **TRANSITIONING TO CLEAN VEHICLES AND FUELS** across all travel modes and vehicle types.

These strategies present unique opportunities and will be most effective if decision-makers, acting quickly and in concert, continually increase the ambitions of their actions, collaboration, and investments. There is no one technology or approach that will solve our transportation challenges unilaterally; we need to develop, deploy, and integrate a wide array of technologies and solutions to ensure we achieve our 2030 and 2050 goals.

Achieving a sustainable transportation future will require implementing bold changes and different sets of solutions to address unique challenges in different locations and across all travel modes and applications. Accordingly, this Blueprint identifies six specific levers that the agencies can use to support and implement these strategies: Policy and Regulation; Infrastructure, Industrial Investments, and Financing; Research and Innovation; Data and Tools; Workforce Education and Training; and Stakeholder Engagement and Public-Private Partnerships.

Transforming our transportation systems over the next three decades will be a complex endeavor, but **by taking a comprehensive and coordinated approach it is a challenge that we can, and must, solve.** In addition to leadership at the federal level, reaching our ambitious climate goals will require collaboration with regional, state, local and Tribal governments; industry; community-based organizations; and non-profit and philanthropic organizations. Together, we must act decisively to provide better mobility options, reduce inequities, and offer affordable and clean mobility solutions to ensure the health of the planet for future generations. **The time to act is now.**

NEXT STEPS: MOVING TOWARDS THE SOLUTION

Addressing the climate crisis requires rapid, dedicated, and coordinated actions. This Blueprint is a critical step by DOE, DOT, EPA, and HUD to provide leadership across the federal government toward achieving the goal of a decarbonized transportation system. However, the Blueprint alone is not enough. The new challenge to each of the agencies, and all of our partners, is to take actions and implement the changes necessary to achieve U.S. climate goals. The strategies, guiding principles, and tools and levers identified in this document will steer each agency's efforts, as will our overarching and historic commitment to coordinate actions in bold and innovative ways. The agencies will implement the strategies presented in this Blueprint to shape policy and regulatory decisions, funding and budget priorities, research goals, stakeholder interactions, and many other agency activities that will impact the future of transportation, energy, and our economy. The agencies will also jointly develop and release more detailed action plans that focus on the specific actions and levers relevant to each agency in order to accelerate decarbonization. Below is a summary of actions described in this Blueprint:

Before 2030 – Turning the Tide on Transportation GHGs: Research and Investments to Support Deployment

Maximize the impact of the historic BIL/IRA investments and catalyze collaboration and private investments

Envision, develop, and demonstrate scalable urban, suburban, and rural planning and land-use solutions, performance measurement, and supporting policies to increase convenience and reduce travel needs, considering environmental justice and equity.

- Convene an interagency group to develop tools and collect data to better understand behavioral changes and opportunities to manage travel demand

Support state and local decision makers with best practices, data, tools, and technical assistance to develop, implement, and evaluate a wide range of demand-management strategies on system-level design solutions to increase convenience and reduce emissions

Work with partners to identify solutions to ensure current and future transportation systems are more equitable and benefit underserved and disadvantaged communities

Support land-use, street design, and development policies that make walking, biking, and rolling easier, safer, and more convenient

Reduce the national transportation cost burden by at least 5% by 2030

Improve reliability, frequency, accessibility, and affordability and expand service for rail and public transportation, and invest in active transportation infrastructure to provide options to safely use more energy-efficient forms of transportation Continue to strengthen standards to improve vehicle efficiency

Provide incentives to support greater use of efficient travel modes and vehicles

Set clear, ambitious but achievable targets across all travel modes (e.g., sales shares of zero-emission vehicles, volumes of sustainable fuels, emissions reduction targets)

Work with international partners to define targets and implementation plans to encourage international shipping and aviation to rapidly decarbonize those modes

Demonstrate a suite of aircraft technologies by 2030 that achieve a 30% improvement in fuel efficiency compared to today's best-in-class aircraft

Reduce aviation emissions by 20% when compared to a business-as-usual scenario

Invest in research and innovation to further develop and demonstrate clean technologies necessary for a decarbonized transportation sector

- Keep lowering battery costs to close purchase price gap with conventional vehicles
- Develop and demonstrate pathways to produce clean hydrogen and sustainable fuels affordably
- Increase production of sustainable aviation fuels to 3 billion gallons a year by 2030

Continue to provide funding and policy incentives to accelerate the uptake of low- or zero-emission vehicles and invest in supporting infrastructure (e.g., vehicle rebates and EV charging infrastructure), especially in low-income and overburdened communities

- Build an equitable network of 500,000 EV chargers by 2030 to support EV adoption
- Achieve 50% of electric light-duty vehicle sales by 2030
- Ensure that 100% of light-duty federal fleet vehicle acquisitions are zero-emission vehicles by 2027 and 100% of medium and heavy-duty vehicles are zero-emissions by 2035
- Achieve 30% zero-emission medium- and heavy-duty vehicle sales by 2030
- Develop a policy toolkit or guidelines to help regional, state, local, and Tribal governments encourage people and freight companies to use EVs.

Develop a robust workforce and supply chain solutions to ensure the U.S. can manufacture enough clean vehicles and fuels to meet rapidly growing demand and that the resulting jobs and economic opportunities are distributed equitably

2030-2040 – Accelerating Change: Scaling Up Deployment of Clean Solutions

Adapt strategies and implementation plans in response to global events, consumer response, and technology progress

Implement urban, suburban, and rural planning and land-use solutions and supporting policies at scale to increase convenience and reduce travel needs

Continue to leverage advanced computing and data analytics to optimize logistics planning and provide options to reduce vehicle miles traveled Administer forward-looking policy and management at the overall transportation-system-level to maximize the positive impact of transformative technologies, like automation, in terms of quality of life and emissions.

Continue to invest in and encourage a greater use of efficient travel modes for passenger and freight to optimize travel and freight logistics and improve fuel economy

- Leverage connectivity, micromobility, and other technologies, as well as innovative business models, to enable multimodal and shared travel and improve options to complement efficient modes like rail and transit for first- and last-mile solutions

Continue to strengthen standards to further improve vehicle efficiency

Transition all new vehicles sales to zero-emission technologies and scale-up sustainable fuels

- Transition light-duty vehicle sales to zero-emission EVs by the mid-2030s
- Achieve 100% zero-emission medium- and heavy-duty vehicle sales by 2040. Ensure that 100% of all federal fleet vehicle acquisitions are zero-emissions vehicles by 2035
- Continue to scale-up use of sustainable fuels for aviation and maritime

Ensure infrastructure needed to support clean technologies is in place

- Build out hydrogen refueling networks for commercial trucks and other applications
- Continue to scale-up equitable EV charging infrastructure and support grid decarbonization
- Scale up clean fuel production, including hydrogen and sustainable aviation fuels
- Effectively integrate future transportation system with the broader energy sector—especially the power grid—to maximize the benefit of renewable energy and support resiliency

Continue to build resilient supply chains and a robust workforce development strategy to enable a full transition from petroleum to clean solutions

2040-2050 – Completing the Transition: A Sustainable and Equitable Future

Ensure that no one is left behind and do our part to achieve a net-zero-emissions economy

Continue to realize and use urban, suburban, and rural land-use and planning solutions and policies to increase convenience and to provide better and more equitable transportation options that reduce emissions across the transportation system

Fully leverage the potential for efficient travel modes like rail, transit, shared multimodal mobility, and maximize vehicle efficiency

Support fleet turnover to fully replace legacy vehicles with clean zero-emission solutions

- Supply 100% of fuel demand with clean fuels (e.g., 35 billion gallons of SAF by 2050)

In addition to guiding federal agencies, this Blueprint is intended to send a strong signal to our partners and other stakeholders, who can look to this document as a guidepost and framework to support and complement their own planning and investments and to further coordinate actions. These stakeholders include local, state, regional, county, and Tribal governments; industry; investors; and community and advocacy groups. Recognizing the urgency of the moment and the critical role that decarbonizing the transportation sector must play in tackling the climate crisis, stakeholders across the transportation sector should continue to pursue ambitious targets, seize the opportunity to implement change, and lead the decarbonization of our transportation system from every angle, starting from and building off of the strategies presented here.

This Blueprint articulates the strategies and the targets needed to enable a transition to a sustainable transportation system by 2050, building upon and expanding existing goals and ongoing efforts for every mode of transportation. It is an exciting first step toward realizing the vision of an improved and sustainable transportation future. Decarbonizing our transportation system will not come without challenges. However, with coordinated and bold actions across

This BLUEPRINT articulates the strategies and the targets needed to enable a transition to a sustainable transportation system by 2050.

the federal government and with our partners, they are challenges that we can meet. We will continue to increase ambition, **setting bold targets for improving our transportation systems and transitioning to zero-emissions vehicles and fuels on a timeline consistent with achieving economy-wide 2030 and 2050 emissions reduction goals.** As we decarbonize our transportation system, we can create a more affordable and equitable transportation system that will provide multiple benefits to all Americans for generations to come—the work is worth the effort. As technology and policy continue to evolve in an ever-changing world, it will be important to continually evaluate and improve our actions, and to continue strengthening the collaborations between DOE, DOT, EPA, and HUD, and with all of our partners. It is up to all of us to make that vision a reality and move forward with creative and innovative solutions toward a better future for all.

ACKNOWLEDGEMENTS

Study Leadership

The following individuals were responsible for the overall leadership and visions behind this Transportation Decarbonization Blueprint:

- DOE: Michael Berube
- DOT: Andrew Wishnia
- EPA: Karl Simon
- HUD: Alexis Pelosi

Study Coordination and Primary Authors

The following individuals led the development and writing of this Blueprint and coordinated the technical work including drafting, reviewing, and editing processes:

- DOE: Matteo Muratori
- DOT: Tatjana Kunz
- EPA: Aaron Hula
- HUD: Michael Freedberg

Main Contributors

The following core team members were responsible for key elements of the writing and revision process that took place from November 2021 to December 2022, including drafting and editing content and addressing comments made by peer reviewers:

- DOE: Kara Podkaminer, Morgan Ellis, Noel Crisostomo, David Hume, Michael Weismiller, Jay Fitzgerald, Neha Rustagi
- DOT: Tony Choi, Elliot Sperling, Becca Ellison, Tyler Clevenger, Serena Alexander, Michael Johnsen
- EPA: Andrea Maguire
- HUD: Lauren Ross
- Communication and graphic support: Clay Carrington, Krista Wilkins, Carson Poe, Brian Orms
- Council on Environmental Quality: Austin Brown, Crystal Bergemann

Secondary Contributors

The following contributors provided a range of technical and analytic input in specific topic areas of the Transportation Decarbonization Blueprint. Individuals who provided valuable peer-review comments are also noted below.

- DOE: Heather Croteau, Gina Coplon-Newfield, Jacob Ward, Raphael Isaac, Erin Boyd, Prasad Gupte, Gurpreet Singh, Kevin Stork, Siddiq Khan, David Anderson, Dave Howell, Zia Haq, Art Wiselogel, Valerie Reed, Marc Melaina, Pete Devlin, Sunita Satyapal, Jose Benitez
- DOT: Hal Connolly, Victor Waldron, Jim Hileman, Kevin Welsh, Kevin Partowazam, Vinay Nagabhushana, Dan Yuska, Michael Carter, Tricia Harr, Sentho White, Steve Nanney, Max Kieba, Kandilarya Barakat, Vincent Holohan, John Gale, John Davies, Alan Mitchell, Ryan Steinbach, Shawn Johnson
- EPA: Britney McCoy, Lisa Snapp, Chris Ramig, Jessica Daniels, Sarah Froman, Chien Sze, Sarah Roberts, Cullen Leggett, Kevin Bolon, Robin Moran, Brian Nelson, Richard Baldauf, Megan Susman, John V. Thomas, Reyes Barboza
- HUD: Regina Gray, Josh Geyer, Robin Keegan, Pamela Blumenthal, Solomon Greene, Warren Friedman, Bruce Haber, Susan Horowitz, Joseph Downes

TRANSPORTATION DECARB BLUEPRINT ACRONYM LIST

AEO ..... Annual Energy Outlook 2022

BETO..... Bioenergy Technologies Office (U.S. Department of Energy)

BIL ..... Bipartisan Infrastructure Law

CAAFI..... Commercial Aviation Alternative Fuels Initiative

CAEP..... Committee on Aviation Environmental Protection

CAFE..... Corporate Average Fuel Economy

Cal-ITP..... California Integrated Travel Program

CCS..... carbon capture and storage

CEF ..... CORSIA eligible fuels

CO_2 ..... carbon dioxide

CORSIA..... Carbon Offsetting and Reduction Scheme for International Aviation

DERA ..... Diesel Emissions Reduction Act

DOE ..... U.S. Department of Energy

DOT ..... U.S. Department of Transportation

EPA ..... U.S. Environmental Protection Agency

eTOD..... equitable transit-oriented development

EOP..... Executive Office of the president

EV ..... electric vehicle

FCAB..... Federal Consortium for Advanced Batteries

FHWA..... Federal Highway Administration

FTA ..... Federal Transit Administration

GDP ..... gross domestic product

GHG ..... greenhouse gas emissions

HOME ..... Home investments Partnership Program

HUD..... U.S. Department of Housing and Urban Development

ICAO ..... International Civil Aviation Organization (United Nations)

IRA..... Inflation Reduction Act

kWh ..... kilowatt-hour

LAI ..... Location Affordability Index

LDV..... light-duty vehicle

LNG..... liquified natural gas

LTS..... Long-Term Strategy of the United States

MDV..... medium-duty vehicle

MHDV ..... medium- and heavy-duty vehicles

MMT ..... million metric tons

MOU ..... memorandum of understanding

NHTSA..... National Highway Traffic Safety Administration

NOx ..... nitrogen oxides

PHMSA ..... Pipeline and Hazardous Materials Safety Administration

PIPES Act..... Protecting our Infrastructure of Pipelines and Enhancing Safety Act

PIDP..... Port Infrastructure Development Program

RD&D..... research, development, and demonstration

ROW ..... right-of-way

SAF ..... sustainable aviation fuel

SFNP..... Sustainable National Flight Partnership

SO_2 ..... sulphur dioxide

TDM..... transportation demand management

tWh ..... terawatt hours

USD ..... United States dollars

USDA ..... United States Department of Agriculture

V2G..... vehicle-to-grid power

V2X..... vehicle-to-other power

VMT ..... vehicle miles traveled

VOC ..... volatile organic compounds

ZESM ..... Zero Emission Shipping Mission

ZEV ..... Zero Emission Vehicle Task Force

DOE/EE-2674 | January 2023