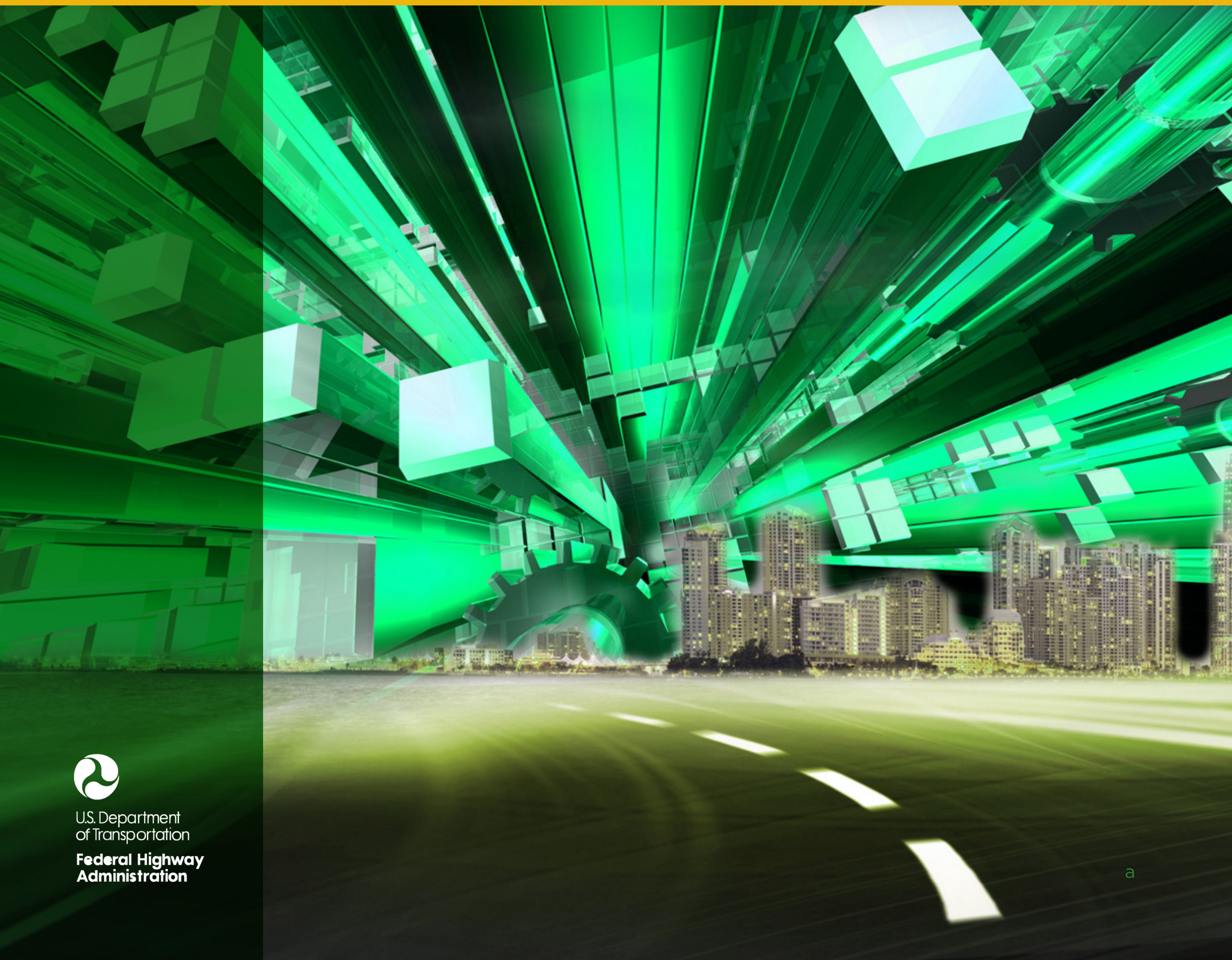
The Exploratory Advanced Research Program

EXPLORATORY ADVANCED RESEARCH

Novel Surface Transportation Modes

FINAL REPORT • DECEMBER 2015



U.S. Department of Transportation
Federal Highway Administration

Foreword

The 21st century is still in its adolescence—a phase denoted for transition amid a search for clarity of identity. The formative years of the new millennium have featured transformative innovations that will continue to influence how we live and work for generations, and in the decades ahead, the world will continue to be shaped by events and forces that are both anticipated and unexpected. In just 15 years, information technology and wireless communications have radically remade everything from the retail marketplace to how we stay in touch with friends and family.

The effect of these paradigm shifts will be enduring and pervasive across industries. How decisionmakers in the public and private sectors respond to the growing influence of emerging technologies on transportation safety and efficiency will determine whether innovation is a disruptive force or one for progress. This is why it is absolutely critical for the United States to modernize existing modes of transport to improve safety, mobility, and environmental sustainability. Innovations like vehicle-to-infrastructure communications and global positioning systems are revolutionizing the U.S. transportation system, but limiting the scope of the national strategy to long-established systems and industries is short-sighted. The U.S. Department of Transportation should not create or maintain arbitrary barriers to innovation; it should be facilitating new opportunities for entrepreneurs with game-changing ideas.

The Novel Surface Transportation Modes project is an initiative fundamentally designed around this concept. This project provided an opportunity for individuals and businesses to make a case for surface transportation solutions that are compelling but categorically "outside of the box." Many of these innovators failed to be heard in the past because there was simply no existing avenue for their proposal. The lessons learned will guide future initiatives like this one. The Novel Surface Transportation Modes project is a promising step forward in the effort to find new and more effective mechanisms for exploring novel transportation solutions.

Gregory D. Winfree
Assistant Secretary for Research and Technology
U.S. Department of Transportation

Notice

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16. Abstract This report summarizes an initial stage investigation into current research and development of alternative modal concepts. The project goals were to gain a better understanding of novel surface transportation concepts that fall outside of the Federal Highway Administration's Exploratory Advanced Research (EAR) Program's regular technology scans; to facilitate interaction and information-sharing among the U.S. Department of Transportation, State and local governments, and private sector innovators; and to explore the role of the public sector in advancing transportation innovation. This report discusses the current state of novel surface transportation modal concepts, identifies opportunities and challenges for these concepts, and presents a set of potential future research needs. The authors of this report have summarized the information from both research on novel modes and the viewpoints shared at the novel modes workshop.		

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Executive Summary

This report summarizes an initial stage investigation into current research and development of alternative modal concepts. The research project was a multimodal effort, organized by the Federal Highway Administration's (FHWA's) Exploratory Advanced Research (EAR) Program, with the participation of the Federal Transit Administration, Federal Railroad Administration, and Office of the Assistant Secretary for Research and Technology. Staff from the John A. Volpe National Transportation Systems Center (Volpe Center) conducted this project on behalf of the EAR Program.

The project goals were to gain a better understanding of novel surface transportation concepts that fall outside of the EAR Program's regular technology scans; facilitate interaction and information-sharing among the U.S. Department of Transportation (USDOT), State and local governments, and private sector innovators; and explore the role of the public sector in advancing transportation innovation. The research team sought preliminary information on novel modal concepts through literature reviews and used these findings to establish the project scope. FHWA also issued a request for information on novel surface transportation systems and received 34 submissions. These submissions comprised a range of concepts for both passenger and freight transportation and represented a wide range of technological readiness levels.

On December 2–3, 2014, in San Francisco, CA, and McLean, VA, with remote participation from both domestic and international participants, the EAR Program convened a workshop on Novel Surface Transportation Modes. Subject matter experts, USDOT staff, and developers of novel modal concepts gathered to discuss broad trends in transportation innovation, hear public and private sector perspectives, and listen to presentations of the concepts under development by the innovators in attendance.

The authors of this report discuss the current state of novel surface transportation modal concepts, identify opportunities and challenges for these concepts, and present a set of potential future research needs. The authors have summarized the information from both research on novel modes and the viewpoints shared at the novel modes workshop.

The research team for this study identified four key challenges common to novel mode development. These challenges include:

- Addressing connections to existing modes and last-mile issues.
- Increasing attention given to passenger experience and comfort.
- Providing sound methods for predicting travel demand and mode choice.
- Enhancing the management and mitigation of risk from an investor perspective.

Researchers also identified four key opportunities for innovators that are common among novel modes. These opportunities include:

- Engaging with Government agencies outside of the transportation sector (e.g., Department of Defense (DOD), Department of Health and Human Services, and Department of Energy (DOE)).
- Working with universities for testing, prototype development, and research.
- Working together to develop standards in collaboration with Government and other stakeholders.
- Taking advantage of unique settings that may be conducive to a new transportation system (e.g., self-contained campuses, airports, and other facilities) or to a specific market (e.g., freight, passenger, and overseas locations).

By taking advantage of these opportunities, innovators would be able to address several of the key concerns relating to investor and societal risk of adopting novel modes, which would enhance the likelihood of investment.

The research team also identified six opportunities for USDOT to facilitate the development and deployment of novel modes. These opportunities include:

- Providing technical support to State agencies to reduce barriers to innovation.
- Encouraging innovation.
- Improving travel demand and mode-choice models.
- Facilitating connections between innovators and university and Government researchers.
- Developing novel testing facilities and paradigms.
- Providing a forum for testing, standardization, and specifications.

Addressing these opportunities would greatly enhance the societal environment for innovation with regard to novel transportation modes within the United States.

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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List of Acronyms and Abbreviations

ATN	automated transit network
DOD	Department of Defense
DOE	Department of Energy
EAR	Exploratory Advanced Research
EV	electric vehicle
FHWA	Federal Highway Administration
GHG	greenhouse gas
HHS	Department of Health and Human Services
PRT	personal rapid transit
R&D	research and development
RFI	request for information
TEV	tracked electric vehicle
TRL	technology readiness level
USDOT	U.S. Department of Transportation

Introduction

The U.S. Department of Transportation (USDOT) funds critical research in many areas, ranging from materials development to behavioral economics. Research results from USDOT research programs help to inform public sector and industry stakeholders and offer guidance for policy formation, investment decisions, and regulation. The USDOT's ongoing mission to advance transportation safety and mobility in a cost-effective way means that these research programs typically focus on well-defined needs and seek regular stakeholder input; however, it is periodically necessary to look beyond these well-defined programs to question what may be on the horizon. In accordance, the Federal Highway Administration's (FHWA's) Exploratory Advanced Research (EAR) Program focuses on longer term, higher risk research areas—with a higher payoff potential—in diverse areas of highway transportation, ranging from advanced transportation modeling to nano-materials.

Transportation technology has mostly evolved incrementally over time, but there have also been instances in which new technologies have proved highly disruptive to existing modes of travel. Historical examples of this include steam ships displacing sailing vessels and railroads displacing canals in the 19th century, and trucks, buses, and air service displacing passenger and freight rail service in the 20th century. During each transition, the Government played a critical role in the adoption of new modal technologies. Today, rapid advances in transportation technology are already showing promise in areas previously considered the realm of science fiction, such as automated vehicles. U.S. Transportation Secretary Anthony Foxx's 30-year framework for the future of transportation, *Beyond Traffic*, provides an overview of some of these future trends and highlights promising technologies.(1)

This report summarizes an initial stage investigation into current research and development (R&D) of alternative modal concepts. The goals of the project were to gain a better understanding of novel surface transportation concepts that fall outside of the EAR Program's regular technology scans; facilitate interaction and information-sharing among USDOT, State and local governments, and private sector innovators; and explore the role of the public sector in advancing transportation innovation. This research project was a multimodal effort, organized by the EAR Program, with the participation of the Federal Transit Administration, Federal Railroad Administration, and Office of the Assistant Secretary for Research and Technology. Staff from the John A. Volpe National Transportation Systems Center (Volpe Center) conducted this project on behalf of the EAR Program.

PROJECT SCOPE

For this project, the term *novel transportation systems* includes intercity (i.e., long distance) and daily travel contexts, both domestic and global. The research team limited the scope of the project to surface transportation only, which is defined here broadly as including elevated or subsurface systems but not maritime or air transportation. They also determined that proposals for novel transportation systems must have conceptually progressed beyond a mere idea (i.e., there must have been studies, or serious consideration, of basic engineering concepts) but not progressed to the point of being a proven, market-ready system. The research team defined this stage as having completed one or more full-scale field demonstrations and having commercial partners, suppliers, or customers in place. They acknowledged that there are many other approaches that could substitute transportation demand (e.g., three-dimensional printing or telecommuting) but such substitution strategies were not within the scope of this project.

The research team noted that novel modes will likely have more than one of the following attributes. A novel mode should:

- Showcase a breakthrough technology.
- Represent a new mode not captured by conventional transportation demand models.
- Establish a new vehicle type or new propulsion technology or system.
- Represent a new ownership structure or business model.
- Offer a new service concept (e.g., manual or automated, point-to-point or hub and spoke, roundtrip or one-way, private or shared).
- Introduce a new system-management concept.
- Implement a new fueling source or infrastructure.

The research team did not consider this to be a complete list of attributes and acknowledged that there may be a novel mode that does not meet any of the criteria presented in this list. Moreover, the novel modes of greatest interest are those that are not in widespread use today and may meaningfully change travel options, travel behavior, economic output, development and operation of transportation rights-of-way, and land-development patterns.

PROCESS

Volpe Center staff conducted this research project for the EAR Program. In addition, a multimodal team of internal USDOT stakeholders guided the development of the project scope, in collaboration with the project team and EAR Program, and participated in shaping and reviewing the project.

The research team sought preliminary information on novel modal concepts through literature reviews. Researchers used these findings to establish the project scope outlined in the previous section. Following this, FHWA issued a request for information (RFI) on novel surface transportation systems and received 34 submissions. These submissions comprised a range of concepts for both passenger and freight transportation and represented a wide range of technological readiness levels. A full list of submissions can be found in Appendix A.

On December 2–3, 2014, the EAR Program convened a workshop on Novel Surface Transportation Modes. The EAR staff coordinated simultaneous convening of the workshop in San Francisco, CA, and McLean, VA, with remote participation from both domestic and international participants. Subject matter experts, USDOT staff, and developers of novel modal concepts gathered to discuss broad trends in transportation innovation, hear public and private sector perspectives, and listen to presentations of the concepts under development by the innovators in attendance. Expert speakers provided context-setting presentations on transportation history, travel demand, freight, and investment. In addition, the expert panelists discussed State and local perspectives and project financing and business model issues. A selection of 24 RFI respondents also provided short pitches to summarize their novel mode concepts. Brief overviews of these concept summaries are presented in Appendix B. These pitches were followed by expert panel discussion of key themes. A summary of the workshop is available at http://www.fhwa.dot.gov/advancedresearch/pubs.cfm.

Part One:
Novel Modes in Context

Why Consider Novel Modes?

The U.S. transportation system offers historically unprecedented levels of mobility, but the research team noted that it does not meet the needs of all users and comes with significant financial and other costs. In accordance, transportation operators and the traveling public are constantly searching for improvements in speed, access, safety, and environmental performance.

Over the past few decades, capacity expansion constraints, funding limitations, and shifting public preferences have led to a focus on improved system management over new construction, particularly by making use of newly available information and communication technologies. Although real improvements in performance have been made, the surface transportation system continues to face significant issues with congestion and emissions. There are also other emerging challenges, such as preserving mobility for an aging population. In accordance, government and industry may benefit by considering an entirely new approach.

New products and services are sometimes described as arising from a combination of societal or market "pull" and technology "push." The former refers to products that are explicitly designed to address unmet needs or other opportunities in the market, whereas the latter refers to a process by which new products are designed primarily to take advantage of technological advances. The following pages summarize key societal and technological factors in transportation innovation today.

Societal Pull Factors

Although the current surface transportation system provides users with high levels of personal mobility, it has significant shortcomings that could create demand for novel modes. In particular, the current surface transportation system is costly in terms of expenditure levels and its impacts on human health and the natural environment. In addition, the current system leaves segments of the population underserved. The key limitations noted by the research team are outlined in the following sections.

User costs

The Bureau of Transportation Statistics estimates that the United States collectively spends approximately $800 billion per year on motor vehicles, fuels, and related items.[2] At the household level, an estimate from the Census Bureau puts the annual spending total for vehicles, fuel, and other vehicle expenses at approximately $8,466 per household, which is higher than food and any other expense category except for housing and shelter.[3] The American Automobile Association separately estimates the direct financial costs of driving a family sedan at approximately $0.59 per 1.6 km (1 mi) or just under $9,000 per year for a typical driver.[4] For many households, maintaining basic mobility, including access to jobs and services, requires one or more vehicles with costs that can consume a significant share of disposable income.

Public Infrastructure Costs

Public sector expenditures on roads, bridges, and other infrastructure include roughly $40 billion per year from Federal-aid programs under the current Moving Ahead for Progress in the 21st Century Act, in addition to an estimated $250 billion in State and local expenditures.[5] According to FHWA's *Conditions and Performance Report*, these levels are not adequate to maintain the road system in its current condition nor to reduce the backlog of deferred maintenance.[6] Other public costs, such as emergency response related to traffic crashes and police costs associated with traffic control and enforcement, are harder to quantify but are undoubtedly substantial. The financial demands of maintaining the country's enormous roadway infrastructure are such that the potential insolvency of the Highway Trust Fund continues to be a pressing issue.

Limited Options for Non-Drivers

The interaction between the current surface transportation system and the low-density development patterns typical in the United States has meant that those who are unable to drive (e.g., because of age or disability) and those who cannot afford or do not want to own a car have fairly limited mobility options or are constrained in their choices of living and working locations. This presents a very large societal cost in terms of foregone employment opportunities, limited access to services, and more broadly in reduced community cohesion.

Safety

According to the National Highway Traffic Safety Administration report, *Traffic Safety Facts 2013*, 30,057 fatalities and just under 1.6 million non-fatal injuries resulted from traffic crashes in 2013. This equates to 10.35 deaths per 100,000 people, which compares unfavorably to other highly developed countries and represents a very large societal cost.[7] Although much progress has been made over the past decades, motor-vehicle crashes are still the leading cause of death for several age groups.

Environment

The United States is the second largest emitter of greenhouse gases (GHGs) after China, and approximately 20 percent of those GHGs come from surface transportation, principally cars and trucks. The United States has announced a target to reduce GHG emissions by 26–28 percent below 2005 levels by 2025.[8] Emissions of criteria pollutants as designated under the Clean Air Act have been reduced considerably in recent years but continue to contribute to health problems, such as asthma.[9]

Other Factors

Another source of societal pull factors could come from demographic and attitudinal changes toward transportation. For example, driver license and vehicle ownership rates among younger Americans have declined, and there is some evidence that this group is more open to innovative approaches, such as bike sharing and ride sourcing. This group could serve as a source of demand-side pull for novel surface transportation systems as an alternative to car ownership or conventional transit services.

Over the long term, broader societal trends could also spur interest in new forms of transportation. These could include changes in settlement patterns, employment locations, or freight flows that stretch the limits of existing transportation systems. Likewise, challenges with security, public health, resource constraints, or adaptations to a changing climate could also lead to interest in new modal options. More optimistically, rising personal incomes over time would also tend to foster interest in transportation systems that offer travel-time savings, greater convenience, or productivity improvements. This dynamic, and other key points about societal pull factors, are distilled in table 1.

Technological "Push" Factors

Technological innovation can drive transportation development and innovation. Recent technological advances of particular relevance to transportation include improvements in wireless communications to vehicles in real time and other wireless transmission (e.g., electrical charging), continued advances in computing power that enable real-time processing of large amounts of information, materials science innovations in lightweight composites and solar charging, and new business models for transportation services (e.g., vehicle sharing and pop-up services).

Improved communications, new sensor technologies, and computing power are driving advances in partial or complete automation of vehicles. Automated vehicles are defined as those vehicles in which at least some aspects of a safety–critical control function (e.g., steering, throttle, or braking) occur without direct driver input. Automated vehicles may use onboard sensors, cameras, global positioning systems, and telecommunications to obtain the information necessary to make judgments regarding safety–critical situations and act appropriately by effectuating control at some level.[10] Although fully-automated

Table 1. Current and future societal needs for transportation systems.

	Current Transportation Systems	Future and Emerging Transportation Systems
Current Societal Needs	Existing systems provide high levels of mobility and convenience but at high cost and with notable limitations.	Future systems would need to be cheaper, safer, faster, more comfortable, and more convenient than is the current set of transportation options.
Future and Emerging Societal Needs	Current modes may not be able to adapt to future needs or societal changes.	Future systems would be developed to respond to new and emerging needs (e.g., for independent mobility for growing elderly population).

(i.e., driverless) vehicles may be many years away, automation has progressed rapidly, and a growing share of vehicles on the market today already have limited forms of automated control (e.g., adaptive cruise control, lane-keeping, and forward-collision avoidance). Potential benefits of automation include improvements in safety and a reduction in accident rates; improvements in traffic flow and fuel efficiency by using sensors and communications to maintain headways; reduced travel times because of reduced congestion, accidents, and arbitrary driver behaviors that cause bottlenecks; and improvements in air quality. Such systems leverage current infrastructure and vehicle ownership models while taking advantage of automation to reduce error and improve system efficiency.

Recent advances in inductive charging of batteries have attracted a great deal of attention for transportation uses, such as charging of electric buses during routine stops and in pavement charging options. Inductive charging, also called wireless charging, is the transfer of a charge from one electrical system to another in close proximity by creating an electromagnetic field in the power source to induce an electromagnetic charge into a destination device. The advantage to this mechanism is that it can be done simply by proximity and does not require vehicles to stop and plug in to a fixed electrical outlet. Inductive charging is considered key to the future of electric vehicles to overcome barriers, such as lack of personal charging space and locations, length of the charging period, and the desire to charge while driving. Inductive-charging mechanisms also have a greatly reduced risk of electric shock; however, they tend to be less efficient because they lose charge as waste heat and need to power the charging source as well as the destination. These charging mechanisms can be slower to charge, but transmission efficiency can approach that of wired systems when coils are of a similar size and in close proximity.(11) Technologies are also improving to reduce losses. For example, several inductive charging systems have been successfully demonstrated in transit environments in the United Kingdom, Germany, Italy, and Korea.(12) The Society of Automotive Engineers is also developing a standard frequency and minimum performance, safety, and testing criteria for inductive charging of electric vehicles, which is expected to further innovation in this area.(13) Many of the current impediments to broader electric-vehicle (EV) adoption relate to the vehicles' limited range and the time and dedicated locations needed for recharging. The extent that widespread, cost-effective, inductive-charging systems can be developed would likely significantly increase EVs' market penetration relative to internal combustion vehicles. In time, motorists could recharge their vehicles while driving or cordlessly recharge at office parks and shopping centers.

Advances in materials science may contribute to both propulsion and construction materials in existing vehicles. A variety of thin-film photovoltaic materials are in development that will be lightweight and cheaper to construct than traditional photovoltaic cells. These materials may become part of vehicle windows and surfaces in the future to assist in propelling the vehicle with renewable solar power. Advances in battery and energy storage technologies, such as organicallybased batteries that can recycle spent lithium and batteries with increased efficiency and reduced toxicity, may further enable the expansion of EVs by increasing range, reducing cost, and improving environmental footprints.[14] Novel composite materials will also increasingly enable the production of lighter weight vehicles with better fuel economy and similar or better safety profiles than current vehicles. The Department of Energy (DOE) estimates that a 10-percent reduction in road vehicle weight can lead to a 6–8 percent fuel-efficiency improvement and suggests that high-efficiency engines made of advanced materials can also lead to improvements in efficiency. In addition, DOE estimates that the combination of reduced weight and engine improvements associated with advanced materials could save over 5 billion gallons of fuel annually by 2030.[15]

Recent developments in vehicle sharing (e.g., car and bicycle sharing) and pop-up ride services that respond to immediate requests (e.g., taxi services such as Uber and bus services such as Bridj) have begun to dramatically alter how a significant segment of the population travels.[16] All of these services depend on improved wireless communications, mobile phone applications, global positioning systems, electronic payment systems, and access to an ad-hoc workforce. As of 2011, over half a million people in the United States and Canada participated in car-sharing services.[17] Survey results suggest that for a certain portion of users, car sharing led to a new lifestyle involving an increase in travel by non-motorized travel modes and public transit in concert with their increased use of car sharing. Other segments of the population, particularly those who began car-sharing membership as carless households, exhibited a decrease in public transit use.[14]

Part Two:
Assessment

Existing Conditions

The project research team reviewed literature reviews, along with the submissions received following the RFI, to better understand basic characteristics of novel transportation systems. USDOT staff also provided input based on their knowledge of additional concepts and research in progress. The review is necessarily somewhat limited based on the project scope outlined earlier in this publication. As noted previously, the research team did not consider maritime or aviation concepts, nor many current trends considered to be novel modes (e.g., ride sourcing through a mobile application) because of their use of existing technologies and systems. An overview of the surface transportation novel mode concepts that the researchers reviewed is outlined in the following section, together with a brief discussion of some of the factors impacting potential viability.

Major Modal Types Identified

Proposed systems may not fit exclusively into one typology and may share elements of two or more.

Personal Rapid Transit and Automated Transit Network Systems

There are many variations on the theme of small, automated, public-transportation vehicles that provide on-demand service for individuals or small groups. Personal rapid transit (PRT) and automated transit network (ATN) systems typically involve fixed guideways, yet have the flexibility to provide point-to-point service within this framework. The introduction of PRT and ATN systems as a general concept is not new, for example, the Morgantown, WV, PRT system began service in 1975 and the Ultra PRT system opened at Heathrow Airport in the United Kingdom in 2011. Each novel mode concept that the research team reviewed in this project typically offers a refinement to the idea, such as lower costs or improved system control. Although there are a few existing examples of commercial PRT systems, these are generally very limited in scale, and the overall concept is not yet in widespread deployment. The research team therefore included PRT and ATN within the scope of the research, especially with respect to future innovations relating to the concept. PRT and ATN systems offer the prospect of combining the flexibility and convenience of personal vehicles with the energy savings and other efficiencies of mass transit; however, it is unclear whether such systems can feasibly scale up to serve high passenger loads without reverting to something more like conventional fixed-route transit. In addition, although PRT and ATN systems are sometimes described as a potential means of addressing the “last-mile” problem of conventional transit services, they too operate on fixed guideways and can face last-mile problems of their own—particularly in the context of low-density settlement patterns in most metropolitan areas.

Platooning and Quasi-Rail Systems

Platooning concepts involve automated operation of conventional automobiles or newly developed vehicle types in platoons that would reduce travel times, fuel consumption, and labor costs. In some applications they use a fixed-guideway system. Platooning concepts require advanced safety systems to ensure that vehicles can travel at very close headways and, in some cases, also require the development of a fixed guideway and specialized vehicles. The close spacing is designed to improve throughput and speeds, while also improving fuel economy through reduced aerodynamic drag. One key challenge for the commercialization of these systems is that similar technologies (e.g., cooperative adaptive cruise control) are currently in development for conventional automobiles. These systems could provide many of the benefits of platooning without the need for developing an alternative modal system.

Hybrid Mode Concepts

Hybrid mode systems combine the functionality of two different transportation modes. In theory, this allows users to take advantage of the benefits of both modes. For example, a hybrid highway–rail vehicle could take advantage of the flexibility of highway travel and the fuel economy of rail transportation. A specific example of a hybrid mode that is progressing toward commercialization is the concept of a "roadable aircraft," such as the aircraft developed by Terrafugia. The on-road capabilities of this aircraft allow it to use the regular road system to cover the distance between the airport and the traveler's ultimate origin and destination, thus removing much of the inconvenience of changing modes. The infrastructure needed to implement these types of approaches often includes interchange stations or facilities and potentially more significant infrastructure when the second mode is not in common use already. In addition, significant vehicle design changes would be required for many systems. The need to operate safely in two different modal environments may require design compromises that increase cost, add weight, or reduce fuel economy. Such systems can also face development challenges because of regulatory issues related to the demands of meeting two different, and potentially conflicting, sets of safety and emissions rules.

Tube Transportation

Tube transportation refers to a set of concepts for very high-speed intercity travel using capsule-like vehicles propelled through tubes that have been fully or partially evacuated to reduce aerodynamic resistance. Entrepreneur Elon Musk's Hyperloop concept, proposed for implementation in California, is a high-profile example. There are other examples of this approach, and multiple competing concepts exist for the specifics of vehicle design, propulsion, and operation. Tube transportation is a surface concept, but its high speeds of potentially 1,300 km/h (800 mi/h) and its limited, long-distance route corridors would likely make it more of a natural comparison to aviation than to automobiles and transit systems. The technology for this concept is still under development, and its cost-effectiveness is not known. The very high speeds also present challenges for right-of-way alignment and passenger comfort while the low-oxygen environment of the tube could require robust emergency protocols and onboard life-support systems.

Infrastructure-Based Vehicle Charging

Mobile recharging of EVs would address some of the key limitations of market penetration and foster greater use of vehicles with no tailpipe emissions. These concepts comprise various forms of recharging for vehicles while traveling on the roadway, usually through contact or near contact with a new form of dedicated infrastructure. A variety of systems have reached the prototype or demonstration phase, but the cost-effectiveness and commercial viability of more widespread deployments has not yet been shown. These systems also generally do not address the limitations of automobile travel, in particular congestion, high vehicle ownership costs, and limited options for non-drivers.

Powered Exoskeleton

Powered exoskeletons are wearable suits that use motors to provide additional power to the wearer's limbs, thereby increasing strength and improving endurance. Several prototypes have been designed for use in military and other settings and for people with mobility impairments. At least one product is in commercial use overseas. If commercialized more broadly for the general public, these kinds of suits would reduce exertion and fatigue on walking trips and could expand the distance that travelers are willing to walk to destinations and other travel modes. In turn this could increase the role for pedestrian trips and mitigate the last-mile problem associated with fixed guideway transit. Reaching this level of consumer acceptance would likely require significant advances in cost, weight, and ease of use. More familiar technologies to augment human power, such as electric-assist bicycles, may provide similar benefits in terms of increasing the radius of non-motorized trips.

Personal Mobility Vehicles

Personal mobility vehicle is an umbrella term for a variety of low-speed, single-passenger motorized vehicles that may travel on sidewalks, public roads, and in some cases, within buildings and elevators. Seated and standing prototypes have been tested in Japan, where the primary intended market is the rapidly aging population. Some vehicles are piloted by the user and others have self-driving capabilities. These vehicles can greatly expand the mobility options of those who have physical difficulties with driving and walking. Unlike the current generation of mobility scooters, many of these vehicles are intended to have both in-building and on-road capabilities, which raises an additional series of engineering and safety challenges.

Self-Driving Electric Shuttles

Self-driving electric shuttles are low-speed, fully automated (driverless) EVs that can serve as multi-passenger shuttles and on-demand personal transport within a defined area. They are typically envisioned for controlled environments, such as campuses and military bases, or for urban areas with little or no vehicle traffic. There are a range of vehicle types and sizes, ranging from small pods to minibuses. Active field operational tests are underway in the United States and Europe, including the U.S. Army's Autonomous Robotics for Installation and Base Operations series of pilot programs and the European CityMobil2 program. For campuses and certain other environments, the self-driving electric shuttle concept offers some of the advantages of PRT and ATN systems with additional flexibility to add or modify services without the challenges of developing an entirely new fixed-guideway infrastructure. Further advances in sensor systems are needed before widespread adoption can be expected.

Shared Fleet of On-Demand Self-Driving Vehicles

A shared fleet of on-demand, self-driving vehicles is a novel mode primarily in its business model and operational concept, rather than in the vehicles themselves or the highway infrastructure. It is possible that some upgrades may be needed to enable fully automated operation (e.g., improved pavement markings and onboard sensing). The concept, which has been articulated in various forms in research publications, is predicated on replacing the current paradigm of personal automobile ownership with the idea of "mobility as a service." Mobility would be provided by a shared fleet of self-driving taxis that could be summoned on-demand by using mobile technology. Compared with conventional taxicabs, this concept envisions shorter wait times and greater availability through centrally coordinated fleet optimization, as well as the ability to offer significantly lower fares because of reduced labor costs. Because cars currently spend most of their time parked, this approach would allow personal mobility needs to be met with a much smaller vehicle fleet, yielding economic and environmental benefits. The approach could also incorporate changes to vehicle propulsion, such as electrification, particularly because the fleet approach could yield economies of scale with the necessary fueling infrastructure. At the same time, some simulations have shown that this approach can actually increase overall vehicle–miles traveled, and therefore also emissions because of the repositioning movements of empty vehicles between trips. The wait times can also grow significantly during times of peak demand. This concept would require significant cultural change to implement, as most motorists are accustomed to having their cars immediately available and commonly leave personal items in the vehicle between trips.

Summary

A brief summary of the major modal concept types considered by the project research team is shown in table 2.

Observations

All of the proposed novel modes are unique in some way; however, several of them have attributes in common. These shared attributes are summarized in the following section.

Motor Vehicle-Based Systems

The majority of concepts reviewed by the research team focus on a motor vehicle, but a few concepts propose a new cycling or pedestrian infrastructure. There were relatively few operator-powered transportation concepts.

Heavy Infrastructure Demands

Several of the concepts envision an extensive and entirely new infrastructure that may be elevated, at grade level, or sub surface. These systems must provide a corresponding large level of benefit to justify their cost and impact on an already crowded built environment. Examples of these systems include evacuated tube transportation systems, variations on maglev technology, and some PRT and ATN systems.

Table 2. A summary of major modal concept types.

Concept	Infrastructure	Vehicles/ Propulsion	Automation	Business Model(s)	Markets/ Scale/ Locations
PRT/ATN	Fixed guideway rail or similar	Small electric rail vehicles	Fully automated	Public service	Local passenger transport, campus or urban center
Platooning/ Quasi-Rail	Modified roadway or new fixed guideway	Conventional or modified automobiles	Partial to full automation	Public service or fee-for-service	Passenger and freight on highways and major routes
Hybrid Mode	Existing infrastructure from two or more modes (e.g., roads and airports)	Varies	Generally not a key component	Individual or shared vehicle ownership	Varies
Tube Transport	Evacuated tube system	Specialized transports	Fully automated	Fee-for-service	Intercity passenger transport on major corridors, possibly very light freight
Infrastructure-Based Vehicle Charging	Charging equipment in roadway	Electric vehicles, potentially with modifications	Varies	Public service or fee-for-service	Passenger and freight on equipped roadways
Powered Exoskeleton	Existing infrastructure (sidewalks)	Electric assist to human power (wearable suit for pedestrian)	None to partial	Individual or shared ownership	Local passenger transport
Personal Mobility Vehicle	Existing road and sidewalk infrastructure and indoors	Very small electric vehicle	Varies	Individual or shared vehicle ownership	Local passenger transport and indoor movements
Self-Driving Electric Shuttles	Existing infrastructure	Small- to mid-size electric vehicle	Fully automated	Public service	Passenger transport on campuses and in some urban centers
Shared Fleet of On-Demand Vehicles	Existing road infrastructure	Automobiles	Fully automated	Fee-for-service	Regional passenger transport within metro areas

Automation

Several of the concepts that the research team reviewed seek to minimize human labor. This is typically to reduce labor costs, address human factors issues, improve safety, and expand operational capabilities.

Diversity in Deployment Scale and Scope

There are large variations in the degree to which the novel modes are intended to disrupt the current transportation marketplace. Some are small scale or niche products that are intended only for certain environments (e.g., institutional campuses or central business districts). Other concepts envision more widespread use but with a strong focus on serving only certain types of trips (e.g., long-distance travel). A few concepts envision that the novel mode will lead to near-total replacement of current road and rail networks.

Outlook

Many of the reviewed concepts are in an early stage of development, which means it is not possible to meaningfully evaluate their potential. The project team identified the following features as highly relevant to the potential of many of the concepts to be adopted.

Changing Transportation Landscape

Many of the concepts reviewed by the research team are motivated by long-standing transportation issues, such as highway congestion and vehicle emissions; however, the transportation landscape is changing. Changes in vehicle automation, wireless technologies, improved materials and batteries, and vehicle ownership models could increase the safety, convenience, and fuel efficiency of the existing transportation system to the point where they diminish the business case for many novel modal concepts.

Automation

The concept of automation promises to improve roadway operations without requiring massive additional infrastructure investment of changes in travel behavior. Market-ready automation of automobiles and transit vehicles could make the development of other modes unnecessary or less cost-effective. For example, many of the concepts reviewed in this project are based on the idea of on-demand fixed-guideway service; however, a fleet of on-demand automated vehicles could provide on-demand service to a wider service area, without the associated costs of maintaining a dedicated guideway.

Vehicle Sharing

As vehicle-sharing options become more familiar over time, and as more businesses and transportation infrastructure cater to them, the increased usage of such services may result in reduced personal vehicle ownership and changes in mode choice associated with vehicle-sharing options. This could encourage the adoption of a novel mode that supports car-sharing services. Car sharing might also be a mechanism for addressing last–mile issues with many transit-oriented modes. It is also possible that car sharing may provide the ease of automobile usage without the need for ownership and may reduce transit usage for some parts of the population. This may be dependent on the segment of the population in which the greatest car-sharing growth occurs.

Electric Vehicles

The combination of wireless and inductive charging opportunities; improved batteries that enable more efficient, environmentally-friendly energy storage; and lightweight vehicles made from innovative composites is likely to drive improvements in EV range, cost, and environmental profiles. This kind of development would tend to diminish the value proposition for some of the proposed novel modes that are predicated largely on saving energy through new modes or infrastructure. A counterpoint here is that existing strains on the national electric grid may need to be resolved before EVs can be fully implemented, even with improvements in battery storage. A flexible grid in which one can provide power to the grid or draw from it would be ideal.

Federal Infrastructure Funding

Federal infrastructure funding from the Highway Trust Fund has been reduced, and competing budgetary obligations (e.g., military and social security) have also reduced funding in this area. This is particularly significant for concepts that require large-scale changes in infrastructure.

Opportunities

There may be opportunities for novel modes to complement the transportation innovations that are being "pushed" by these technological shifts. Ongoing developments in vehicle automation could provide enabling technologies or synergies for novel modes that are based on automated operation. In addition, complementary approaches to addressing last-mile issues, such as car- and bicycle-sharing schemes, may facilitate the deployment of transit-oriented novel mode approaches. Such complementarity may be an important contributor to the success of novel mode implementation in coming decades.

EVALUATION CONSIDERATIONS

Novel modes include a combination of new technologies and new application of technologies that exist or are currently being developed. There are commonly accepted practices for evaluating novel technology maturity, but other considerations must also be weighed when considering the potential of a novel mode. Some of the elements that can be considered when evaluating novel modal concepts are outlined in the following section.

Technological Maturity

It is critical for developers and potential investors or customers to understand the maturity of technology. The appropriate next step depends on the maturity of a technology and may include further research, bench testing in a laboratory, a naturalistic trial in the field, or implementation. Technology readiness level (TRL) scales are widely used by U.S. Government agencies to evaluate the maturity of novel or developing technologies. For example, the Department of Defense (DOD) and National Aeronautics and Space Administration both use technology readiness assessments when considering novel applications. This tool has also been adapted for bioenergy technology development and for the EAR Program. The adapted TRL scale used by the EAR Program is shown in table 3.

Technology readiness assessments start with the observation of a phenomena that could potentially provide an opportunity (TRL 1). This is followed by the invention of an approach to take advantage of the observed phenomena or opportunity (TRL 2) and experimental exploration and proof of concept (TRL 3–4). The next levels involve

Table 3. The EAR Program's technology readiness level for highway research scale.

	Technology readiness level (TRL)	Description	To achieve the given TRL, you must answer yes to Every question. Discuss any uncertain answers.
Basic Research	**1**	Basic principles and research	• Do basic scientific principles support the concept? • Has the technology development methodology or approach been developed?
	2	Application formulated	• Are potential system applications identified? • Are system components and the user interface at least partly described? • Do preliminary analyses or experiments confirm that the application might meet the user need?
	3	Proof of concept	• Are system performance metrics established? • Is system feasibility fully established? • Do experiments or modeling and simulation validate performance predictions of system capability? • Does the technology address a need or introduce an innovation in the field of transportation?
Applied Research	**4**	Components validated in laboratory environment	• Are end-user requirements documented? • Does a plausible draft integration plan exist, and is component compatibility demonstrated? • Were individual components successfully tested in a *laboratory environment* (i.e., a fully controlled test environment where a limited number of critical functions are tested)?
	5	Integrated components demonstrated in a laboratory environment	• Are external and internal system interfaces documented? • Are target and minimum operational requirements developed? • Is component integration demonstrated in a *laboratory environment* (i.e., a fully controlled setting)?

Table 3. The EAR Program's technology readiness level for highway research scale.

	Technology readiness level (TRL)	Description	To achieve the given TRL, you must answer yes to Every question. Discuss any uncertain answers.
Development	**6**	Prototype demonstrated in relevant environment	• Is the operational environment fully known (i.e., user community, physical environment, and input data characteristics as appropriate)? • Was the prototype tested in a realistic environment outside of the laboratory (i.e., a *relevant environment*)? • Does the prototype satisfy all operational requirements when confronted with realistic problems?
	7	Prototype demonstrated in relevant environment	• Are available components representative of production components? • Is the fully integrated prototype demonstrated in an *operational environment* (i.e., real world conditions, including the user community)? • Are all interfaces tested individually under stressed and anomalous conditions?
	8	Technology proven in operational environment	• Are all system components' form, fit, and function compatible with each other and with the operational environment? • Is the technology proven in an operational environment (i.e., does it meet target performance measures)? • Was a rigorous test and evaluation process completed successfully? • Does the technology meet its stated purpose and functionality as designed?
Implementation	**9**	Technology refined and adopted	• Is the technology deployed in its intended operational environment? • Is information about the technology disseminated to the user community? • Is the technology adopted by the user community?

validation, scale up, and prototyping (TRL 5–7), followed by full-scale demonstration and testing (TRL 8). The final level is commercialization (TRL 9).

There can be one or several "exit criteria" for each level that demonstrate completion of that TRL. For example at TRL 2 (i.e., formulation of technology or application concept), DOD dictates that the proponent has begun invention of the technology or application, but these are still speculative. The exit criterion is to have published papers or other works that outline the application or technology under consideration, with some supporting analyses. Once this has been completed, the technology or application is considered TRL 2 and working toward TRL 3.

An evaluator who wants to understand the technical readiness of a novel mode or technology could request a rigorous self-assessment by the novel mode proponent by using a TRL scale, with documentation and data to support the self-assessment. An alternative option could be for an evaluator to attempt to perform a TRL evaluation with the information provided by a proponent, although such an evaluator-estimated TRL will likely be constrained by the available information.

Environmental, Social, and Economic Sustainability

In addition to the technical maturity of a novel mode, there are other considerations that may influence the assessment of viability. These can include environmental, social, economic sustainability, and viability issues as well as considerations related to the regulatory landscape. In this project, the term *sustainability* includes environmental, social, and economic aspects. A sustainable activity is considered to be one that can be maintained without resources over time.

Environmental Performance

Improved environmental performance is often a key selling point for novel modal concepts. There are many environmental challenges associated with existing modes that could be avoided with advance consideration. Therefore, novel mode evaluations should assess overall environmental performance and the relative performance of a novel mode compared with existing modes that would be replaced.

Environmental benefits may include improved fuel efficiency or use of alternative propulsion options that reduce dependence on fossil fuels. This approach would reduce GHG emissions and improve local air quality while avoiding other environmental issues associated with fossil resource. Other secondary environmental elements may also be integrated into the design (e.g., rainwater capture and green roofs or walls). Large-scale infrastructure development, however, particularly with a substantial land area footprint, may lead to the release of carbon from land-use change (i.e., a change in land surface area from carbon-sequestering vegetation to man-made surfaces). In addition, the production and installation of any infrastructure will also carry an initial release of life-cycle GHG emissions that must be counted against the potential benefits of a novel mode during the payback period. Moreover, infrastructure installation may affect biodiversity, storm-water runoff, hydrology and other ecosystem functions, wetlands, and endangered and threatened species. Developers and evaluators of novel modes should be aware of these and other environmental considerations, particularly those required to be considered under the

National Environmental Policy Act of 1969 (42 U.S.C. § 4321 et seq.). Regulatory and funding agencies must also consider the potential environmental impacts and benefits of a novel mode as part of the evaluation.

Social Sustainability

The term *social sustainability* reflects the societal acceptance and equity of an activity. For novel modes, the primary social need is to address safety. This not only applies to the technical performance of a novel mode (e.g., crash rates, redundancies, and monitoring of vehicle and infrastructure condition) but also to usage modes (e.g., late-night service and vehicle sharing). Safety is likely to be the highest priority for regulatory agencies and community planners. Evaluators who assess novel modes should expect failure-mode analyses for infrastructure, vehicles, and a variety of use cases. Social acceptability will also be affected by perceptions of the novel mode's impact on issues like property values, visual landscapes, privacy, and equal access to transportation. The evaluator should expect the proponent to be able to describe potential impacts on environmental justice communities (e.g., placement of infrastructure, accessibility, or cost).

Economic Sustainability

The term *economic sustainability* is focused on economic feasibility and equity. Any evaluation of a novel mode will assess the business model and market. An evaluator should consider whether the novel mode proponent has identified the target user population, analyzed users' willingness to pay, and addressed any cultural or psychological barriers to novel mode adoption and use. A viable business model will need to be identified that covers the operational costs of the system, provides a return on invested capital, and has reasonable administrative costs. This model may be based on user fees, device sales, subscriptions, public subsidies, or other revenue streams.

The scale and scalability of a novel mode will have critical implications for economic viability. Questions for an evaluator to consider include, at what scale will an installation break even? Can the mode easily be expanded or scaled up? Will there be intermediate benefits prior to full-scale implementation? The intended ownership model of the mode is also a critical consideration. It will be critical to establish how society will finance the development and deployment of a novel mode. For example, will it be a public–public, public–private, or private–private ownership model? Likewise, who will pay for changes in existing modes to accommodate interfacing with the novel modes? Who will pay for modal failures in service, performance, or safety? Who is responsible for long-term maintenance? Economic sustainability considerations may also include the ability to pay a living wage to workers across the pay scale.

Reliability and Resilience

Reliability and resilience are also components of long-term system viability. Reliability refers to consistency of operations and performance (e.g., travel time, on-time performance, and energy or fuel efficiency) as well as the level of ongoing maintenance and repair. Resilience measures focus on tolerance to a variety of conditions or the ability to rapidly recover from changes in conditions or disruption. In many cases, the design considerations for reliability and resilience may be the same. For example, duplication of critical components of a system (i.e., redundancy) may make an overall system both more reliable and more resilient with backups and fail-safes in place to maintain performance and avoid disruption. In other cases, the approach to reliability and resilience may differ. For example, to maximize system reliability and ongoing performance, one might focus on overbuilding of facilities or "hardening" against issues like extreme weather events; however, to maximize resilience and the ability to quickly recover from disruption, one might intentionally allow certain portions of the system to fail if that means that the overall system can quickly and inexpensively be brought back online after failure. Evaluators who assess novel modes should include estimates of ongoing reliability of performance, ongoing maintenance and repair requirements, and expected system tolerance to environmental and economic conditions. Novel modes that focus on coastal or low-lying areas may be particularly vulnerable to extreme weather events or climatic variations and should be evaluated for resiliency to inundation, storm surge, and high winds in particular. Those modes that rely on proprietary replacement parts or a consistent high level of maintenance may prove vulnerable to supplier issues or reduced operational budgets. Failure-mode analyses address reliability and resilience issues.

Regulatory Challenges

Technical readiness and sustainability performance of a novel mode can both be addressed; however, the novel mode may never reach commercialization without appropriate regulatory systems in place to enable novel mode development and implementation or to reduce barriers to entry into the marketplace. Regulatory frameworks vary by mode in that some modes are regulated at the Federal level and others may be regulated by State or local agencies. For entirely new modes, regulatory oversight may be unclear. Novel mode proponents need to be aware of regulatory requirements for their proposed mode, and this should also be a consideration for viability when evaluating a proposal. For example, use of and interchange with existing infrastructure (e.g., highway or railway right-of-ways) requires an understanding of the associated legal and regulatory restrictions. In addition, occupational health and safety regulations, environmental regulations and land-use restrictions, ownership considerations, and national and international standards all need to be considered as part of any novel mode implementation and should be addressed as early as possible in the novel mode design, development, and implementation.

Roles in Transportation Innovation

Public and private sector organizations have complementary, and sometimes overlapping, roles to play in transportation innovation. A brief overview of these organizations and their roles is outlined in the following sections.

Federal Level

At the Federal level, the USDOT and other agencies support transportation innovation through direct funding of research and demonstration projects. Additional support is available through technology transfer, access to test beds and research facilities, and other supporting activities, such as standards, outreach, policy guidance, and international harmonization. Federal investment in innovation is driven by each agency's mission, and the topics that are selected will typically have broad-reaching applications.

State and Local Agencies

State and local agencies, including State DOTs, localities, and regional transit authorities, are the entities that own and operate most of the country's highway and transit systems. As such, they are typically the primary "customers" for innovative products. These agencies are often constrained by budgets and procedural requirements, but some agencies are actively fostering innovation through demonstration projects, streamlined processes, and partnerships. In more limited cases, they may also provide direct research funding for projects with high local relevance.

Private Sector

The private sector works to identify and develop new transportation concepts and business models that will generate a return on investment. This may include advocacy for modes and projects and collaborative efforts to work on technical standards or other industrywide priorities.

Universities and Research Institutes

Universities and research institutes typically support earlier stage R&D projects and feasibility studies. Academia also plays an important role in the evaluation of projects and concepts. This role includes evaluation of environmental impacts, technical performance, cost-effectiveness, and overall societal impact.

Findings

The following pages summarize major findings regarding innovation context and challenges and opportunities for novel modal systems.

Innovation Context

The major findings regarding innovation context for novel modal systems are summarized in the following sections.

Transportation Innovation

Transportation innovation has historically been mostly incremental rather than revolutionary. A review of transportation history suggests that today's highway, transit, and freight systems are the products of decades of incremental improvements in areas such as vehicle propulsion, control systems, materials, and telecommunications. Transportation investments have long time horizons and have almost always involved interaction between the public and private sector. The success of new concepts has been influenced at least as much by legal and institutional considerations as by technological ones.

Current Road and Transit Systems

Current road and transit systems offer high levels of mobility and convenience. Although new transportation concepts may provide significant advantages in travel speed, emissions, or other service characteristics, they will also likely need to provide comparable levels of personal convenience and flexibility to be considered as alternatives. For example, roadways are simple and offer a flexible deployment environment for a wide range of uses. New concepts like bus rapid transit and bike sharing can be incorporated into the transportation system without major modifications.

Partial Automation

Passenger and freight transportation are both introducing partial automation. The development of semi-automated systems offers efficiency improvements without the need for dedicated right-of-way. For example, freight distribution centers can process shipments more quickly with automated systems, and automotive "driver-assist" systems may improve highway throughput and safety. These developments are still ongoing but offer the possibility of addressing some of the limitations of current transportation modes.

Personal Travel Patterns

Personal travel patterns are in transition. Survey data show shifts from "maintenance" travel (e.g., commuting or errands) to other trip purposes. Travel patterns are also shifting to more situational, rather than habitual, mode choice, and attitudes toward transportation are changing among younger age groups. In addition, concurrent technological and societal changes have influenced the overall need to travel and have introduced a range of substitutes for travel, such as videoconferencing and social media.

Challenges

The major findings regarding challenges for novel modal systems are summarized as follows.

Connections to Existing Modes

New concepts need to consider connections to existing modes and the whole trip chain, including the first and last mile. The relatively low-density land-use patterns in the United States make it difficult for fixed guideway systems to transport all passengers to the doorstep of their ultimate destination, particularly outside of highly developed urban centers. Because travelers tend to place a strong premium on one-seat rides and view transfers as undesirable, any transitions should be as seamless as possible.

Passenger Comfort

Increased attention to passenger experience and comfort is warranted. Passenger comfort (e.g., vehicle interiors, seating, and windows) and the overall passenger experience exerts a strong influence on mode choice and will need to be addressed as new transportation concepts move forward. In particular, high travel speeds will require careful management.

Travel Demand

Forecasting travel demand and mode choice has become more difficult in general and even more so for novel modes. After decades of fairly steady growth, there have been significant fluctuations in vehicle-miles traveled in recent years. This has caused several public and private traffic forecasts to miss the mark. Personal travel patterns are also in transition, which makes it more difficult to forecast overall travel demand and mode shares. This challenge is even greater for novel modes as there is little to no historical data to draw upon, and consumer demand is difficult to estimate for entirely new concepts.

Risk Management

Potential investors in transportation systems place a strong emphasis on managing and mitigating risks. For the public sector in particular, there are often concerns about system complexity, reliability, and maintenance requirements because of fluctuating budgets and workforce issues. Agency budgets often go through lean periods when routine maintenance may be neglected, so it is important that the assets be robust to that kind of neglect. The rigidities of the public procurement process can also limit investment in novel technology. For the private sector, the issues are somewhat different, but there is still a strong focus on risk management. Key issues include developing a business model (i.e., a viable means of generating revenues from the system) and the potentially long time periods before initial investments are repaid. As a result of these risk considerations, investors in both the public and private sectors have a preference for time-tested technology and systems that are easier to build, operate, and maintain.

Opportunities

The research team's major findings regarding opportunities for novel modal systems are summarized below.

Federal Research Programs

Novel modes and their underlying technologies may have other applications that would be of interest to Federal research programs outside of USDOT (e.g., DOD, the Department of Health and Human Services (HHS), and DOE). Innovators should consider whether there are non-transportation applications of the underlying technologies that may attract research funding in fields such as defense, health, or energy. There are many examples of new products being commercialized outside their initial focus area.

State and Local Agencies

Some State and local agencies are actively pursuing transportation innovation. Jurisdictions such as the State of Texas and the City of San José, CA, have established innovation zones, made changes to their procurement processes, and implemented public–private partnerships and other initiatives to facilitate the development of new transportation concepts. Although these agencies, and others like them, are in the minority within the public sector, they represent an opportunity to partner with a public agency that is willing to address its barriers to innovation head on to develop improved transportation services.

Changes in Travel Patterns

Changes in travel patterns are breaking the automobile "monoculture." Private automobiles continue to predominate in surface transportation, but survey data have begun to show lower driver licensure and vehicle ownership rates among younger age groups. This is accompanied by a greater willingness to use new concepts such as bike sharing, car sharing, and mobile applications. This suggests greater openness to new transportation modes that are developed.

University Partnerships

University partnerships can help with research, modeling, and demonstrations. University partnerships can include student research projects, independent validation, use of test facilities, development of prototypes, or other work. In addition to the practical benefits of these partnerships, the association of a university with the concept can help the concept gain traction and greater visibility.

Standards Setting

Standards setting can accelerate innovation in some cases. Workshop participants at the EAR Program's Novel Surface Transportation Modes workshop in December 2014 discussed situations in which standards can foster or stifle innovation. Many participants said that standards could be helpful in the development of PRT and ATN systems by reducing the risk of dependence on a single supplier or maintenance organization for long-term system viability. The Federal Government, or public sector, does not need to set these standards but in some cases could be a convener and bring stakeholder groups together. In other cases, professional associations and other standards-setting bodies may take the lead.

Specific Applications

Novel mode concepts should focus on specific applications in which they may be more viable as a niche product for certain trip types or settings. For some novel mode concepts, the most relevant near-term applications may be in specific trip types or operating environments, such as campus settings, urban centers, or small freight shipments. Other systems may also be best suited to overseas emerging markets, where the existing transportation infrastructure is more limited.

FUTURE RESEARCH AND SUPPORT NEEDS

Based on the major findings noted in the previous sections, the research team identified several areas where USDOT could enhance its support of new concepts in surface transportation. These are outlined in the following pages.

Technical Assistance

Technical assistance could be provided to State and local agencies on how to reduce institutional barriers to innovation. Some of the barriers identified include inflexible public procurement processes, workforce issues, and budget uncertainties. The promotion of information exchange is an established Federal role in transportation, and the USDOT already has several programs that promote peer-to-peer learning among State and local agencies. One possibility would be a case study or "lessons learned" research based on selected local agencies that have had prior success in this area.

Improved Access

Improved access to Federal research facilities and test beds is another area where USDOT could enhance its support of new concepts. Where security and other considerations permit, providing greater access to these facilities would allow innovators to test and refine their concepts and gather data that can be used for evaluation. The availability of test beds is an important part of moving toward greater technological readiness. Moreover, evidence of successful and safe operation in a closed setting is often required before transportation agencies will entertain the prospect of a demonstration project on public roadways.

Travel-Demand Forecasts

Further research into improving travel-demand forecasts and mode-choice models would help to support new concepts in transportation. The evolving transportation landscape, demographic and attitudinal changes, volatile fuel prices, and other factors have made it more difficult for planners and modelers to forecast travel demand and mode choice. This has presented challenges for both conventional and novel modes, but improved modeling capabilities are particularly important for assessing the viability and cost-effectiveness of new concepts.

Outreach Activities

Outreach to connect innovators with Federal programs and universities is another area where USDOT can enhance its efforts. USDOT can help to connect transportation innovators with its existing programs, such as the Small Business Innovation Research program and the EAR Program, as well as foster connections to related programs at other Federal agencies. Universities are also a potentially valuable source of research and evaluation support for novel concepts. USDOT can play a role in facilitating outreach between innovators and universities, either through informal outreach or more formally through the University Transportation Centers Program.

Testing and Validating

Further research into new paradigms for testing and validation of complex systems would also help to support new concepts in transportation. Concepts involving artificial intelligence or automation often cannot be adequately tested using conventional methods and must incorporate simulation and other elements into their validation approaches. This is an emerging area with many current research efforts, and it is an important one for novel modes because of the risk-averse nature of many transportation agencies. USDOT could have a role to play in sponsoring further research in this area and disseminating findings.

Testing, Standards, and Certification

Support is also needed for independent testing, standards, and certification. Novel transportation modes are likely to require standardization to address investment, safety, and operational risks before they become economically and socially viable. USDOT could work with the National Institute of Standards and Testing, or private independent standards and testing institutions, to set specifications and protocols for an incipient technology. This would aid in developing and establishing consistent standards and compliance testing for infrastructure and operations of novel modes.

CONCLUSION

This report on FHWA's novel surface transportation modes research, sponsored by the EAR Program, discusses the current state of novel surface transportation modal concepts, identifies opportunities and challenges for these concepts, and presents a set of potential future research and technical support needs. Information in this report has been summarized from research on novel modes along with the viewpoints shared at the Novel Surface Transportation Modes workshop, convened by the EAR Program in December 2014.

Transportation technologies evolve over time in response to changing societal needs and technological advances. The 20th century saw the rise of privately owned motor vehicles traveling on public roadways as the dominant surface transportation in the United States, complemented by bus and rail services. These conventional modes provide a very high level of mobility and flexibility and set a high bar for novel modes to overcome in garnering public interest and market share. Interest in novel concepts remains high, in part because of high societal costs and other limitations of current modes.

Modal concepts reviewed in this project were largely relatively early in their technical maturity, although a few are closer to implementation. Each concept is unique, though many involve common elements such as automation and advanced propulsion and control. Some concepts have been designed for widespread adoption and displacement of current modes, whereas others are highly targeted to particular applications. As documented previously in this report, changing personal travel behavior and societal needs, along with emerging technological innovations, could present challenges for these novel modes but may also spur demand for new mobility options. USDOT will continue to monitor these developments and fund critical transportation research to improve passenger and freight transportation system in the United States.

The research team for this study identified four key outstanding challenges common to novel mode development. These challenges include (1) addressing connections to existing modes and last-mile issues, (2) increasing attention given to passenger experience and comfort, (3) improving accuracy of predicting travel demand and mode choice, and (4) enhancing management and mitigation of risk from an investor perspective.

Researchers for this study also identified six key opportunities for innovators that are common among novel modes. These opportunities include:

- Engaging with Government agencies outside of the transportation sector (e.g., DOD, DOE, or HHS).
- Engaging with State and local agencies.
- Addressing changes in travel patterns and a greater openness to new transportation modes.
- Working with universities for testing, prototype development, and research.
- Working together to develop standards in collaboration with Government and other stakeholders.
- Taking advantage of unique settings that may be most conducive to a new transportation system (e.g., self-contained campuses, airports, and other facilities) or to a specific market (e.g., freight, passenger, or locations with limited, legacy infrastructure such as with emerging economies or significant shifts in land-use and settlement patterns).

By taking advantage of these opportunities, innovators would be able to address many of the key concerns relating to investor and societal risk of adopting novel modes and would enhance the likelihood of investment.

The research team also identified six opportunities for USDOT to facilitate the development and deployment of novel modes. These opportunities include:

- Providing technical support to State and local agencies to reduce barriers to innovation.
- Supporting access to Federal research facilities and test beds.
- Improving travel-demand and mode-choice models.
- Facilitating connections between innovators and university and Government researchers.
- Developing novel testing facilities and paradigms.
- Supporting independent testing, standardization, and specifications.

Addressing these opportunities would greatly enhance the societal environment for innovation with regard to novel transportation modes within the United States.

Appendices

APPENDIX A: LIST OF RFI RESPONDENTS

Project Title	Submitter
Advanced Transportation Technologies, New West Technologies	Greogory Wilcox
Airbornway Corporation	Ramesh B. Malla
Beamways AB	Bengt Gustafsson
BeemCar Ltd.	Peter Lovering
BiModal Glideway	William D. Davis, Jr.
BM Design Oy, Bubblemotion	Asko Kauppi
CargoFish Physical Internet	Robert DeDomenico
CyberTrain International	Neil B. Sinclair
Davidheiser Design and Third Generation Roadway	Roger Davidheiser
Electrodynamic Wheels	Jonathan Bird
Elways AB	Gunnar Asplund
ET3	Daryl Oster
Fastran	Ennis C. Sullivan II
Freedom Transit, Solar Transportation Technologies	Jim Beregi
(Hybrid-) Electric Roadtrains	Bruce McHenery
Hybrid Personal Transport, Inc.	Thomas Pumbelly
Innov8Transport	Patrick Kennedy
Interstate Traveler Co.	Justin Sutton
LeviCar Unlimited	Josh Levi
Lumod GmbH, Speedway	Christian Foerg
Magna Force, Inc., Lev X	Jo Klinski
MonoCab VRT	David Whittaker
Overland ATS, Elevated Dual Mode High Speed Rail	Waldemar F. Kissel, Jr.
Owen Transit Group	William E. Owen
SkyTran and The Ferguson Group	Bill Ferguson
SHWEEB-CAN	Robert Laurence
SwiftTram	Becky English
Taxi 2000, SkyWeb Express	Mike Lester
TEV (Tracked Electric Vehicle) Project	Caroline Carrick
Transit Control Solutions	Peter Muller
Tubular Rail, Inc.	Robert Pulliam
Tunnel Bus System	Li Mingshen
VECTORR™ Technology, Flight Rail Corporation	Max P. Schlienger
Zetta Research	Kim Rubin

APPENDIX B: SELECTION OF RFI RESPONDENT CONCEPT SUMMARIES

Project Title	Aerial Highway
Submitted by	Rodger L. Gibson, Airbornway Corporation
Summary	• Autonomous, freight/passenger car that runs on a light aerial cable from which it draws electricity.
Status	Proof of concept developed.

Project Title	Automated Transit Network
Submitted by	Eugene Nishinaga and Peter Muller, Transit Control Solutions/PRT Consulting Inc.
Summary	• New vehicular control algorithms implemented through Transit Control Solutions, which can integrate with existing commercial off-the-shelf products.
Status	1/32 scale model (45.72-m (150-ft track)) constructed. Tests conducted and findings are summarized in report. Software engineering currently in progress.

Project Title	Beamways Adaptive ATN System
Submitted by	Bengt Gustafsson, Beamways AB
Summary	• Automated transit network with adaptable vehicle size and platooning. • Vehicles suspended on elevated monorail system. • Solar-powered.
Status	Technology patented. Costing and guideway structural study completed. Simulation completed. University team working on system.

Project Title	BeemCar
Submitted by	Peter Lovering, BeemCar Ltd.
Summary	• Personal rapid transit system. • Lightweight pods suspended from a network of carbon fiber beams propelled by Linear Synchronous Motor and partly powered by solar energy.
Status	Seeking funding for demonstration.

APPENDIX B: SELECTION OF RFI RESPONDENT CONCEPT SUMMARIES

Project Title	**Bubblemotion**
Submitted by	Asko Kauppi, BM Design Oy
Summary	• Automated personal rapid transit system. • Vehicles travel on elevated rail.
Status	Static track strength simulations and cost–benefit analysis completed.

Project Title	**CargoFish**
Submitted by	Robert DeDomenico, CargoFish Physical Internet
Summary	• Initial phase: Track-based, underground, capillary network that delivers small payloads using small motor-driven traction drive track vehicles. • Secondary phase: Larger, heavier gauge arterial network is installed to move people and freight.
Status	Operational proof-of-concept prototype developed.

Project Title	**Comprehensive MagLev**
Submitted by	Joshua Levin, LeviCar Unlimited
Summary	• Vehicle body can attach to a road chassis for conventional driving or the maglev chassis/track for guideway transportation. • Dual mode. Vehicles can travel on existing streets.
Status	Hardware components built and tested together and functioned properly together as a prototype.

Project Title	**Drive on Drive off Truck Ferry**
Submitted by	Robert Pulliam, Tubular Rail, Inc.
Summary	• Expansion of the current national rail system to incorporate flatbeds (accommodating three to four trucks) into the rolling stock. • Trucks align on 18 m by 24 m (60 ft by 80 ft) flatbed perpendicular to movement of train. • Supporting rails on either side of the main track 9 m (30 ft) from the center.
Status	Technology patented and demonstration model built.

APPENDIX B: SELECTION OF RFI RESPONDENT CONCEPT SUMMARIES

Project Title	**Electric Dual Mode Skyway**
Submitted by	Travis Knapp, Innov8Transport
Summary	• Automated high-speed road/rail. • Wheel-wing technology that enables existing vehicles (e.g., car, bus, and truck) to dock onto road/rail. • On/off-board at designated locations. • Automated platooning.
Status	Full-scale wheel-wing latches have been built and tested.

Project Title	**Elevated Dual Mode High-Speed Rail**
Submitted by	Waldemar Kissel, Overland ATS, LLC
Summary	• Elevated steel rail infrastructure with electrified security rail in center. • Vehicles have bimodal wheels and multipurpose sensory saddle.
Status	Multiple patents issued and pending. Model and demonstration prototypes developed.

Project Title	**Hybrid Electric Roadtrains**
Submitted by	Bruce McHenry, Tommaso Gecchelin, and Dr. Tim Gordon, McHenry Enterprises
Summary	• "Combine" through mechanical coupling to form a single, train-like vehicle. • Hybrid-electric vehicles; range of the vehicle is not limited by storage of electricity. • Requires driver in the lead vehicle.
Status	Conceptual phase of development.

Project Title	**Hybrid Personal Rail Transit System**
Submitted by	Thomas Pumpelly, Hybrid Personal Transit, Inc.
Summary	• Infrastructure: Elevated electrified monorail located in a freeway median. • Modified vehicles drive onto monorail from roadway access points. Vehicles can use existing infrastructure. • Dual mode. Vehicles can travel on existing streets.
Status	Conceptual drawings prepared. Preliminary engineering designs for system components done. Simulations conducted.

APPENDIX B: SELECTION OF RFI RESPONDENT CONCEPT SUMMARIES

Project Title	**Hydrogen Super Highway**
Submitted by	Justin Sutton, Interstate Traveler Co., LLC
Summary	• Integrates elevated maglev transportation system with municipal conduit. • Solar-powered, converted to hydrogen power to self-sustain system. • Operating system will facilitate routing and position control.
Status	Computer simulations performed.

Project Title	**Infrastructure System for Powering Vehicles while Driving**
Submitted by	Gunnar Asplund, Elways AB
Summary	• Conductive system feeds all vehicle types (e.g., electric vehicles) electricity through rail in road while driving. • Conductors placed beneath the surface and only energized when a vehicle passes.
Status	Technology patented and demonstration model built.

Project Title	**Low-Cost Maglev Transportation Using Electrodynamic Wheels**
Submitted by	Jonathan Bird, University of North Carolina at Charlotte and Electrodynamic Wheels
Summary	• Maglev transportation using electrodynamic wheels passive guideway.
Status	Sub-scale force and three-dimensional eddy-current analyses complete. Sub-scale vehicle demonstration complete.

Project Title	**MonoCab VRT**
Submitted by	David Whittaker, MonoCab VRT
Summary	• Elevated guideways. • Propulsion by electrically powered drive trains at each end of vehicle, incorporates regenerative braking.
Status	Concept report and case studies prepared. Trailer mounted display model developed.

APPENDIX B: SELECTION OF RFI RESPONDENT CONCEPT SUMMARIES

Project Title	OTG HighRoad and Silver Bullet
Submitted by	William Owen, Owen Transit Group, Inc.
Summary	• Elevated, automated guideway with a T-shaped rail that supports two-way transportation. • Silver Bullet faster than HighRoad and designed for commuting.
Status	Engineering analyses, business plan, and ridership analysis complete.

Project Title	SkySMART
Submitted by	Robert Laurence, SHWEEB US-Fl. Inc
Summary	• Suspended, bi-directional, steel and hypercomposite guideway that operates above, below, or at ground level. • SMARTpods full automated. • Runs off of grid electric, solar, battery, and optional human power.
Status	Proof of concept completed. Final R&D in progress.

Project Title	SkyTran Automated Transit Networks
Submitted by	John Cole, SkyTran, Inc.
Summary	• An aircraft that "flies" within an elevated guideway system via magnetic containment. • Propulsion by "magnetic screw." Spinning magnet arrays within the tubular reaction rail induce eddy current forces that center and propel the magnet array axially within the rail. • Travels up to 241 km/h (150 mi/h) and can add up to three lanes of capacity.
Status	Working 1/5 scale prototype that demonstrates propulsion and levitation. Will soon demonstrate switching.

Project Title	Speedway
Submitted by	Christian Foerg, Lumod GmbH
Summary	• Long distance, electric propulsion for any vehicle. • Wandering magnetic field under the road powers vehicles and inductively charges their internal batteries.
Status	Initial technical test completed.

APPENDIX B: SELECTION OF RFI RESPONDENT CONCEPT SUMMARIES

Project Title	The TEV Project
Submitted by	Will Jones and Caroline Jones Carrick, TEV Project
Summary	• Restricted, electrified highway lane. • Rubber tired electric cars, driverless minicabs and buses, and automated-vehicle platoons can draw electricity from the track.
Status	Design studies, animations, and technical report developed.

Project Title	A Third Generation of Roadway
Submitted by	Roger Davidheiser, Davidheiser Design
Summary	• Light-weight vehicles that interface with track infrastructure electrically and autonomously, providing high-speed travel. • Dual mode. Vehicles can travel on existing streets.
Status	Scale model constructed. Studies performed.

Project Title	UltraLight Rail Transit
Submitted by	Neil Sinclair, CyberTran International
Summary	• Small, light, autonomous, high-speed passenger rail vehicles for long-distance commuting.
Status	Near full-scale test deployments developed.

Project Title	VECTORR™ High-Speed Passenger Rail
Submitted by	Max Schlienger and John Reardan, Flight Rail Corporation
Summary	• High-speed, elevated guideway system that uses vacuum/pressure to propel a free piston, magnetically coupled to the vehicle, for propulsion. • Stationary power systems can use a wide range of fuels, including electricity.
Status	1/6 scale prototype constructed. Testing conducted.

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