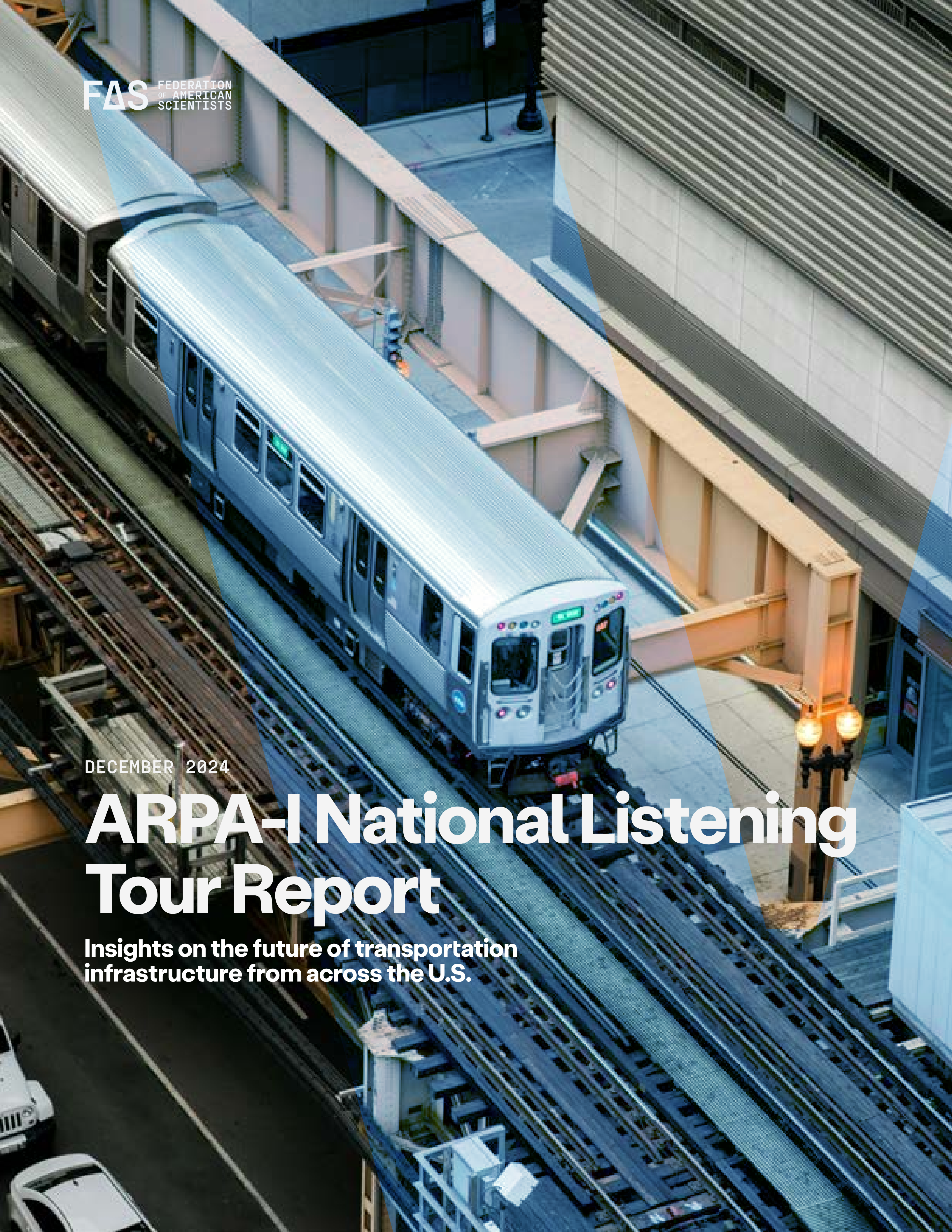


FEDERATION OF AMERICAN SCIENTISTS

DECEMBER 2024

ARPA-I National Listening Tour Report

Insights on the future of transportation infrastructure from across the U.S.

About FAS

The **Federation of American Scientists (FAS)** is an independent, nonpartisan think tank that brings together members of the science and policy communities to collaborate on mitigating global catastrophic threats. Founded in November 1945 as the Federation of Atomic Scientists by scientists who built the first atomic bombs during the Manhattan Project, FAS is devoted to the belief that scientists, engineers, and other technically trained people have the ethical obligation to ensure that the technological fruits of their intellect and labor are applied to the benefit of humankind. In 1946, FAS rebranded as the Federation of American Scientists to broaden its focus to prevent global catastrophes.

Over 75 years later, the Federation of American Scientists is still working to minimize the risks of significant global threats, arising from nuclear weapons, biological and chemical agents, and climate change. The organization also works to advance progress on a broad suite of contemporary issues where science, technology, and innovation policy can deliver dramatic progress, and seeks to ensure that scientific and technical expertise have a seat at the policymaking table.

Acknowledgements

We would like to extend our gratitude to the attendees who participated throughout the ARPA-I National Listening Tour and contributed their energy and ideas to yield thoughtful outputs for the transportation infrastructure community to consider. We would also like to thank our Workshop hosts Cornell Tech, Georgia Tech, University of Washington, and Newlab Detroit, as well as the organizers and facilitators from the U.S. Department of Transportation and the Federation of American Scientists.

Executive Summary

The United States is in the midst of a once in a generation effort to rebuild its transportation and mobility systems. Through the Infrastructure Investment and Jobs Act (IIJA) of 2021, hundreds of billions of dollars of new investments are flowing into American highway, rail, transit, aviation, port, pipeline, and active transportation projects.

This transportation infrastructure will be tested by new and emerging threats ranging from increased risk of flooding and heatwaves to supply chain disruptions and cyberattacks. Citizens are also rightly demanding more from the transportation sector—enhanced safety, faster project delivery, lower costs, increased sustainability, efficiency, resiliency, and a more equitable system for all users.

Meeting this moment will require bold investments in new and emerging transportation technologies—new materials, construction techniques, operations systems, planning tools, advanced sensing, computation, and beyond. Authorized in the IIJA, the Advanced Research Projects Agency – Infrastructure (ARPA-I), a new agency within the U.S. Department of Transportation (DOT), is poised to catalyze the transportation innovation ecosystem and accelerate and commercialize essential technologies that solve persistent infrastructure problems.

To inform its research agenda, ARPA-I embarked on a National Listening Tour from September 2023 through June 2024 to gather insights from a wide range of stakeholders from across the transportation ecosystem. With convenings held in the Pacific Northwest, Southeast, Midwest, and Mid-Atlantic, the tour provided several opportunities for ARPA-I to engage with 280 leading transportation experts. The goal was to ensure that ARPA-I heard both the priorities and capabilities of a broad range of transportation and infrastructure stakeholders from across the ecosystem.

Of the 280 participants, 99 (35%) were from academia; 58 (21%) were from private corporations; 42 (15%) were from policy and nonprofit organizations; 38 (14%) were from federal, state, and local transportation agencies; 37 (13%) were from startups; and 6 (2%) were financial investors. The ideas shared by these participants will help shape ARPA-I's future research agenda and will provide a framework for the Agency's ambitions that will be achieved in part with the participation of and input from this broad ecosystem of stakeholders.

Purpose and Organization of this Report

This report summarizes the insights collected over the course of the ARPA-I National Listening Tour in 2023 and 2024 and the inaugural ARPA-I expert community convening in Washington, DC in December 2022. Insights were gathered from 280 participants in the form of written worksheets and transcribed notes from discussions during the Workshops. The insights summarized in sections 4-7 of this report are intended to inform potential areas for future innovative advanced research and development (R&D) programs to be funded and managed by ARPA–I.

This report is organized into the following sections:

Laying the Groundwork for ARPA-I

In November 2021, Congress passed the Infrastructure Investment and Jobs Act (IIJA), allocating $550 billion in new funding for various programs within the U.S. Department of Transportation (DOT), including the establishment of the Advanced Research Projects Agency-Infrastructure (ARPA-I). Modeled after highly successful agencies like the Defense Advanced Research Projects Agency (DARPA) and the Advanced Research Projects Agency-Energy (ARPA-E), ARPA-I aims to address significant transportation infrastructure challenges through innovative technology solutions.

ARPA-I's mission involves funding high-risk, high-reward next-generation innovative technologies with the potential to revolutionize U.S. transportation infrastructure. The agency aims to develop innovative solutions that reduce long-term infrastructure costs, minimize environmental impacts, enhance the safe and efficient movement of goods and people, and improve infrastructure resilience against physical and cyber threats.

To achieve its goals, ARPA-I will support projects that advance early-stage novel research with practical applications, translate conceptual technologies to prototype and testing stages, develop advanced manufacturing processes, and accelerate technological advancements in areas where industry may not invest due to technical and financial uncertainties.

> It's not just repairing the things we've got [...] but making sure that future is safer than the one we inherited, cleaner than the one we inherited, and more equitable than the one we inherited. And that depends not just on putting resources into the things we already know how to do, but learning how to do things we thought were never possible.
>
> Secretary of Transportation Pete Buttigieg on the ambition of ARPA-I during the June 2023 White House ARPA-| Summit

ARPA-I continues a legacy of ARPAs that have delivered breakthrough innovations in a number of sectors. DARPA, established in 1958 in response to the Soviet Sputnik launch, has led to significant technological advances, including the internet, GPS, and mRNA vaccines. Inspired by DARPA's success, the government created similar agencies for other critical sectors, including the Intelligence Advanced Research Projects Activity (IARPA), ARPA-E, and the Advanced Research Projects Agency-Health (ARPA-H). ARPA-I will adopt many of the core cultural traits and rigorous ideation processes honed by prior ARPAs to seek similar breakthroughs for the transportation infrastructure sector.

To lay the groundwork for ARPA-I's future, the White House Office of Science and Technology Policy (OSTP) and DOT hosted an inaugural ARPA-I Summit in June 2023 during which a series of announcements were made on future ARPA-I activities. These announcements included:

Supercharging Infrastructure R&D Made Possible by the Bipartisan Infrastructure Law Programs: ARPA-I announced plans to work with DOT program offices to develop an innovative research agenda that complements flagship investment areas in the Bipartisan Infrastructure Law, including the $5 billion Safe Streets and Roads for All program, the $8.7 billion PROTECT resilient infrastructure program, and the $7.5 billion National Electric Vehicle Infrastructure program. This research agenda will identify technical chokepoints in each domain that could be overcome through a focused R&D initiative.

Partnering with Communities Across the Nation: ARPA-I is launching a national listening tour with leading researchers, entrepreneurs, companies, and transportation advocates to ensure that ARPA-I reflects the priorities and capabilities of transportation and infrastructure R&D stakeholders across the ecosystem. The listening tour will begin in the Pacific Northwest and will feature locations across the country.

Request for Information (RFI): ARPA-I invites the public and experts across a variety of modes, sectors and disciplines to provide their ideas and input on high-potential areas for ARPA-I to explore.

Advancing the Intersection Safety Challenge: ARPA-I is highlighting the USDOT Intersection Safety Challenge, a multi-phased challenge that began with a $6 million prize competition that leveraged machine vision, sensor fusion, and real-time decision making to create safer conditions for pedestrians, cyclists, and drivers at intersections. The first phase of the Intersection Safety Challenge was initiated in 2023. It featured a number of characteristics that have been successful aspects of other ARPA programs, including performance-based procurement, stage-gated programs, cross-disciplinary teams and expertise, high-impact domains and open innovation ecosystems.

Building upon the initiatives announced in June 2023, DOT has since undertaken additional efforts related to key transportation infrastructure areas. In January 2024, DOT announced the winners of the first phase of the U.S. DOT Intersection Safety Challenge, a call for opportunities "to transform roadway intersection safety by incentivizing new and emerging technologies that identify and address unsafe conditions involving vehicles, and vulnerable road users at intersections." In February 2024, DOT announced an RFI about opportunities and challenges of artificial intelligence (AI) in transportation, along with the $15 million Complete Streets AI Initiative–a new opportunity for American small businesses to leverage advancements in AI to improve transportation.

Since its authorization, ARPA-I has made steady progress to gather insights from across our country's transportation infrastructure experts and is prepared for future ARPA-I projects that will be both appropriately ambitious and focused on our largest transportation problems.

ARPA-I National Listening Tour Overview

The ARPA-I National Listening Tour was the continuation and expansion of an inaugural ARPA-I expert community convening held at DOT headquarters in Washington, DC in December 2022 titled Transportation, Mobility, and the Future of Infrastructure. The National Listening Tour stops included:

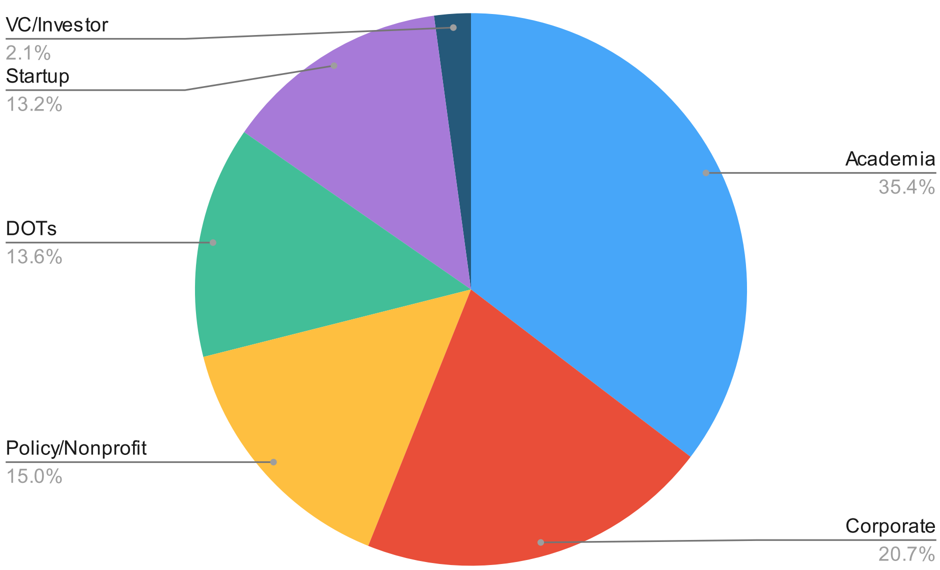
- Pacific Northwest (hosted by the University of Washington in Seattle, WA) - September 2023
- Southeast (hosted by the Georgia Institute of Technology in Atlanta, GA) - February 2024
- Midwest (hosted by Newlab in Detroit, MI) - March 2024
- Mid-Atlantic (hosted by Cornell Tech in New York, NY) - June 2024

The purpose of the ARPA-I National Listening Tour was to convene leading researchers, entrepreneurs, companies, and other transportation innovators and initiate a dialogue to ensure that ARPA-I reflects the priorities and capabilities of transportation and infrastructure R&D stakeholders across the ecosystem.

Each Workshop followed a consistent format of plenary presentations from DOT leadership highlighting the opportunity and imperative of this community's involvement, along with providing background on the unique cultural and structural components that set ARPA agencies up to seed breakthrough innovations, how ARPAs ideate advanced research program designs, and crucial roles that partners outside of government can participate in ARPA-I programs.

Beyond the plenary presentations, the bulk of each Workshop consisted of breakout activities and discussions that focused on some combination of ideal future visions for what U.S. transportation infrastructure could look like in 10-20 years, the biggest problems facing U.S. transportation infrastructure, and novel technological breakthroughs and opportunities that have the potential to solve those fundamental problems.

In total, 280 transportation infrastructure experts participated in the four Workshops and the inaugural convening in Washington, DC. These experts included representatives from academia; corporations; policy and nonprofit organizations; federal, state, and local departments of transportation; venture capital (VC) and other investment firms; and startups.



Promising Ideas for Future ARPA-I R&D Programs

While the DOT continues to engage in strategy development and seek expert inputs to help shape ARPA-I's initial set of research priorities once fully resourced, several promising ideas were uncovered during the ARPA-I National Listening Tour. Those ideas are described below in no particular order, along with the potential impact they could have on U.S. transportation infrastructure systems at scale. These ideas are not meant to serve as a current representation of priorities or research agendas of ARPA-I, but instead as a showcase of the creative and transformative solutions that the U.S. transportation infrastructure expert community is capable of envisioning.

AI-enabled efficiency throughout the infrastructure lifecycle

One of the most pervasive challenges in U.S. transportation infrastructure is the inefficiency of current project planning, design, and construction processes. Traditional methods often involve lengthy timelines, costly overruns, and frequent delays due to a lack of coordination and integration between stakeholders, planners, and contractors. These inefficiencies contribute to significant cost burdens on public funds and delay the delivery of much-needed transportation maintenance and improvements.

To address this challenge, one concept raised during the Workshops was that of a fully integrated, AI-enhanced project planning, design, scheduling, and construction schema. This idea leverages advancements in AI and "digital twin" technologies to streamline the entire lifecycle of transportation infrastructure projects—from conception to completion. By incorporating digital twins at all scales (geographic, structural, and temporal), the solution provides a powerful opportunity.

Implementing this AI-enhanced system would significantly accelerate the delivery of transportation infrastructure projects across the U.S., reducing both project completion times and overall costs. By enabling predictive analysis and continuous optimization, it would also lead to better resource allocation, reducing material waste and minimizing environmental impact. The result would be more efficient, resilient infrastructure systems that can adapt to future demands more effectively.

Priming physical road infrastructure for a digital future

The rigidity of traditional road infrastructure design remains a key issue contributing to inefficient traffic management, safety concerns, and costly, timely physical infrastructure adaptations. Physical road infrastructure like bike lanes, vehicle lanes, and curbs are static and not reflective of the fluid nature of transportation needs, particularly in urban environments. A suite of technologies such as AI, drones, automated systems, and sensor-equipped barriers could be used to create smart lanes and barriers that adjust according to live traffic data, weather conditions, or sudden hazards, by rerouting traffic or narrowing lanes to optimize for current conditions.

If the U.S. could develop systems like this that have been piloted in other countries (e.g., Spain), the impact on transportation infrastructure would be transformative. City planners would have the ability to program infrastructure dynamically, creating safer, more adaptive environments for cyclists and other road users. The result would be fewer accidents, better traffic management, and more efficient use of space, with the additional benefit of reducing emissions by promoting cycling over car travel. The flexible nature of this infrastructure could also support emerging technologies such as connected vehicles and autonomous driving systems and allow the U.S. to design more sustainable, future-proof cities that prioritize adaptability, safety, and user-centric design.

Automated maintenance and on-site manufacturing

ARPA-I National Listening Tour Workshop participants repeatedly raised concerns around transportation construction and repair challenges, including labor shortages, inconsistent funding, slow project timelines, inefficiencies in traditional construction methods, and high carbon emissions to these methods.

Technologies including AI, robotics, and large-scale additive manufacturing, were noted for their potential to solve these challenges when applied at scale. AI-powered systems can monitor roads and bridges in real-time, predicting failures and enabling proactive repairs. Once detected, autonomous drones and robots can perform immediate repairs, reducing downtime and keeping workers safe by eliminating the need for human intervention in unsafe environments. Simultaneously, on-site manufacturing, using 3D printing and generative design, can produce infrastructure components directly at construction sites, reducing the need for long-distance transportation and reducing carbon emissions.

These solutions, especially if applied in tandem with one another, have the potential to make infrastructure maintenance autonomous, continuous, safer, and more cost-effective. On-site manufacturing would speed up construction projects and minimize logistical challenges while reducing the substantial impact the transportation sector currently has on carbon emissions.

New and emerging alternative PNT technologies

Positioning, Navigation, and Timing (PNT) services are essential to the nation's critical infrastructure, enabling the safe, secure, and efficient operation of transportation systems for federal, state, commercial, and private entities across the U.S., including tribal lands and territories. These services provide crucial data that supports air and maritime supply chains, freight logistics, efficient roadway operations, crash prevention, and shared road use among vehicles and pedestrians. PNT services also ensure the safety and efficiency of aviation operations. For decades, the Global Positioning System (GPS) has been the backbone of PNT, continually evolving to improve accuracy, integrity, and security while expanding its applications.

However, despite the emergence of technologies like inertial navigation systems and Light Detection and Ranging (LiDAR) to improve the reliability of PNT data, these tools still have limitations. GPS, for example, relies on satellites, making it vulnerable to space weather disturbances and adversarial actions. Additionally, GPS systems can be compromised by threats such as jamming and spoofing.

Quantum sensors offer a promising solution, providing navigation capabilities in areas where GPS signals are weak or unavailable. These sensors use the principles of quantum mechanics to measure physical properties like time, acceleration, and magnetic fields with unprecedented accuracy. Quantum clocks, for instance, provide exceptional timekeeping precision, critical for synchronizing networks and systems. Quantum inertial sensors deliver highly accurate position and velocity measurements, making them invaluable during extended periods where GPS is unavailable. Meanwhile, quantum gravimeters and quantum magnetometers, which are passive systems, can operate under all weather conditions, at any time, and in featureless terrains such as oceans. These sensors enable gravitational anomaly-aided navigation (GravNav) and magnetic anomaly-aided navigation (MagNav). They collectively offer pathways to make our PNT systems more precise, more reliable and resilient.

Repurposing transportation rights-of-way for infrastructure of the future

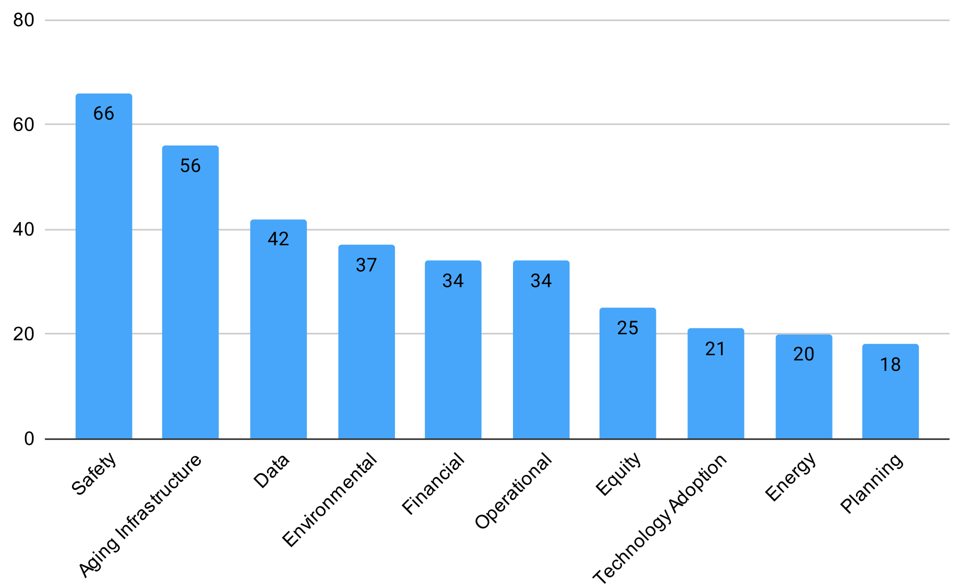
Another critical challenge raised throughout the Workshops was that of meeting the growing demand for electric vehicles (EVs) and the integration of modern, sustainable technologies at scale. The current network, designed for traditional internal combustion engines, lacks the infrastructure to support widespread EV adoption and smart technologies like connected and autonomous vehicles.

One solution posed during Workshops (and as part of the White House's Net-Zero Game Changers Initiative) is to repurpose existing transportation rights-of-way (ROWs) along highways and railroads for dual use, enabling the development of EV charging infrastructure and clean energy transmission without the need for costly land acquisition or major structural changes. With 48,000 miles of interstate highways and 140,000 miles of freight railroads, the U.S. has a vast network of ROWs that can be leveraged for new infrastructure. These ROWs can host charging stations, and in some cases, technologies like inductive charging embedded within roadways, allowing vehicles to recharge as they drive. This would make long-distance EV travel more feasible, eliminating range anxiety and encouraging broader adoption of electric vehicles.

Technological innovations like high-voltage underground cables and modular interconnection power electronics would help ensure grid stability while integrating energy and transportation infrastructure. These tools would allow the grid to balance the energy demands of electric vehicles in real time, creating a smarter, more resilient transportation network.

Challenges Facing U.S. Transportation Infrastructure

A portion of each Workshop breakout discussion focused on identifying the fundamental problems and challenges facing U.S. transportation infrastructure. Throughout these discussions, 353 individual responses were gathered. Themes that emerged consisted of problems related to safety, aging infrastructure and maintenance, data access and other data issues, environmental sustainability and resilience, financial constraints, operational inefficiencies related to existing structures and processes, equity and accessibility, technology adoption and scaling, energy and electrification, and community and planning challenges. Each of these broad themes that arose is broken down in further detail below.



Categories of Transportation Infrastructure Challenges

Safety (66 mentions): Safety remains a paramount issue with transportation-related fatalities once again topping 40,000 in the U.S. during 2023. Factors raised by participants as contributing to safety risks include impaired driving, driver distractions, excessive speeds, and inadequate infrastructure accommodations for vulnerable road users like pedestrians and cyclists. Unsafe street and intersection designs were also a critical concern, described as "the majority of intersections outside of urban centers are not designed to accommodate pedestrians safely." The rise in the size and weight of vehicles, along with the general car-centric nature of much of U.S. transportation infrastructure, were frequently noted as an impediment to pedestrian safety. Multiple participants noted that current infrastructure prioritizes vehicle speed and efficiency over driver, pedestrian, and cyclist safety.

Aging Infrastructure (56 mentions): Aging physical infrastructure continues to be a top concern for many experts. Challenges participants pointed to included failing bridges, deteriorating road conditions, and corrosion of materials, resulting in considerable maintenance backlogs. Participants also frequently pointed to outdated designs that do not accommodate modern transportation needs and struggle to adapt to contemporary demands, including electrification needs and the ability to withstand climate-related events.

Data Inadequacies (42 mentions): Many participants made reference to a significant lack of real-time and comprehensive data for the transportation planning the U.S. needs. For instance, data on pedestrian and bike activities to analyze crash risks effectively is often historic, segmented, inaccurate, and inaccessible. Data collection on vehicle collisions takes up to a year, delaying critical safety decisions. Digital infrastructure gaps were a frequent concern, noting "many areas lack the necessary digital infrastructure for modern transportation systems." The need for better people-oriented data was also emphasized, referring specifically to data on pedestrian and cyclist movements to improve safety.

Environmental Sustainability and Resilience (37 mentions): The transportation sector is the largest contributor (28%) to U.S. greenhouse gas emissions. Accordingly, participants called out these emissions rates, the environmental impact of larger vehicles, the carbon intensive materials and processes currently used in infrastructure construction, and the need for influencing travel behavior towards low carbon trips. Alongside sustainability concerns, infrastructure resilience was another common challenge raised.

Financial Constraints (34 mentions): According to participants, high costs associated with constructing, repairing, and maintaining transportation infrastructure limit the scope and speed of improvements. Public agencies face difficulties in efficient procurement and funding allocation, exacerbated by a backlog in maintenance and capital improvements. There were also mentions of profit-driven interests in car infrastructure, limited revenue from fares, and the need for funding catalysts and public-private collaborations.

Operational Inefficiencies (34 mentions): Operational inefficiencies were a recurring theme among discussions, specifically fragmented management with comments like "the lack of coordination between agencies results in redundant efforts." Inefficiencies in resource utilization were highlighted along with a lack of coordination across transportation modes.

Equity and Accessibility (25 mentions): Disparities in access to transportation infrastructure affect low-income and rural communities, as well as vulnerable populations. Car-centric infrastructure impacts and social inequities are major concerns. There are also challenges related to accessibility for people with disabilities, rural area connectivity, and access to reliable wireless connectivity for digital infrastructure advancements.

Technological Integration (21 mentions): Slow adoption of new technologies and integration with legacy systems are major hurdles, with participants asserting that there is resistance to adopting new technologies in the transportation sector. Challenges with autonomous vehicle integration, maritime and port digital integration, and procurement of new technologies are significant. There is also a need for improved cybersecurity alongside digital infrastructure buildout.

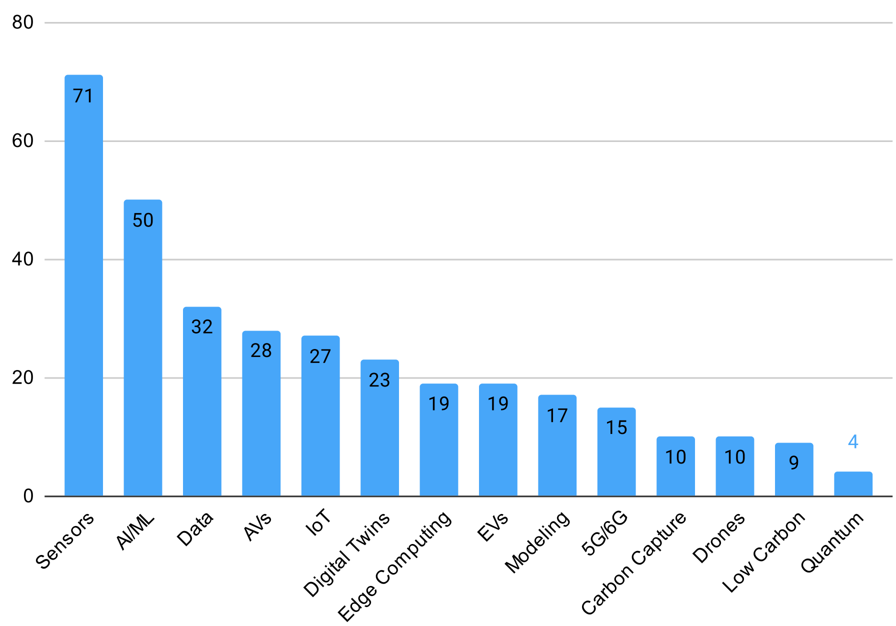
Energy and Electrification (20 mentions): Grid limitations in rural areas and the need for improved electric vehicle (EV) charging infrastructure were common among discussions around our largest transportation infrastructure challenges. Specifically, there pointing to a mismatch between the transportation sector and the electric grid, as the current grid is not designed to handle the demands of electric transportation.

Community and Planning Issues (18 mentions): Slow community engagement processes and the need for adaptable project designs were frequently cited issues. Encouraging transit ridership and the need for inclusive transportation planning are also mentioned.

Opportunities to Solve U.S. Transportation Infrastructure Challenges

Building upon ARPA-I National Listening Tour breakout discussion on U.S. transportation infrastructure's biggest challenges, Workshop participants shifted their attention to solving these problems. In order to do so, they brainstormed and discussed current and coming opportunities upon which we must capitalize in order to solve our most pressing challenges highlighted in the section above.

Throughout these discussions, 415 individual responses were gathered. Participant insights included policy suggestions, stakeholder engagement strategies, and infrastructure improvements, but the primary focus of these discussions–given ARPA-I's scope–was on technological opportunities (accounting for 334 of the 415 responses). Key themes raised include the integration of cutting-edge technologies such as artificial intelligence (AI) and machine learning (ML) AI, sensor technology, internet of things (IoT), digital twins, and edge computing to enhance data collection, processing, and real-time decision-making. Participants also emphasized the need for interoperable systems, standardization of data, and the creation of national repositories to streamline information sharing and improve infrastructure planning.



Technology Opportunities

Given ARPA-I's focus on technology solutions, the primary opportunity types identified throughout National Listening Tour Workshops were cross-cutting technologies, described in detail below.

Sensors and Sensor-related Technologies (71 mentions): Sensors were the most frequently cited technology opportunity to address transportation infrastructure problems including real-time detection of hazards, infrastructure wear and tear, and the need for accurate, continuous data collection. Examples of specific sensor technologies or applications included:

- Multiple sensors on new vehicles to increase accessible and real-time data
- High tech cameras to detect pedestrians and reduce the risk of accidents in urban areas

- Low-cost sensors for infrastructure condition assessment to identify early signs of infrastructure failure and reduce the risk of catastrophic failures
- Sensor systems on bridges and within technology like geosynthetics

AI and Machine Learning (AI/ML) (50 mentions): AI and ML were mentioned throughout the National Listening Tour Workshops as necessary pieces to solve complex problems related to traffic management, predictive maintenance, and autonomous vehicle operations. AI and ML can improve the accuracy of predictions, optimize system performance, and automate decision-making processes. Examples of specific types and applications include:

- AI that can model and predict behavior
- Generative AI to address the issue of unforeseen scenarios in autonomous vehicle operations by generating solutions in real-time
- AI/ML to accelerate new materials and structures
- Physics-informed AI to accurately model infrastructure impacts

Data Standardization and Management (32 mentions): One opportunity that may not have one specific technology tool to point to, but is inherently a technological opportunity, is data standardization and management. This would tackle the issue of fragmented data systems, ensuring consistency and interoperability across various modes, networks, and stakeholders. This would facilitate better decision-making and more efficient infrastructure management. Examples of specific standardizations and management tools include:

- Standardized data formats
- National data repositories to create centralized databases
- Federated data change management
- Data version control

Autonomous Vehicles (AVs) (28 mentions): Participants pointed to advancement and widespread rollout of AV technology as perhaps the biggest transformation to come in U.S. transportation systems. Achieving this maturation and scale could address the problem of human error in driving, which is a leading cause of crashes. AVs could optimize traffic flow and reduce congestion, making transportation systems both safer and more efficient. Examples of AV applications and associated technologies include:

- Dedicated AV lanes between major transportation centers
- AV-ready road network
- Fully capable and scalable AV technology

Internet of Things (IoT) (27 mentions): IoT technology can help solve the problem of disconnected systems by enabling communication between various elements of the transportation network. Participants assert it as a way to achieve real-time monitoring, improve safety, and increase efficiency. Examples of IoT applications include:

- IoT and AI integration reducing the need for hardware devices
- Leveraging IoT to reduce urban congestion by creating connected spaces that optimize mobility

Digital Twins (23 mentions): Digital twins have the potential to address inefficient planning and maintenance by providing accurate virtual representations of physical infrastructure. This would allow for better simulation, monitoring, and optimization, leading to more informed decision-making. Examples of applications from Workshop participants include:

- Digital twin immersive testing to identify potential unexpected failures before physical implementation
- Digital twins of infrastructure and traffic models to improve traffic management by simulating real-world conditions and enabling proactive responses to potential issues

Edge Computing (19 mentions): According to many participants, edge computing could completely fix the issue of latency in data processing, which is critical for applications requiring immediate responses, such as AVs and real-time traffic management systems. Examples of edge computing applications include:

- Real-time processing and decision-making
- Onboard and edge computing capabilities to enable vehicle and infrastructure to operate autonomously

Electric Vehicles (EVs) (19 mentions): Participants pointed to the readily apparent opportunity that EVs represent if the technology, costs, and infrastructure can be achieved at scale. To get to scale, it was widely acknowledged that we need more efficient EV charging experience, with infrastructure that allows for rapid charging along service areas. Another challenge for EV adoption is the need to build a widespread, reliable charging network that can meet the demands of all users, including long-haul trucks.

Modeling-related Technologies (17 mentions): Modeling technologies are essential for predicting infrastructure performance, traffic patterns, and the impact of various interventions. Examples of modeling-related technologies raised by participants were:

- Predictive modeling to optimize safety planning and real-time traffic management
- Behavioral modeling to improve AV prediction and safety

5G/6G Communication (15 mentions): Advanced communication technologies like 5G and 6G were mentioned as crucial for enabling real-time data exchange between vehicles, infrastructure, and central systems. An example is the deployment of 6G to support point-to-point communications in vehicle-to-everything (V2X) systems. Examples of applications include:

- 6G integrated sensing and communication to provide ultra-low latency necessary for AV operations and other critical applications
- 6G support for point-to-point communications in vehicle-to-everything (V2X) systems
- Pervasive broadband and level of service

Carbon Capture Technologies (10 mentions): Carbon capture technologies are critical for reducing greenhouse gas emissions across the transportation sector. Example mentioned by participants include:

- Carbon capture methods such as amine-based technology, solid pellets, portable units, and direct air capture
- Use renewable hydrogen to decarbonize steel production
- Apply carbon capture, utilization and storage to cement

Drones and Related Technologies (10 mentions): Workshop discussions around drones noted that they offer innovative solutions for infrastructure monitoring, logistics, and transportation management.

- 3D mobility enhancement through drones for last-mile delivery
- Swarms of drones used for large-scale infrastructure inspection

Low Carbon-related Innovations (9 mentions): Similar to carbon capture technologies, low carbon-related innovations will be important in reducing carbon emissions. Example of technologies raised during breakout discussions include:

- Low carbon materials to reduce the carbon footprint of physical infrastructure like roads and bridges
- Energy-storing materials (multifunctional concrete)

Quantum Computing (4 mentions): Quantum computing was raised a few times throughout discussions as a means for quantum material sensor development and also quantum sensing for unprecedented precision in infrastructure monitoring.

Non-technology Opportunities

Although policy and regulation were deemphasized during the National Listening Tour (as ARPA-I is a research and development funding agency), a number of non-technology opportunities were proffered by participants throughout discussions and are captured below.

Policy suggestions: Policy-related opportunities focused on creating a supportive regulatory framework, aligning financial investments with long-term infrastructure goals, and ensuring that policies are inclusive and equitable. These policies were intended to address challenges in planning, funding, and implementing large-scale infrastructure projects. Specifically, participants discussed opportunities to craft policies to ensure that transportation investments prioritize underserved communities, addressing the problem of unequal access to transportation resources.

Stakeholder engagement strategies: Participants emphasized the opportunity presented by involving diverse groups, particularly those traditionally underserved or impacted by infrastructure projects to raise the voices of all community members so that infrastructure development is responsive to their needs.

Physical infrastructure improvements: Non-technology-specific infrastructure improvements highlighted throughout the Workshops included enhancing the physical aspects of transportation systems, such as road design and public transit accessibility.

For instance, increasing the use of roundabouts can help solve the problem of high accident rates at traditional intersections. Additionally, developing complete streets infrastructure that supports all users, including pedestrians and cyclists, addresses the problem of limited accessibility and safety on roads designed primarily for vehicles.

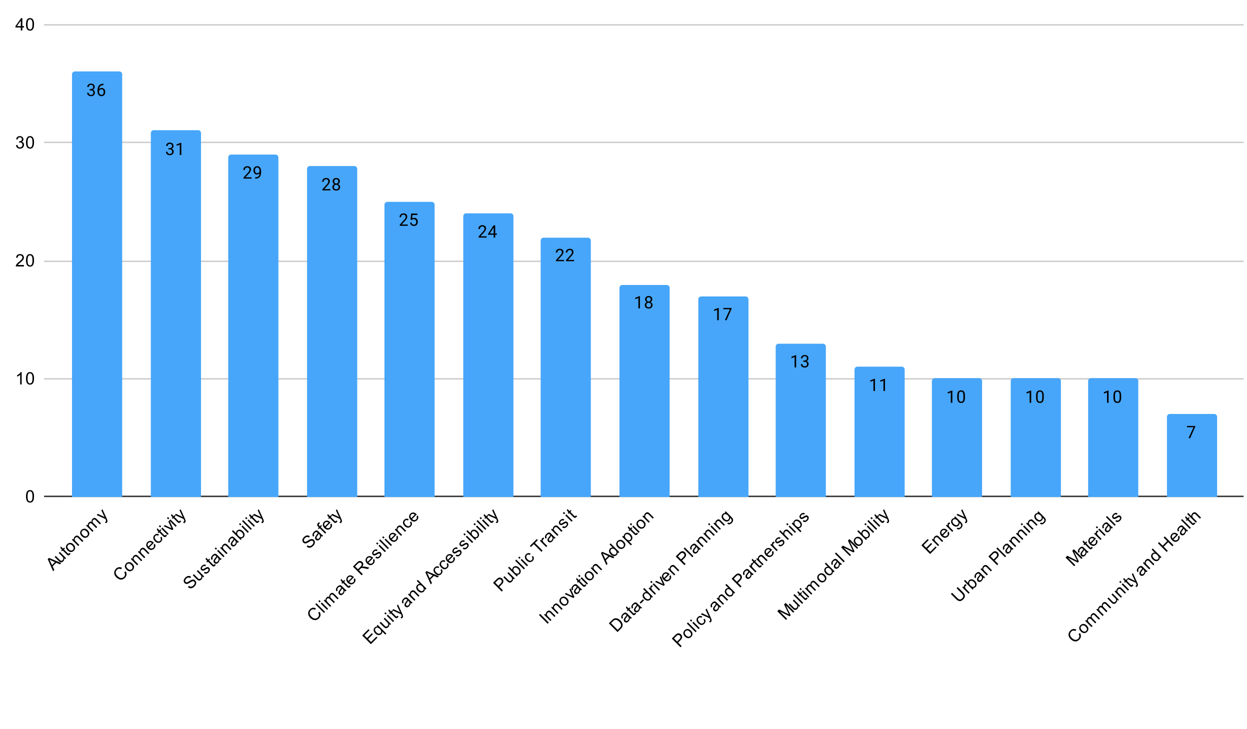
Financial and economic strategies: Opportunities raised centered on creating sustainable funding mechanisms for transportation infrastructure projects. These strategies address the challenges of securing adequate, long-term financing for both new projects and the maintenance of existing infrastructure. Ideas included alternative funding mechanisms such as value capture or tolling.

Predictions for U.S. Transportation Infrastructure in 10-20 Years

One of the key criteria for any good ARPA project is that it is appropriately ambitious. To set that level of ambition, ARPA-I National Listening Tour participants were asked to make a prediction for U.S. transportation infrastructure 10-20 years from now, taking an ambitious perspective and focusing on what could be. Throughout these discussions, 291 individual predictions were gathered. Despite the wide ranging and sometimes narrowly focused predictions, continuous themes emerged to help reveal a shared vision for what participants want to see in the transportation systems of tomorrow.

Participants frequently emphasized the importance of widespread adoption and integration of advanced technologies such as autonomous vehicles, AI-driven traffic management, and real-time data communication to create a connected and efficient transportation network. Sustainability also emerged as a central theme, with many predicting a shift toward carbon-neutral transportation systems powered by renewable energy sources. Ideas included dynamic wireless charging for electric vehicles, infrastructure embedded with carbon sequestration capabilities, and the widespread adoption of alternative fuels like hydrogen. The focus on sustainability also extended to construction practices, with participants envisioning the use of self-healing and recyclable materials to build resilient infrastructure that can adapt to climate challenges.

Equity and accessibility were also frequently mentioned, with a strong emphasis on creating a transportation system that serves everyone, regardless of location or socioeconomic status. Visions included universal Americans with Disabilities Act (ADA) compliance, free public transportation, and the development of equity-based planning tools to ensure that investments benefit all communities. The overarching ambition is to build a transportation network that is not only technologically advanced and environmentally sustainable but also inclusive and equitable, providing reliable access to mobility for all.



Categories of Predictions for U.S. Transportation Infrastructure in 10-20 years

Automation and Autonomy (36 mentions): Participants imagined a future dominated by autonomous systems, including self-driving cars, autonomous shuttles, and urban air mobility. These systems would be interconnected, allowing for seamless operation and enhanced efficiency. Ideas included autonomous vehicle fleets, virtual "rails" for guiding autonomous vehicles, and the deployment of autonomous drones for transport. The overarching vision was a transportation ecosystem where human error is minimized, and transportation becomes more efficient and safer.

Connectivity (31 mentions): Connectivity was seen as the backbone of transportation infrastructure in the future, with participants envisioning a fully interconnected system where vehicles, infrastructure, and personal devices communicate seamlessly. Advanced technologies such as quantum sensing, AI-driven traffic management, and universal communication standards were proposed to create a hyperconnected network. This would enable real-time traffic management, reduce congestion, and optimize the flow of goods and people.

Sustainability and Environmental Impact (29 mentions): Participants proposed a wide range of ideas aimed at reducing the environmental impact of transportation in the future. These included self-healing materials that extend infrastructure life and reduced emissions associated with frequent maintenance and construction, carbon sequestration integrated into construction materials, and the development of energy-generating infrastructure such as smart trails to generate energy for electric bikes. Participants also discussed the potential of dynamic wireless charging for electric vehicles and the large-scale adoption of alternative fuels, ensuring that the transportation system is not only sustainable but actively contributes to environmental restoration.

Safety (28 mentions): Safety innovations were a frequent theme, with participants proposing strategies to achieve a near-zero fatality transportation system. Ideas included expanding Vision Zero strategies, integrating AI for real-time risk detection, and deploying automated enforcement systems to prevent unsafe driving behaviors. The reimagining of urban spaces to prioritize pedestrian and cyclist safety was also highlighted, with infrastructure designed to protect the most vulnerable road users.

Climate Resilience (25 mentions): Participants emphasized the importance of building infrastructure that can withstand and adapt to the impacts of climate change. Ideas included the use of self-healing and self-sensing materials, modular designs for easier repairs and upgrades, and infrastructure that is resilient to extreme weather events. The vision was for transportation infrastructure that is not only durable but also adaptable to future climate challenges, contributing to overall climate resilience.

Equity and Accessibility (24 mentions): Ensuring equity and accessibility was a priority for participants when thinking about the future, with ideas like universal ADA compliance, free public transportation, and the development of equity-based asset management tools. The goal was to create a transportation system that serves all communities, including those that are traditionally underserved, such as rural areas and marginalized populations.

Public Transit (22 mentions): Public transit was envisioned as a fully integrated, multimodal system that is easy to use and highly efficient. Participants proposed the elimination of car-centric roadways in urban areas, replacing them with dedicated lanes for public transit, cycling, and walking. High-speed rail development, particularly in key regions, and the expansion of micro-mobility options were also highlighted as ways to enhance last-mile connectivity and reduce reliance on personal vehicles.

Innovation and Technology Adoption (18 mentions): Participants predicted a future where technologies like AI, quantum computing, and digital twins have been adopted at scale to optimize infrastructure performance and maintenance. These technologies at scale would allow for real-time monitoring, predictive maintenance, and dynamic system adjustments, and contribute to transportation systems being more efficient, resilient, and future-proofed.

Data-driven Planning (17 mentions): Participants envisioned the use of AI for real-time data analysis, along with the establishment of national data standards to ensure seamless integration across different modes, organizations, and stakeholders.

Policies and Partnerships (13 mentions): Despite not being the focus of ARPA-I policy and governance were mentioned as enablers for many of the ambitious future visions. Participants proposed establishing public-private partnerships to fund and manage infrastructure projects and allow for more flexible and innovative financing models. They also envisioned equity-based asset management tools and policies, increased cross-jurisdictional collaboration, and policies to set national guidelines for climate adaptation in infrastructure design and construction.

Multimodal Mobility (11 mentions): The collective vision for mobility included creating a seamless multimodal transportation system that allows users to easily switch between different modes such as bikes, trains, and buses. Participants hope for the development of unified payment systems to enhance the user experience and reduce reliance on personal vehicles.

Energy (10 mentions): Energy integration predictions centered on using renewable energy sources, bidirectional EV charging for grid stability, and dynamic load management systems. Overall, participants want a future where transportation systems are tightly integrated with energy networks, ensuring reliability while reducing the carbon footprint of the transportation sector.

Urban Planning (10 mentions): Urban planning-related visions included the removal of highways in cities, replacing them with green spaces, light rail, and pedestrian-friendly streets. Participants also predicted the development of high-speed rail corridors connecting major cities, reducing the need for air travel and long car journeys, and integrating land use with transportation planning for more sustainable urban growth.

Materials and Construction (10 mentions): Participants want to see increased use of self-healing and self-sensing materials to extend infrastructure lifespans by centuries. Modular construction techniques and adopting low-carbon materials were also noted as ways to reduce construction times, costs, and environmental impact.

Community and Health Impacts (7 mentions): Transportation infrastructure was envisioned by some as a tool for improving community health and well-being in the future. Ideas included designing infrastructure that supports physical and mental health, reducing the "pink tax" on transportation for women and families, and creating transportation systems that enhance social cohesion and community safety.

Conclusion

As ARPA-I continues its mission to revolutionize transportation infrastructure, it is essential to sustain and expand the support of the transportation expert community and stakeholders across the country. ARPA-I's success will depend on the collective effort of researchers, innovators, policymakers, and industry leaders who recognize the agency's potential to drive breakthrough solutions. To truly tackle our biggest transportation infrastructure challenges, we must deepen our commitment to collaboration, align resources strategically, and remain focused on innovative, high-impact outcomes. The expert community should continue to engage with DOT and ARPA-I, push the boundaries of what is possible in their own work, and seek to build the support necessary to turn ARPA-I's ambitions into reality.

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