Electric Bicycle (E-bike) Trends, Impacts, and Opportunities: Literature Review Summary

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13. ABSTRACT (Maximum 200 words)

Electric bicycles (e-bikes) represent a rapidly growing transportation mode and evolving policy area in the United States. E-bikes present an opportunity to reduce car travel, improve health, and increase access for traditionally underserved populations; however, the relationship between e-bikes and safety, infrastructure, equity, and the environment are not fully understood and remain of interest to decision makers and potential riders. This literature review examines relevant sources through 2022 from North America, Europe, and Asia to develop a baseline understanding of e-bikes, their emerging role in the transportation sector, and how they may advance Federal transportation goals. The literature review begins with an overview of the legislative and regulatory context surrounding e-bikes in the United States at the national and State levels. It continues by examining existing research on the impacts of e-bikes on eight key topic areas: ridership trends; safety; physical activity and health; accessibility; equity; trail infrastructure and environment; energy and emissions; and freight use cases. Each topic area section also includes a summary of gaps in research and future research needs identified by the project team.

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Contents

1. Introduction

Electric bicycles (e-bikes) represent a rapidly growing transportation mode and evolving policy area in the United States. E-bikes are similar to traditional bicycles but have a small electric motor and battery. A classification system spearheaded by the Bicycle Product Suppliers Association and the bicycle advocacy coalition PeopleForBikes[1] uses a three-tier methodology to classify e-bikes and is considered the industry standard adopted by some Federal agencies and the majority of States. It was codified into title 23, United States Code (U.S.C.) in the Infrastructure Investment and Jobs Act (Public Law 117-58, also known as the Bipartisan Infrastructure Law) in November 2021 (23 U.S.C. 217(j)(2)). The classes are defined as:

- A "class 1 electric bicycle," or "low-speed pedal-assisted electric bicycle," is a bicycle equipped with a motor that provides assistance only when the rider is pedaling, and that ceases to provide assistance when the bicycle reaches the speed of 20 miles per hour.
- A "class 2 electric bicycle," or "low-speed throttle-assisted electric bicycle," is a bicycle equipped with a motor that may be used exclusively to propel the bicycle, and that is not capable of providing assistance when the bicycle reaches the speed of 20 miles per hour.
- A "class 3 electric bicycle," or "speed pedal-assisted electric bicycle," is a bicycle equipped with a motor that provides assistance only when the rider is pedaling, and that ceases to provide assistance when the bicycle reaches the speed of 28 miles per hour, and is equipped with a speedometer.

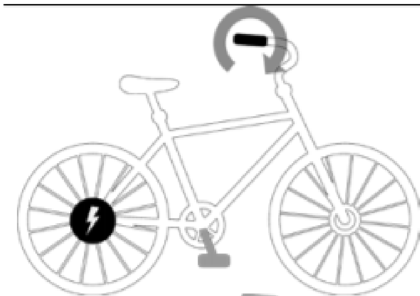
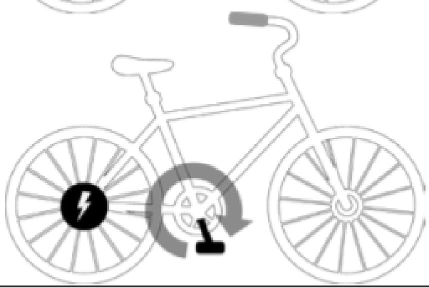
All classes limit the motor's power to one horsepower. Table 1 summarizes the characteristics of class 1, 2, and 3 e-bikes. The three-tier classification system includes two main types of e-bikes: pedal-assisted bicycles and throttle-assisted bicycles. A rider must pedal a pedal-assisted bicycle to engage the electric motor, whereas a rider uses a handlebar-mounted throttle to engage the electric motor of a throttle-assisted bicycle (Figure 1).

Table 1. E-bike characteristics based on classification

E-bike Class	Type of Electric Assistance	Top Assisted Speed
Class 1	Pedal	20 mph
Class 2	Throttle	20 mph
Class 3	Pedal	28 mph

[1] Bicycle Product Suppliers Association and PeopleForBikes merged in 2019, with PeopleForBikes taking over management of all Bicycle Product Suppliers Association business-oriented projects: https://2019.peopleforbikes.org/merger/.

Figure 1. Common e-bike types and terminology[2]

	E-bike type	Alternative terms [a]
	Powered bicycle (PB, E-PB)	**Throttle-assisted bicycle**; electrically propelled bicycle (EPB); electric bike power-on-demand (POD); on-demand bikes; motorized bicycle
	Power-assisted bicycle (PAB, E-PAB)	**Pedal-assisted bicycle**; electrically assisted bicycle (EAB); pedal electric cycle (**pedelec**); electric pedal assist cycle (EPAC); human-powered hybrids

[a] Bold indicates more commonly used terms in North America.

E-bikes have a number of applications as personally owned bicycles, in bike share fleets, for urban freight delivery, as adaptive bicycles that meet the needs of riders with different abilities, and as mountain bikes. E-bikes are generally charged using standard household power or, in the case of bike share systems, at docking stations.

E-bike use has grown rapidly in recent years. Advances in technology have enabled e-bikes to travel longer distances and have lowered costs, making them more affordable than ever before.[3] Demand for e-bikes in the United States has risen recently, with sales from bike shops and other retailers increasing from 273,000 in 2020 to 368,000 in the first eleven months of 2021. In addition, US imports of e-bikes, which incorporates direct-to-consumer sales, rose from 463,000 in 2020 to 790,000 in 2021, surpassing electric car imports.[4] In Europe, e-bike sales exceeded 5 million in 2021, bringing the market share of e-bikes among all bicycles to almost 25 percent electric.[5]

Communities have also incorporated e-bikes into their bike share fleets; the percentage of bike share systems deploying e-bikes increased from 28 percent in 2019 to 50 percent in 2021. The number of trips taken by shared e-bikes increased from 9.9 million in 2020 to 18.8 million in

[2] MacArthur, J., and Kobel, N. (2014) Regulations of E-Bikes in North America. Transportation Research and Education Center. https://pdxscholar.library.pdx.edu/trec_reports/126/.
[3] Salmeron-Manzano, E., Manzano-Agugliaori, F. (2018). The Electric Bicycle: Worldwide Research Trends. Energies. https://www.mdpi.com/1996-1073/11/7/1894.
[4] Boudway, I. January 21, 2022. America's Best-Selling Electric Vehicles Ride on Two Wheels. https://www.bloomberg.com/news/articles/2022-01-21/u-s-e-bike-sales-outpaced-electric-cars-in-2021.
[5] Sutton, M. July 7, 2022. European electric bike sales pass 5 million. https://cyclingindustry.news/european-electric-bike-sales-pass-5-million-all-bikes-22-million/.

2021, or 28 percent of all shared bike trips. When available in shared systems, e-bikes were ridden 36 percent more often than conventional bikes.[6]

The growth in e-bikes has a number of implications for policymakers and practitioners at the Federal, State, and local levels. E-bikes present an opportunity to reduce car travel, improve health, and increase access for traditionally underserved populations; however, the relationship between e-bikes and safety, infrastructure, and the environment—including the ability of e-bikes to reduce carbon emissions—are not fully understood and remain of interest to decision makers and potential riders.

This literature review examines relevant sources through 2022 from North America, Europe, and Asia to develop a baseline understanding of e-bikes, their emerging role in the transportation sector, and how they may advance Federal transportation goals. The Volpe National Transportation Systems Center (Volpe Center) conducted this literature review in support of the Federal Highway Administration (FHWA) Office of Human Environment.

The literature review begins with an overview of the legislative and regulatory context surrounding e-bikes in the United States at the national and State levels. It continues by examining existing research on the impacts of e-bikes on eight key topic areas. Each topic area section also includes a summary of gaps in research and future research needs identified by the project team. Table 2 summarizes key findings and research gaps identified in the literature review.

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[6] North American Bikeshare & Scootershare Association (NABSA). (2022). 3rd Annual Shared Micromobility State of the Industry Report.

Table 2: Summary of literature review findings and research gaps

Topic Area	Key Findings	Research Gaps
Ridership Trends	• E-bikes appeal to new audiences by lowering the barriers of entry to bicycling. • E-bike users tend to be older and have higher income and educational attainment than traditional bicycle riders. About 85 percent of e-bike users are male. • E-bike users tend to take longer and more frequent trips than riders of traditional bicycles. • E-bikes most commonly replace trips taken by traditional bicycle. E-bikes likely lead to a reduction in vehicle miles traveled, but in the U.S., generally do not fully act as a substitute for a car.	• Examining the mode shift of e-bike users to better understand potential impacts on travel patterns. • Understanding the role that the growing number of e-bike incentive programs play in increasing and promoting ridership. • Examining the gender discrepancy among riders to determine how to promote greater e-bike use.
Safety	• Research has not found significant differences between the behavior of traditional bicycle riders and e-bike riders. • Average speeds for e-bikes are faster than traditional bicycles. However, this may be due to e-bikes having higher uphill speeds. • E-bike riders tend to be older and have a higher rate of single-bicycle crashes; men have a higher rate of crashing than women while women have a higher rate of suffering a serious injury.	• Understanding whether e-bike crash rates are growing faster than e-bike ownership rates or whether the increased number of e-bike crashes is simply the result of increased e-bike ownership. • Studying the difference in safety risks between e-bike classifications. • Understanding risk factors contributing to battery fire risks.
Physical Activity and Health	• E-bikes have a lower threshold for physical exertion than traditional bicycles, but they require enough exertion to meet recommended heart rate intensities for exercise.	• Better understanding the health effects of riding an e-bike in comparison to other methods of exercise and micromobility modes through longer term observational studies. • Understanding the health impacts by demographic, especially for older adults.

Topic Area	Key Findings	Research Gaps
Accessibility	• E-bikes are commonly used by older adults and people with physical limitations that make riding a traditional bike difficult. • People with physical limitations are more likely to use e-bikes for recreation and exercise than for commutes. • Design characteristics, including lightweight construction, step-through frame, and tricycle style bikes can help enable the accessibility of e-bikes.	• Empirical and observational approaches are necessary to confirm survey findings. • Investigating strategies to better integrate adaptive e-bikes into bike share fleets, including understanding the needs of users with disabilities and how to design, finance, and operate programs.
Equity	• The high upfront cost of e-bikes is a barrier to e-bike ownership and ridership. • Some shared e-bike operators provide alternative means of access for unbanked individuals or those without a smartphone, such as "text-to-unlock" features. • E-bike enforcement bans vary nationwide. There are concerns that lower-income individuals and minorities may be disproportionately burdened by these policies.	• Examining the factors that contribute to the gender discrepancy among e-bike riders. • Examining the effectiveness of policies targeted at increasing e-bike ridership among traditionally underserved populations. • Examining whether stigmas or fears of harassment discourage e-bike ridership among certain groups.
Trail Infrastructure and Environment	• Only one primary study has been conducted on Class 1 e-mountain bike (e-MTB) impacts on natural surface trails, which initially suggested that there was not a significant difference in soil displacement between e-MTBs and traditional mountain bikes. • Research on mountain bike impacts shows that their presence can disturb wildlife and impact ecosystems; e-MTB impacts are expected to be similar but limited research is available.	• Further understanding degradation of natural surfaces from different classes of e-bikes and how e-MTBs affect surrounding wildlife. • Determining the specific impacts of e-bikes on plant life in comparison to other methods of travel on natural surface trails. • Better understanding the risk of combustion of e-bike batteries and the possible fire damage in forested environments.

Topic Area	Key Findings	Research Gaps
Energy and Emissions	• Environmental impacts of e-bikes are driven by emissions associated with both producing and using/charging e-bikes. • E-bikes have lower lifecycle greenhouse gas and air pollutant emissions than internal combustion engine vehicles, but higher emissions than traditional bicycles. The extent of environmental benefits of e-bikes depends on mode shift behavior, degree of e-bike market penetration, and attributes of electricity generation.	• Location-specific analysis, particularly in the U.S. context, is needed to validate modeled increases in e-bike mode share and determine environmental benefits. • Exploring the longevity of lithium ion batteries, which has implications for environmental impacts associated with their production and end-of-life management. • Novel energy storage and battery recycling approaches are needed to improve battery performance and minimize environmental impacts.
Freight Use Cases	• European studies have shown benefits of using e-bikes for urban freight deliveries and their potential to replace motor vehicle delivery trips. • Cargo e-bikes are limited by their lower cargo capacity, local topography and weather, battery range and recharge times, courier fatigue, and regulations regarding e-bike use. • A few pilot studies in the United States are currently demonstrating the viability of cargo e-bikes as an urban freight solution, but they are ongoing and limited data is available.	• Using e-bikes for urban freight is needed in the U.S. context. • Effective financial models for consolidation or distribution centers. • Existing research has focused on time and money savings; additional research is needed on other benefits of using e-bikes for urban freight, such as noise and pollution abatement; ease of navigation and parking; improved delivery reliability; and improved safety for vulnerable road users.

2. Legislative and Regulatory Context

Before the early 2000s e-bikes were considered to be motor vehicles for the purpose of most Federal laws and regulations. Motor vehicles are generally regulated differently from nonmotorized vehicles in both manufacturing and operations. Regulations for motor vehicles tend to be stricter to ensure the safety of users and the public. Stricter requirements in the manufacturing of a product can increase the cost of bringing a product to market. Likewise, stricter operational regulations, such as registering a vehicle or limiting where a vehicle can travel, can limit a consumer's desire to own an e-bike, therefore limiting a consumer base.

Defining e-bikes as distinct from motor vehicles and from traditional bicycles allows for greater flexibility in regulating each product. As e-bikes emerge as popular products, more and more State and local governments are considering e-bikes as a separate category from both motor vehicles and traditional bicycles. This section describes the current regulatory context for e-bikes for the Federal government, Federal land management agencies (FLMAs), and State and local governments. It also briefly describes international approaches to regulating e-bikes.

2.1 Federal Laws and Regulations

Innovations in electric motors and battery technology have made e-bikes into an attractive low-speed alternative mode of transportation. Federal statutes have been amended to define e-bikes, provide general safety specifications, and outline where they can be used. The Consumer Product Safety Commission (CPSC) is charged with regulating the manufacturing of low-speed e-bikes.[7] Distinguishing e-bikes from other modes of transportation provides manufacturers with greater certainty in what safety and product designs would be acceptable on the market.

In 2002, Congress amended the Consumer Product Safety Act, 15 U.S.C. § 2085, to define an e-bike as, "a two- or three-wheeled vehicle with fully operable pedals and an electric motor of less than 750 watts (1 horse power), whose maximum speed on a paved level surface, when powered solely by such a motor while ridden by an operator who weighs 170 pounds, is less than 20 miles per hour (mph)."[8] At the same time, Congress stated: "For purposes of motor vehicle safety standards issued and enforced… [by the National Highway Transportation Safety Administration (NHTSA)], a low-speed electric bicycle… shall not be considered a motor vehicle as defined by section 30102(6) of title 49, United States Code."[9] Therefore, e-bikes are subject to product safety regulations similar to traditional bicycles and are not subject to NHTSA vehicle standards.[10] The Consumer Product Safety Act only applies to product safety regulation; it does not discuss traffic laws or vehicle codes.

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[7] MacArthur, J., & Kobel, N. (2014). Regulations of E-Bikes in North America. National Institute for Transportation and Communities. https://pdxscholar.library.pdx.edu/cgi/viewcontent.cgi?referer=&httpsredir=1&article=1127&context=trec_reports.

[8] Public Law 107-319, Section 1 (116 STAT. 2776; Dec. 4, 2002). https://www.congress.gov/107/plaws/publ319/PLAW-107publ319.pdf.

[9] Public Law 107-319, Section 2 (116 STAT. 2776; Dec. 4, 2002). https://www.congress.gov/107/plaws/publ319/PLAW-107publ319.pdf.

[10] PeopleForBikes. (2015). Electric Bicycle Law Basics. https://s3-us-west-2.amazonaws.com/static.peopleforbikes.org/uploads/E-Bike%20Law%20Primer%20v3%20%281%29.pdf.

For purposes of Federal highway programs, an e-bike is defined under 23 U.S.C. § 217(j)(2)*,* as amended by Section 11133 of the Infrastructure Investment and Jobs Act (IIJA) (Public Law 117-58, also known as the "Bipartisan Infrastructure Law" (BIL)), as "a bicycle equipped with fully operable pedals, a saddle or seat for the rider, and an electric motor of less than 750 watts; that can safely share a bicycle transportation facility with other users of such facility; and that is a class 1 electric bicycle, class 2 electric bicycle, or class 3 electric bicycle." Starting with any grant application or State highway safety plan submitted under chapter 4 of title 23, U.S.C., for fiscal year 2024 or thereafter, 23 U.S.C. § 405(g)(1)(C), as amended by IIJA will establish that an individual using an electric bicycle is considered a nonmotorized road user.

Under 23 U.S.C. § 149, as revised by IIJA, shared e-bike projects are now an eligible activity under the Congestion Mitigation and Air Quality (CMAQ) program.[11] For consistency, FHWA interprets this eligibility as applicable to Transportation Alternative Set-Aside projects as well.[12] Since IIJA changed the definition of an electric bicycle in section 217(j)(2), e-bike infrastructure is eligible under the Transportation Alternative Set-Aside.[13]

Per 23 U.S.C. § 217(h)(4), e-bikes may be permitted on nonmotorized trails and pedestrian walkways that use Federal highway program funds where State or local regulations permit their operation. An FHWA memorandum clarifies these requirements by formulating a framework for considering motorized use on nonmotorized trails and pedestrian pathways.[14]

For projects funded under the Recreational Trails Program (RTP), the term "motorized recreation" means "off-road recreation using any motor-powered vehicle, except for a motorized wheelchair" (23 U.S.C. § 206(a)(1)). Therefore, for RTP-funded projects, e-bikes are a motorized use.

2.2 Federal Land Management Agency Approaches

In August 2019 the Department of Interior (DOI) issued Order 3376, which aimed to "increase recreational opportunities for all Americans, especially those with limitations, and to encourage the enjoyment of lands and waters managed" by DOI. The order provided policy direction to DOI bureaus that e-bikes shall be allowed where other types of bicycles are allowed, and e-bikes shall not be allowed where other types of bicycles are prohibited. The order initiated several efforts to reform existing e-bike policies of FLMAs. Four DOI bureaus (Bureau of Land Management, Bureau of Reclamation, Fish and Wildlife Service, and National Park Service) have finalized rule changes regulating the use of e-bikes within their jurisdictions. All four bureaus have adopted a modified definition of an e-bike codified in 15 U.S.C. § 2085 that incorporates a three-tier classification system. The FLMAs also introduced a slight modification

[11] Under 23 U.S.C. 149(b)(7), a project or program is eligible for CMAQ funding if it "shifts traffic demand to nonpeak hours or other transportation modes, increases vehicle occupancy rates, or otherwise reduce demand for roads through such means as…shared micromobility (including bikesharing and shared scooter systems)."
[12] *See* FHWA Transportation Alternatives Set-Aside Implementation Guidance as Revised by the Infrastructure Investment and Jobs Act. https://www.fhwa.dot.gov/environment/transportation_alternatives/guidance/ta_guidance_2022.pdf.
[13] *Id.*
[14] FHWA Framework for Considering Motorized Use on Nonmotorized Trails and Pedestrian Walkways under 23 U.S.C. § 217. https://www.fhwa.dot.gov/environment/bicycle_pedestrian/guidance/framework.cfm.

of the definition used at 15 U.S.C. § 2085 by changing that statute's language of "less than 750 watts" to "not more than 750 watts."

In March 2022, the U.S. Department of Agriculture Forest Service adopted changes to the Forest Service Manual (FSM) that clarified how e-bikes are managed on National Forest System (NFS) lands. The updates[15] align the Forest Service with 27 States and DOI's e-bike rules in adopting a standard definition for an e-bike and a three-tiered classification for e-bikes. Section 7715.5(4) provides specific criteria and guidance for designating e-bike use on trails. Table 3 provides more information on the rules changes for the DOI bureaus and the guidance update for the Forest Service.

Table 3: Federal Land Management Agency E-bike Regulatory and Guidance Changes

Agency	**Reference**	**Changes**
Bureau of Land Management	43 CFR part 8340	• Adopts modified e-bike definition in 15 U.S.C. 2085 with a three-tier classification. • Defines e-bikes as an "off-road vehicle" where the e-bike is being used on roads and trails upon which mechanized, non-motorized use is allowed; where the e-bike is being used in a manner where the motor is not exclusively propelling the e-bike for an extended period of time; and where the authorized officer has expressly determined that e-bikes should be treated the same as non-motorized bicycles. • Discretion for district and field managers to determine when e-bikes should be used in areas during the land-use planning or implementation decision-making process where the e-bike's motorized features are not being exclusively to propel the e-bike for an extended period of time on roads and trails upon which mechanized, non-motorized use is allowed (43 CFR 8342.2(d)). • Operation of e-bikes is permitted on those areas and trails designated as open to off-road vehicle use (43 CFR 8341.1(a)) and on those areas designated as limited if the person operating the e-bike conforms to all terms and conditions of the applicable designation orders (43 CFR 8341.1(b)). • Prohibits the operation of an off-road vehicle in violation of State laws and regulations relating to use, standards, registration, operation, and inspection of off-road vehicles. To the extent that State laws and regulations do not exist or are less stringent than the regulations in 43 CFR prat 8340, the regulations in part 8340 are minimum standards and are controlling (43 CFR 8341.1(d)).

[15] Forest Service Manual Travel Management. Chapter 7700, Zero Code. Chapter 7710 Travel Planning.

Agency	Reference	Changes
Bureau of Reclamation	43 CFR part 420	• Adopts modified e-bike definition in 15 U.S.C. 2085 with a three-tier classification (43 CFR 420.5(h)). • Excludes e-bikes from the definition of an "off-road vehicle" while being used on roads and trails upon which mechanized, non-motorized use is allowed, that are not being used in a manner where the motor is being used exclusively to propel the e-bike for an extended period of time, and where the Regional Director has expressly determined that e-bikes should be treated the same as non-motorized bicycles (43 CFR 420.5(a)(7)). Reclamation lands are generally closed to off-road vehicle use (43 CFR 420.2), although areas or trails may be opened to off-road vehicle use (43 CFR 420.22).
Fish and Wildlife Service	50 CFR 27.31(m)	• Adopts modified e-bike definition in 15 U.S.C. 2085 with a three-tier classification. • Discretion for refuge managers to designate roads and trails as open to e-bikes. • If refuge manager determines that e-bike use is a compatible use on roads or trails, e-bike riders are afforded all of the rights and privileges, and subject to all of the duties, of the operators of nonmotorized bicycles on roads and trails if the motor is not used exclusively to propel the rider for an extended period of time.
National Park Service	36 CFR 1.4, 36 CFR 4.30(i)	• Adopts modified e-bike definition in 15 U.S.C. 2085 with a three-tier classification. • Allows the use of e-bikes on park roads, parking areas, and administrative roads and trails that are otherwise open to bicycles if designated by the Superintendent (36 CFR 4.30(i)(1)-(2)). Prohibits using the e-bike's electric motor exclusively to move an e-bike for an extended period of time without pedaling (36 CFR 4.30(i)(3)). • Requires that if superintendents open locations to e-bikes or specific classes of e-bikes, that they notify the public pursuant to 36 CFR 1.7 (36 CFR 4.30(i)(1)). • Subjects person operating or possessing an e-bike to several regulatory provisions that apply to bicycles (36 CFR 4.30(i)(5)). • Clarifies that superintendents have the authority to limit or restrict e-bike use after taking into consideration public health and safety, natural and cultural resource protection, and other management activities and objectives (36 CFR 4.30(i)(7)). • Prohibits the possession of e-bikes in designated wilderness areas (36 CFR 4.30(i)(4)).

Agency	Reference	Changes
Forest Service	FSM 7700 Travel Management; FSM Chapter 7710 Travel Planning	• Establishes an e-bike definition and three-tier classification (Section 7705). • Adds a paragraph in FSM 7715.72 to enhance coordination with appropriate Federal, State, and local governmental entities and Tribal governments on travel management decisions and operational practices on routes crossing multiple jurisdictions to provide continuity of recreation experiences. • Adds specific guidance on designating NFS trails and areas on NFS lands for motor vehicle use; establishes a category of Trails Open to E-Bikes Only in FSM 7711.3; and revises FSM 7715.5 to add a criterion to consider trail management objectives in designating trails for motor vehicle use generally and to add criteria and guidance for designating e-bike use on NFS trails.

2.3 State and Local Approaches

State and local approaches to defining and regulating e-bikes vary by jurisdiction and have evolved through piecemeal legislation. States and local public agencies have the primary responsibility for regulating e-bikes on roads and trails under their jurisdiction. This section describes State approaches to defining and regulating e-bikes based on information compiled by the National Conference of State Legislatures and PeopleForBikes. As this is a rapidly evolving policy area, refer to these organizations for the most current State-specific information.

Almost all States specifically define e-bikes as distinct from both traditional bicycles and motor vehicles. The remaining States either do not define e-bikes or they designate them as a different vehicle class (i.e., as motorized vehicles, mopeds, or bicycles). Of the States that define e-bikes, the majority use the three-tier classification system found in 23 U.S.C. 217(j)(2).[16]

Depending on the State, an e-bike may have to be registered with a State or local licensing agency similar to how motorized vehicles are registered. Several States require an operator's license, such as a driver's license, to ride an e-bike. Additionally, some States have age restrictions for operating an e-bike, with age minimums ranging from 14 to 18 years old. Many States that use the three-tier classification system require an e-bike owner to properly label their e-bike with its classification type if not already done so by the manufacturer.

Helmet requirements for riding e-bikes range from requiring helmets for all operators and passengers to no requirements at all. Some States base helmet requirements on a rider's age (e.g., requiring helmets only for those under a certain age). Furthermore, a number of States have stricter helmet requirements for Class 3 e-bikes than for Classes 1 and 2. Finally, for some States

[16] This number changes frequently. See the PeopleForBikes e-bike page for current information: https://www.peopleforbikes.org/topics/electric-bikes.

that do not define an e-bike, such as Alaska, those States default to moped helmet requirements.[17]

Figure 2: Signage showing where e-bikes are and are not allowed on recreational trails. Image source: [City of Boulder, CO](#)

Where e-bikes can be operated also varies by State and local jurisdiction, especially in regard to trails and public lands. For example, Arizona, Minnesota, Utah, and Washington specifically allow e-bike operation on bicycle paths or greenways**.** Other States and local jurisdictions allow specific classes of e-bikes (e.g., Class 1 and 2) on bicycle paths, while other classes (e.g., Class 3) are only allowed to operate on roadways. Other States have codified e-bikes within the existing definition of traditional bicycles and grant them the same access allowed for traditional bicycles.

Knowing where e-bikes are permitted can be difficult to determine for riders and authorities, since transportation facilities can transition without notice between different jurisdictions. Signage can help clarify where e-bikes are allowed and reflects the local nature of e-bike regulation. Signs prohibiting motorized vehicles on certain recreational trails are common, but they do not typically expressly address e-bike usage. There are limited examples of local governments using signage to convey restrictions on use of e-bikes on multiuse paths and recreational trails.[18] For example, the Marin Municipal Water District in the California Bay Area prohibits e-bikes on recreational trails in their watershed management area, and Park City, UT bans e-bikes on single-track trails (see Figure 2). The City of Boulder, CO uses signage to convey both where e-bikes are restricted and where they are allowed on various recreational trails (see Figure 3). Some localities also use maps to convey where e-bikes can be used on recreational trails and multiuse paths; examples include Park City, UT and Boulder, CO.

Figure 3: Example signs prohibiting e-bikes on trails. Image source: Marin Municipal Water District (left) and Park City, UT (right)

[17] A regularly updated list of helmet requirements for e-bike users by State can be found at https://helmets.org/ebikelaws.htm.
[18] Part 9 of the Manual on Uniform Traffic Control Devices (MUTCD) provides standards for bicycle signs on roadways and shared-use paths. Many signs in use related to e-bikes, including the examples provided in this report, may not be allowable by the MUTCD for placement in all locations.

Signs regulating e-bikes are sometimes paired with speed limits, but speed limits are generally applicable to all trail users and not specific to e-bikes. For example, Seattle's recent [multiuse trail policy](#) established a 15 mph speed limit for all users, including users of e-bikes. Examples of signs distinguishing among e-bike classifications are scarce; but two such instances are in [Acadia National Park](#) and [Seattle](#), where signage indicates only certain classes of e-bikes are allowed on shared use paths (see Figure 4).

Figure 4: Example signs specifying e-bike class requirements.
Image source: [Seattle](#) (left) and [Acadia National Park](#) (right)

2.4 International Approaches

Legal frameworks for e-bikes in the European Union (E.U.) provide a unifying governing standard for its member states. E.U. directive EN15194 defines a "pedelec" e-bike and legally classifies it as a bicycle for the purposes of consumer and manufacturing safety standards, but not for operational restrictions. In addition to this directive, European Harmonized Directive 2006/126 requires a driving license for operating all "two and three-wheel vehicles with a maximum design speed of more than 25 kilometers per house (km/h) (15 mph) but not more than 45 km/h (28 mph)."[19]

Canada defines a "powered assisted bicycle" as having pedals, capable of being propelled by muscular power, having a 500 watts or less motor, and having electric assistance that shuts off at 19.9 mph. In Canada, provinces reserve the authority to require licensing and to set other restrictions like age minimums and helmet requirements.[20]

In March 2022, the [United Nations passed a resolution](#) encouraging member states to promote bicycle use and incorporate sustainable active mobility into public transportation and development strategies, including shared, cargo and adaptive bicycles, but the resolution does not refer specifically to e-bikes.[21]

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[19] Bike Europe. (2017). Rules & Regulations on Electronic Cycles in European Union. Trade Journal for the Bicycle, E-Bike & Scooter Market. http://bike-eu.com.s3-eu-central-1.amazonaws.com/app/uploads/2015/09/rules-regulation-on-electric-cycles-in-the-european-union-may-2017.pdf.

[20] MacArthur, J., & Kobel, N. (2014). Regulations of E-Bikes in North America. National Institute for Transportation and Communities. https://pdxscholar.library.pdx.edu/cgi/viewcontent.cgi?referer=&httpsredir=1&article=1127&context=trec_reports.

[21] United Nations General Assembly Integration of mainstream bicycling into public transportation systems for sustainable development. (March 15, 2022) A/RES/76/255.

3. Existing Research on E-bikes

This section provides a summary of literature on e-bikes across the following topic areas: ridership trends, safety, physical activity and health, accessibility, equity, trail infrastructure and environment, energy and emissions, and freight use cases. This literature review includes academic journal articles as well as reports published by research organizations, governments, and nonprofit organizations. It reflects articles published through September 2020. Many of the findings in the literature review are derived from surveys of e-bike riders and their results may be subject to self-selection bias.

3.1 Ridership Trends

E-bike use is a rising phenomenon in the United States. Existing literature on ridership trends is primarily derived from surveys and interviews with e-bike users. The North American Survey of Electric Bicycle Owners, published by the Transportation Research and Education Center in 2018, provides a critical baseline understanding for the motivations behind e-biking and some initial findings and trends across the United States. Stronger and more conclusive findings about ridership trends come from studies in Europe and China, where e-bikes have been commonplace for well over a decade.

Motivations for E-biking: Globally, e-bikes appeal to new audiences by lowering the barriers of entry to bicycling. The North American Survey of Electric Bicycle Owners found that e-bikes help to increase ridership among individuals deterred from bicycling by physical limitations, topographic barriers, perceived safety risk, and distance to cycle.[22] The survey also found that 14.6 percent of respondents were motivated to purchase an e-bike to carry cargo or kids. This same study, along with another examining e-bike use in China, found that e-bikes users, especially women, felt safer traveling through intersections on e-bikes in part due to the improved balance at higher speeds and greater acceleration, which allows users to keep up with cars.[23] A study that relied on interviews of e-bike users in the Sacramento, California area found that a primary motivation for purchasing e-bikes is their ability to allow users to maintain speed and reach their destination with significantly less physical exertion and effort.[24] A longitudinal, online survey of residents of seven European cities found that e-bike riders reported longer distances per trip (9.4 km) compared to traditional cyclists (4.8 km), as well as longer total daily travel distances (8.0 vs. 5.3 km per person, per day).[25] A separate study in which 66 randomly selected individuals in Norway were given an e-bike to use for a limited time found that e-bike

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[22] MacArthur, J., Harpool, M., Scheppke, D., Cherry, C. (2018). A North American Survey of Electric Bicycle Owners. Portland State University Transportation Research and Education Center. https://trec.pdx.edu/research/project/1041.

[23] Weinert, J., Ma, C., & Cherry, C. (2007). The transition to electric bikes in China: History and key reasons for rapid growth. Transportation, 34(3), 301–318. https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.624.8330&rep=rep1&type=pdf.

[24] Popovich, N., Gordon, E., Shao, Z., Xing, Y., Wang, Y., & Handy, S. (2014). Experiences of electric bicycle users in the Sacramento, California area. Travel Behaviour and Society. https://www.sciencedirect.com/science/article/abs/pii/S2214367X13000185.

[25] Castro, A., et al. (2019). Physical activity of electric bicycle users compared to conventional bicycle users and non-cyclists: Insights based on health and transport data from an online survey in seven European cities. Transportation Research Interdisciplinary Perspectives. https://www.sciencedirect.com/science/article/pii/S259019821930017X.

users take longer and more frequent trips for both recreational and utilitarian purposes than a control group using traditional bicycles.[26]

Mode Shift: A number of recent studies have tried to determine what modes are most commonly being replaced by e-bike trips, yielding mixed results. Overall, the research suggests that e-bikes are most commonly replacing trips taken by traditional bicycles, but are also likely leading to a reduction in vehicle miles traveled by personal automobile. Most of this research relies on self-reported behavior and is thus influenced by response bias, which should be considered when drawing conclusions. A study using data from three national mobility surveys in the Netherlands revealed that e-bike ownership strongly reduces traditional bicycle use, as e-bikes commonly serve as a replacement for a traditional bicycle. The study found that it was significantly less common for an e-bike to act as a substitute for a car.[27] The findings from this study may not be generalizable to the U.S. as bicycles account for 25 percent of daily trips in the Netherlands compared to around 2 percent of trips in the United States.[28] A survey of e-bike users in Shanghai, China similarly found that most e-bike users relied on a traditional bicycle or a bus prior to acquiring an e-bike. Fewer than five percent of respondents in the survey reported using a car as their primary travel mode before switching to an e-bike. [29]

In the United States, where private car ownership is significantly higher, a study of an electric bike share system in California found that e-bikes were most commonly replacing trips taken by personal automobile or a ride-hailing service.[30] A study averaging mode replacement survey data from 21 cities from 2018 to 2021 found that 37 percent of all shared micromobility trips replace trips made by cars.[31] However, research on the mode shift between e-bikes and cars remains limited in the United States, making it difficult to assess the impact of the shift.

Demographics: The demographics of e-bike users tend to skew older and have higher income and educational attainment than traditional bicycle users.[32,33] E-bikes expand access for those with physical limitations and limited mobility, which may explain why users tend to be older than traditional bicycle users. Research suggests that the high upfront cost of e-bikes is a likely explanation for why users tend to have a higher income. Studies of e-bike users in China found that wealthier individuals were more likely to purchase e-bikes and individuals often transitioned

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[26] Fyhri, A., Fearnley, N. (2015). Effects of E-bikes on Bicycle Use and Mode Share. Transport and Environment. https://www.sciencedirect.com/science/article/pii/S1361920915000140.
[27] Kroesen, M. (2017). To what extent do e-bikes substitute travel by other modes? Evidence from the Netherlands. Elsevier. https://www.sciencedirect.com/science/article/pii/S1361920916304837.
[28] Harms, L., Kansen, M. (2018). Cycling Facts. Netherlands Institute for Transport Policy Analysis. https://english.kimnet.nl/publications/publications/2018/04/06/cycling-facts.
[29] An, K., Chen, X., Xin, F., Lin, B., Wei. L (2013). Travel Characteristics of E-bike Users: Survey and Analysis in Shanghai. Procedia – Social and Behavioral Sciences. https://www.sciencedirect.com/science/article/pii/S1877042813023343.
[30] Fitch, D., Mohiuddin, H., Handy, S. (2020). Electric Bike-Share in the Sacramento Region is Replacing Car Trips and Supporting More Favorable Attitudes Towards Bicycling. Institute of Transportation Studies, University of California, Davis. https://escholarship.org/uc/item/8gm3w9qp.
[31] North American Bikeshare & Scootershare Association (NABSA). (2022). 3rd Annual Shared Micromobility State of the Industry Report.
[32] Cherry, C., & Cervero, R. (2007). Use characteristics and mode choice behavior of electric bike users in China. Transport Policy, 14(3), 247–257. https://www.sciencedirect.com/science/article/pii/S0967070X07000169.
[33] MacArthur, J., Harpool, M., Scheppke, D., Cherry, C. (2018). A North American Survey of Electric Bicycle Owners. Portland State University Transportation Research and Education Center. https://trec.pdx.edu/research/project/1041.

from the bus or using a traditional bicycle to an e-bike upon having the financial means.[34] The gender discrepancy between e-bike users is proportionally lower than that of traditional bicycle users in the United States; however women remain underrepresented among e-bike users.[35] The North American Survey of Electric Bicycle Owners identified 85 percent of e-bike users as male.[36] This same study found that women were more likely than men to use e-bikes to transport children and cargo.[37]

Incentive Programs: A white paper[38] reviewed 53 existing incentive programs[39] in North America, finding that the majority offer cash incentives in the range of $200-600 as post-purchase rebates or point-of-sale discounts. Frequent attributes of incentive programs include restricting recipients to those below certain income thresholds and requiring purchase from local sellers instead of online retailers. Programs are typically administered through power districts and local governments. One Norwegian study[40] of incentive program effectiveness found a 17 percent increase in cycling mode share that resulted from a 500 euro purchase subsidy.

Research Gaps: As e-bikes are a quickly growing trend, there are a number of topic areas related to ridership trends that require more extensive research. There continues to be limited research on the shift to e-bikes from other modes in the United States, and how many e-bike trips are replacing trips previously taken by car. A reduction from car travel to other modes could lead to numerous benefits for communities, including reduced traffic congestion and emissions and improved health through increased physical activity, making this a critical research area to continue pursuing. Another area of future research involves analyzing e-bike incentive programs. A number of governments have pursued programs including subsidies and rebates that intend to incentivize the public to purchase e-bikes; however, the effectiveness of these programs (including other incentives such as low-interest loans) could be further examined to help inform future policy decisions. Lastly, further research could continue looking at the gender discrepancy among e-bike users in the United States to determine whether e-bikes could help to decrease car travel for utilitarian purposes, especially for women, by providing individuals a greater ability to include additional stops in a trip, or to chain trips.

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[34] An, K., Chen, X., Xin, F., Lin, B., Wei. L (2013). Travel Characteristics of E-bike Users: Survey and Analysis in Shanghai. Procedia – Social and Behavioral Sciences. https://www.sciencedirect.com/science/article/pii/S1877042813023343.
[35] Yanocha, D., Allan, M. (2019). The Electric Assist: Leveraging E-bikes and E-Scooters for more Livable Cities. Institute for Transportation and Development Policy. https://www.itdp.org/wp-content/uploads/2019/12/ITDP_The-Electric-Assist_-Leveraging-E-bikes-and-E-scooters-for-More-Livable-Cities.pdf.
[36] MacArthur, J., Harpool, M., Scheppke, D., Cherry, C. (2018). A North American Survey of Electric Bicycle Owners. Portland State University Transportation Research and Education Center. https://trec.pdx.edu/research/project/1041.
[37] Ibid.
[38] Bennett, C., MacArthur, J., Cherry, C., & Jones, L. (2022). Using E-Bike Purchase Incentive Programs to Expand the Market – North American Trends and Recommended Practices. https://ppms.trec.pdx.edu/media/project_files/E-bike_Incentive_White_Paper_5_6_2022.pdf.
[39] MacArthur, John and Bennet, Cameron. E-Bike Incentive Programs in North America. Portland State University Transportation Research and Education Center. January 19, 2022. https://trec.pdx.edu/news/e-bike-incentive-programs-north-america-new-online-tracker.
[40] Beate Sundfør, H. & Fyhri, A. (2022). The effects of a subvention scheme for e-bikes on mode share and active mobility. Journal of Transport and Health. https://doi.org/10.1016/j.jth.2022.101403.

3.2 Safety

Determining the safety of e-bikes and the safety behavior of e-bike riders is an important factor in determining whether e-bikes should be regulated differently than traditional bicycles. Initial research on the safety implications of e-bikes tended to originate from Europe or China. Despite the cultural and geographical differences of this international research, these studies can still inform a basic understanding of how riders behave while using e-bikes. Opportunities to study the safety implications of e-bikes within the U.S. have grown as U.S. e-bike ownership has increased. Over the last decade, studies of e-bike safety in the U.S. have been narrow and based on surveys or crash reporting. For example, of 10 reported e-bike rider fatalities identified through a CPSC analysis[41] of 2017-2019 data, six were associated with motor vehicle collision, one was a single-bicycle crash, and one was a collision with a pedestrian. In the last five years, research has attempted to confirm reporting assumptions by using Global Positioning System (GPS) and Geographic Information System (GIS) mapping technology to develop primary data comparing how e-bike riders behave compared to traditional bicyclists. Studies have also explored the differences in crash risk and injury between different classes of e-bikes.

Demographic Differences: Research has shown that e-bikes attract different types of riders than traditional bicycles, and they may experience different types of risks. A study in Switzerland found that the average age of e-bike riders involved in crashes was between 40-65 years old. The same analysis found that e-bike riders were involved more in single-bicycle crashes than traditional bike riders, including those who experienced more traffic conflicts.[42] A study in the Netherlands found that older riders are more prone to single vehicle e-bike crashes because of the difficulty with balance in handling the heavier weight of the bikes during a dismount.[43] CPSC identified 10 reported e-bike rider fatalities in 2017-2019, 7 of which were over the age of 60, and 9 of which were male.[44]

Another study looking at e-bike rider behavior in Switzerland found that, on average, men have a higher risk of crashing than women. However, the risk of suffering a serious injury is higher for women, older adults, and those who consider themselves unfit.[45] Unsurprisingly, the rider's experience may also affect their risk of crashing.

Rider Behavior: Some studies have used GPS devices to track rider behavior. A study from Tennessee that followed the GPS activities of both e-bikes and traditional bicycles found that speeds of traditional bicycles varied widely, but e-bike speeds were mostly consistent. The study

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[41] CPSC. (2020). Micromobility Products-Related Deaths, Injuries, and Hazard Patterns: 2017–2019. https://www.cpsc.gov/s3fs-public/Micromobility-Products-Related-Deaths-Injuries-and-Hazard-Patterns-2017%E2%80%932019.pdf?90dOQxCOSzGvGRFGX6UF6Z6zvQhV9R1P.

[42] Weber, T., Scaramuzza, G., Schmitt, K. (2014). Evaluation of e-bike accidents in Switzerland. Accident Analysis & Prevention, 73. https://www.sciencedirect.com/science/article/pii/S0001457514002231.

[43] Schepers, P., Fishman, E., den Hertog, P., Wolt, K., & Schwab, L. (2014). The safety of electrically assisted bicycles compared to classic bicycles. Accident Analysis & Prevention, 73.

[44] CPSC. (2020). Micromobility Products-Related Deaths, Injuries, and Hazard Patterns: 2017–2019. https://www.cpsc.gov/s3fs-public/Micromobility-Products-Related-Deaths-Injuries-and-Hazard-Patterns-.2017%E2%80%932019.pdf?90dOQxCOSzGvGRFGX6UF6Z6zvQhV9R1P.

[45] Hertach, P., Uhr, A., Niemann, S., Cavegn, M. (2018). Characteristics of single-vehicle crashes with e-bikes in Switzerland. Accident Analysis & Prevention, 117. https://www.sciencedirect.com/science/article/pii/S000145751830174X.

assumed that this difference is due to e-bikes being able to maintain consistent speeds over hills and rolling terrain. Between the two groups, there was not a significant difference in wrong way violations on one-way and two-way streets, although e-bikes went slower when traveling the wrong way, relative to their average speed. Furthermore, there was also little difference in stop sign violations between the two groups. However, when running a stop sign, traditional bicycles, on average, did so at higher speeds than e-bikes.[46] The study concluded by stating "e-bike riders, almost without exception, behave approximately the same as regular riders and…there are not compelling reasons, from a safety behavior perspective, to regulate them differently."[47]

Other studies have looked into the reasons for e-bike crashes. A study in Switzerland found that the most common crash causes were slippery road surfaces and inappropriate speeds and the most common crash mechanism was skidding and falling.[48]

Speed: Much of the research on e-bike safety has focused on their speed compared to traditional bicycles. Electric motors provide additional power, with some e-bikes able to exceed 20 mph. However, this does not mean that e-bikes are always going this fast in practice. Studies have evaluated the spot speed, average speed, and top speed of e-bikes.[49] Spot speed is the speed an individual rider is able to travel at a specific location; spot speeds when going uphill tend to be higher for e-bikes than for traditional bicycles. This is distinct from average speed, or top speed, which may be similar between riders of both bicycle types.

Several studies have recorded average speeds of e-bike riders to be 8 to 8.5 mph faster than traditional bicycle riders.[50,51] However, much of this differential may be because e-bikes travel at higher speeds uphill than traditional bicycles. The Tennessee GPS study found that e-bike riders, on average, travel 0.93 mph slower than traditional bicycles on shared pathways. A follow-up study on a fixed course found that e-bike riders rode faster on average over a trip. Between the two types of bikes, speeds were the same on flat and downhill road segments, but were higher for e-bikes on uphill segments.[52]

Trip Purpose: The purpose of an e-bike trip can impact safety risk. For instance, a Swiss study found that, on average, those who commute to and from work using e-bikes have a higher risk of crashing than those using e-bikes for recreation. The study also found that riders who used electric mountain bikes (e-MTBs) had a lower crash risk than riders of traditional e-bikes. [53]

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[46] Langford, C., Chen, J., Cherry, R. (2015). Risky riding: Naturalistic methods comparing safety behavior from conventional bicycle riders and electric bike riders. Accident Analysis & Prevention, 82. https://www.sciencedirect.com/science/article/pii/S0001457515001992.
[47] Ibid.
[48] Hertach, P., et al. (2018). Characteristics of single-vehicle crashes with e-bikes in Switzerland. https://www.sciencedirect.com/science/article/pii/S000145751830174X.
[49] Johnson, M. (2015). Safety Implications of E-bikes. Royal Automobile Club of Victoria. https://research.monash.edu/en/publications/safety-implications-of-e-bikes.
[50] Dozza, M., et al. (2016). Using Naturalistic Data to Assess E-Cyclist Behavior. Transportation Research Part F: Traffic Psychology and Behaviour, vol. 41. https://www.sciencedirect.com/science/article/pii/S1369847815000662.
[51] Langford, C., Chen, J., Cherry, R. (2015). Risky riding: Naturalistic methods comparing safety behavior from conventional bicycle riders and electric bike riders. https://www.sciencedirect.com/science/article/pii/S0001457515001992.
[52] Ibid.
[53] Hertach, P., et al. (2018). Characteristics of single-vehicle crashes with e-bikes in Switzerland. https://www.sciencedirect.com/science/article/pii/S000145751830174X.

More research needs to be done to better understand these findings. Recreational riders may have fewer distractions, ride in areas with fewer traffic conflicts, and plan their trips in a way that avoids traffic conflicts. Commuters in urban areas tend to face more obstacles and traffic conflicts as well.

Conflict Among Modes: An analysis of crashes and near crashes in Sweden found that e-bikes conflicted more often with motorized vehicles than traditional bicycles did (i.e., motor vehicles more frequently triggered a crash or near crash for e-bikes relative to traditional bicycles).[54] The study postulated that this may be due to drivers' inability to distinguish e-bikes from traditional bicycles combined with differences in e-bike rider behavior and speed relative to those of traditional bicyclists. Higher e-bike speeds mean drivers have less time to notice and react to them, and drivers' inability to distinguish e-bikes from traditional bicycles may lead drivers to underestimate e-bikes' speed. The study suggests that higher rates of e-bike conflict with motor vehicles could also be explained by e-bike riders using routes with higher likelihood of interactions with motorized vehicles relative to routes chosen by traditional bicyclists (i.e., e-bike riders may be more likely than traditional bicyclists to use roads instead of shared-use paths).

E-bike Classifications: Several studies have tried to determine if there is a higher risk of crashing or severe injury with certain classes of e-bikes by using crash reporting data such as from databases maintained by hospitals.[55] However, crash reporting data does not always identify what class of e-bike was involved in an incident, and Class 3 e-bikes are often indistinguishable from other classes because of their inherent similar physical features. The faster top assisted speeds of Class 3 e-bikes may be associated with more severe crash and injury risks than the e-bike classes with slower top assisted speeds (1 and 2).

Battery Fire Risks: Although unlikely, e-bike batteries have a risk of combustion.[56] Generally, lithium batteries can cause a fire, whether they are new, used, defective, or damaged; however, damaged, defective, or recalled batteries have greater potential than undamaged lithium batteries to short circuit, release heat, or cause a fire.[57] Increased fire risk is associated with low-quality batteries and chargers, unsafe charging practices that overload electrical circuits, and physical damage to batteries and related components.[58]

For example, the New York City Fire Department investigated 104 e-bike or e-scooter battery fires in 2021 and 174 in 2022.[59] Responses to battery fire concerns in New York City have

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[54] Dozza, M., et al. (2016). Using Naturalistic Data to Assess E-Cyclist Behavior. https://www.sciencedirect.com/science/article/pii/S1369847815000662.

[55] Baschera, J., et al. (2019). Comparison of the Incidence and Severity of Traumatic Brain Injury Caused by Electrical Bicycle and Bicycle Accidents-A Retrospective Cohort Study From a Swiss Level I Trauma Center. World Neurosurg. v126 https://pubmed.ncbi.nlm.nih.gov/30857998/.

[56] Liu, X., et al. (2018). Thermal Runaway of Lithium-Ion Batteries without Internal Short Circuit. Joule. v. 2. https://www.sciencedirect.com/science/article/pii/S2542435118302800.

[57] PHMSA. (2022). Safety Advisory Notice for the Transportation of Lithium Batteries for Disposal or Recycling. https://www.phmsa.dot.gov/training/hazmat/safety-advisory-notice-transportation-lithium-batteries-disposal-or-recycling.

[58] Verzoni, A. (2022). Emerging Issues: Full Throttle. *National Fire Protection Association Journal*. https://www.nfpa.org/News-and-Research/Publications-and-media/NFPA-Journal/2022/Fall-2022/Features/E-bikes.

[59] Schuerman, M. (2022, October 30). Fires from exploding e-bike batteries multiply in NYC — sometimes fatally. *NPR*. https://www.npr.org/2022/10/30/1130239008/fires-from-exploding-e-bike-batteries-multiply-in-nyc-sometimes-fatally.

included universities banning use of electric micromobility devices on campus,[60] the New York City Housing Authority considering banning electric micromobility devices in its properties,[61] public transit providers banning electric micromobility devices on trains,[62] and the city updating fire codes to impose limits on storing and charging electric mobility devices.[63]

A CPSC analysis[64] of micromobility hazards during 2017-2019 identified no fire-related incidents for e-bikes during that period. In contrast, CPSC identified[65] 330 fire-related incidents involving other (non-e-bike) electric micromobility devices; two of these incidents resulted in three deaths. The vast majority of these fire incidents are associated with products manufactured prior to the development of voluntary standards for electric micromobility products (i.e., UL 2272). The UL 2849 standard, most recently revised in 2022, specifically covers electrical systems for e-bikes. In October 2022, CPSC issued a recall for a particular model of e-bike after the manufacturer received six reports of incidents involving fire, explosions, or sparks, including four reports of burn injuries.[66] In December 2022, CPSC issued a letter urging companies that manufacture, import, distribute, or sell micromobility devices to ensure their products comply with applicable safety standards, including UL 2272 and UL 2849.[67]

To reduce battery fire hazards, CPSC recommends that e-bike owners be present when charging batteries; use only the charger that came with the e-bike; use only manufacturer-approved replacement batteries; follow manufacturer instructions for charging; unplug the e-bike when charging is complete; and not use e-bikes with batteries modified or replaced by unqualified personnel.[68]

Research Gaps: More research on the safety implications of e-bikes is needed to determine risks to riders and other road users, including pedestrians. Although there is an increasing trend of e-bike crashes, this could be attributed to the increasing trend of e-bike ownership.[69] More research, including regression analyses, is needed on whether crash rates are growing faster than e-bike ownership rates, and what other factors are associated with e-bike crashes. Further, more

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[60] Richardson, K. (2022, December 11). Fordham University to ban e-scooters from all university property. *ABC7 NY*. https://abc7ny.com/fordham-university-e-scooter-ban-scooter-new-york-city/12559682/.

[61] Cuba.J. (2022, October 21). NYCHA Backs Down From Banning E-Bikes on its Property. *Streetsblog NYC*. https://nyc.streetsblog.org/2022/10/21/exclusive-nycha-backs-down-from-banning-e-bikes-on-its-property/.

[62] Shenk, H. (2021, June 23). The PATH Train Just Quietly Banned E-Bikes at All Times. *Streetsblog NYC*. https://nyc.streetsblog.org/2021/06/23/the-path-train-just-quietly-banned-e-bikes-at-all-times/.

[63] Verzoni, A. (2022). Emerging Issues: Full Throttle. *National Fire Protection Association Journal*. https://www.nfpa.org/News-and-Research/Publications-and-media/NFPA-Journal/2022/Fall-2022/Features/E-bikes.

[64] CPSC. (2020). Micromobility Products-Related Deaths, Injuries, and Hazard Patterns: 2017–2019. https://www.cpsc.gov/s3fs-public/Micromobility-Products-Related-Deaths-Injuries-and-Hazard-Patterns-2017%E2%80%932019.pdf?90dOQxCOSzGvGRFGX6UF6Z6zvQhV9R1P.

[65] CPSC. (2020). Safety Concerns Associated with Micromobility Products. https://www.cpsc.gov/s3fs-public/Report-on-Micromobility-Products_FINAL-to-Commission.pdf?THHIorYXAZ.KiZnobh1o7.7.lN9nNCLo.

[66] CPSC. (2022). E-Bikes Recalled Due to Fire, Explosion and Burn Hazards; Distributed by Ancheer. https://www.cpsc.gov/Recalls/2023/E-Bikes-Recalled-Due-to-Fire-Explosion-and-Burn-Hazards-Distributed-by-Ancheer.

[67] CPSC. (2022, December 20). CPSC Calls on Manufacturers to Comply with Safety Standards for Battery-Powered Products to Reduce the Risk of Injury and Death. https://www.cpsc.gov/Newsroom/News-Releases/2023/CPSC-Calls-on-Manufacturers-to-Comply-with-Safety-Standards-for-Battery-Powered-Products-to-Reduce-the-Risk-of-Injury-and-Death.

[68] CPSC. (n.d.). Micromobility: E-Bikes, E-Scooters and Hoverboards. https://www.cpsc.gov/Safety-Education/Safety-Education-Centers/Micromobility-Information-Center.

[69] Hertach, P., et al. (2018). Characteristics of single-vehicle crashes with e-bikes in Switzerland. https://www.sciencedirect.com/science/article/pii/S000145751830174X.

research is needed not only to determine the differences in risks between traditional bicycles and e-bikes, but also on the nuances between different classifications of e-bikes. Also, to better understand speeds of e-bikes relative to traditional bicycling, studies should distinguish spot speeds from average speeds. Lastly, further research on risk factors contributing to e-bike battery fire risks to prevent battery fires is needed. Such research could address best practices for regulatory approaches (e.g., alternatives to pausing shared micromobility programs); differences in risk between e-bikes and other electric micromobility devices, including electric mobility aids for people with disabilities; differences in risk between personal and shared e-bikes; industry rates of adoption of UL 2849; and equity impacts regarding fire risk in multifamily housing and for people relying on e-bikes for delivery jobs. Two Federal interagency groups, the Lithium Battery Safety Working Group and Lithium Battery Interagency Coordination Group, will continue work on addressing potential electrical hazards, including battery charging, use, storage, and transportation issues.[70]

3.3 Physical Activity and Health

Existing literature generally shows that riding e-bikes has positive results for a rider's health. E-bikes have a lower threshold for physical exertion than traditional bicycles, but still may provide enough exercise to contribute to good health. Furthermore, e-bikes provide mobility to those with physical limitations that may otherwise prevent them from bicycling.[71] Lastly, research shows that riding e-bikes can enhance the mental health and cognitive function of riders, which is particularly important for riders who have difficult performing the minimum level of effort required to ride a traditional bicycle.

Physical Activity: Exercise is important in maintaining good health and managing certain chronic health conditions such as Type 2 diabetes or cardiovascular complications. However, medical conditions or poor physical fitness can impede an individual's ability to get sufficient physical activity. The amount of physical exertion required for traditional bicycling could discourage potential riders, particularly those with poor physical fitness or who live near hilly terrain.[72] A benefit to using e-bikes is that they can maintain speed with less effort than traditional bicycles.[73] Researchers have studied whether the lower level of effort required to ride an e-bike allows riders to get sufficient exercise. For instance, Tennessee researchers found that e-bikes require 24 percent less energy than a riding a traditional bicycle and 64 percent less energy than walking over the same distance.[74]

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[70] CPSC. (2020). Safety Concerns Associated with Micromobility Products. https://www.cpsc.gov/s3fs-public/Report-on-Micromobility-Products_FINAL-to-Commission.pdf?THHIorYXAZ.KiZnobh1o7.7.lN9nNCLo.

[71] Fishman, E., Cherry, C. (2015). E-bikes in the Mainstream: Reviewing a Decade of Research. Transport Reviews. https://www.researchgate.net/publication/280572410_E-bikes_in_the_Mainstream_Reviewing_a_Decade_of_Research.

[72] De Geus, B., Hendriksen, I. (2015). Cycling for transport, physical activity and health: What about Pedelecs? Cycling Futures: From Research into Practice. https://www.researchgate.net/publication/282752633_Cycling_for_transport_physical_activity_and_health_What_about_Pedelecs.

[73] Fishman, E., Cherry, C. (2015). E-bikes in the Mainstream: Reviewing a Decade of Research. Transport Reviews. https://www.researchgate.net/publication/280572410_E-bikes_in_the_Mainstream_Reviewing_a_Decade_of_Research.

[74] Langford, C., et al. (2017). Comparing Physical Activity of Pedal-assist Electric Bikes with Walking and Conventional Bicycles. Journal of Transport & Health, v. 6. https://wsd-pfb-sparkinfluence.s3.amazonaws.com/uploads/2017/10/1-s2.0-S2214140516303930-main.pdf.

Studies have found that pedal assist motors of e-bikes help riders overcome exertion barriers while still encouraging some level of physical activity. Despite having pedaling assisted by a motor, e-bikes can provide adequate physical activity necessary in reducing the chance of sedentary lifestyle diseases.[75] In Switzerland, 18 sedentary participants rode e-bikes in a hilly environment, and researchers compared their effort to the effort of walking and using traditional bicycles. The study concluded that e-bikes were effective in providing physical activity with heart rate intensities meeting the recommended levels set by the American College of Sports Medicine.[76] In a similar study, eight adult riders had their oxygen consumption and routes recorded by using a portable oxygen analyzer and GPS technology. Riders used both e-bikes and traditional bicycles. The authors concluded that while e-biking requires less physical effort, intensity levels during e-biking are sufficient to provide health benefits.[77]

E-bikes also have the potential to offer exercise to individuals who face chronic health problems. One small-scale study reported that providing individuals with Type 2 diabetes an e-bike to use for 5 months led to a 10 percent increase in power output, a sign of increased fitness likely to be the result of increased physical activity.[78]

Mental Health and Wellbeing: Using e-bikes for physical activity can also improve an individual's mental health and wellbeing. A quantitative study exploring the impacts of physical activity using traditional bicycles and e-bikes on cognitive function of older non-bike riders showed improvements in several executive and cognitive functions for e-bike riders. In some cases, e-bike riders benefited as much, or in some cases more, than traditional bicyclists. A possible explanation is that e-bikes require less physical exertion than traditional bikes and can be more rewarding for participants to cycle.[79] The authors of the study elaborated that an e-bike can provide peace of mind as riders can travel longer distances without having to worry about getting back. In another study conducted at the University of Tennessee, riders of e-bikes acknowledged positive benefits compared to other modes of transportation. Users of the university e-bike share reported that e-bikes required less exertion and that they had higher levels of enjoyment when using an e-bike over walking or using a traditional bicycle.[80]

Research Gaps: Most of the research on the health benefits of riding an e-bike is based on short durations of usage. More information is needed to understand the long-term effects of riding an e-bike, in comparison to other methods of exercise and micromobility modes. Furthermore, more research is needed to explore the health impacts on specific demographics, in particular for older riders who tend to use e-bikes more than other age groups.

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[75] Fishman, E., Cherry, C. (2015). E-bikes in the Mainstream: Reviewing a Decade of Research. Transport Reviews. https://www.researchgate.net/publication/280572410_E-bikes_in_the_Mainstream_Reviewing_a_Decade_of_Research.
[76] Ibid.
[77] Cauwenberg, J., et al. (2018). E-bikes among older adults: benefits, disadvantages, usage, and crash characteristics. Transportation. https://www.researchgate.net/publication/327534317_E-bikes_among_older_adults_benefits_disadvantages_usage_and_crash_characteristics.
[78] Bourne, J., et al. (2019). Electrically assisted cycling for individuals with type 2 diabetes mellitus: protocol for a pilot randomized controlled trial. BMC. https://pilotfeasibilitystudies.biomedcentral.com/articles/10.1186/s40814-019-0508-4.
[79] Leyland, L., et al. (2019). The effect of cycling on cognitive function and well-being in older adults. PLoS ONE.
[80] Langford, C., et al. (2017). Comparing Physical Activity of Pedal-assist Electric Bikes with Walking and Conventional Bicycles.

3.4 Accessibility

Since e-bikes require less physical exertion than traditional bikes, they have potential to support independent mobility for older populations or those with otherwise limited physical ability, enabling bicycle transportation to be feasible for more people.[81, 82] Research on e-bikes and accessibility has primarily relied on surveys of e-bike users, including those with limited physical ability, to identify their reasons for using e-bikes, the types of trips they make using e-bikes, safety perceptions, and design considerations related to accessibility (i.e., adaptive e-bikes).

Reasons for Using E-bikes: In the North American Survey of Electric Bicycle Owners, approximately one quarter indicated they had a physical limitation (e.g., mobility, dexterity, or sensory impairments or health issues like respiratory, heart, or weight problems) that made riding a traditional bicycle difficult.[83] Those with physical limitations indicated they used e-bikes because they could negotiate hills with less effort and go farther.[84] E-bikes are perceived by some physically limited users as "equalizers," allowing riders to keep up with a friends and family who cycle faster.[85] Older adults identified similar reasons for using e-bikes, namely reducing physical strain and effort associated with using traditional bicycles.[86] Some e-bike users with disabilities have identified how e-bikes have enabled them to more fully participate in work/school life; for example, in an interview, a person with a disability reported that use of an e-bike allowed them to benefit from bicycle infrastructure on campus.[87]

Trip Purpose: The North American Survey of Electric Bicycle Owners found that people with physical limitations were more likely to use e-bikes for recreation or exercise and less likely to use them for commutes or other utilitarian purposes.[88] Relatedly, they were less likely to choose replacing car trips with e-bikes than adults without physical limitations.[89] Consistent with that

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[81] Leger, S., Dean, J., Edge, S., Casello, J. (2019). If I had a regular bicycle, I wouldn't be out riding anymore: Perspectives on the potential of e-bikes to support active living and independent mobility among older adults in Waterloo, Canada. Transportation Research Part A, Vol. 123, 240-254. https://www.sciencedirect.com/science/article/abs/pii/S0965856418300016.
[82] Gordon, E., Shao, Z., Xing, Y., Wang, Y., Handy, S. (2012). Experiences of Electric Bicycle Users in the Davis/Sacramento, California Area. Transportation Research Board 2013 Annual Meeting. https://www.researchgate.net/publication/262878008_Experiences_of_electric_bicycle_users_in_the_Sacramento_California_area.
[83] MacArthur, J., Harpool, M., Scheppke, D., Cherry, C. (2018). A North American Survey of Electric Bicycle Owners. Portland State University Transportation Research and Education Center. https://trec.pdx.edu/research/project/1041.
[84] Ibid.
[85] Ibid.
[86] Leger, S., Dean, J., Edge, S., Casello, J. (2019). If I had a regular bicycle, I wouldn't be out riding anymore: Perspectives on the potential of e-bikes to support active living and independent mobility among older adults in Waterloo, Canada. Transportation Research Part A, Vol. 123, 240-254. https://www.sciencedirect.com/science/article/abs/pii/S0965856418300016.
[87] Gordon, E., Shao, Z., Xing, Y., Wang, Y., Handy, S. (2012). Experiences of Electric Bicycle Users in the Davis/Sacramento, California Area. Transportation Research Board 2013 Annual Meeting. https://www.researchgate.net/publication/262878008_Experiences_of_electric_bicycle_users_in_the_Sacramento_California_area.
[88] MacArthur, J., Harpool, M., Scheppke, D., Cherry, C. (2018). A North American Survey of Electric Bicycle Owners. Portland State University Transportation Research and Education Center. https://trec.pdx.edu/research/project/1041.
[89] Ibid.

finding, another study determined that many older e-bike riders began using the technology after an injury, replacing trips they would have made by traditional bicycle.[90]

Safety: According to the same survey of North American e-bike owners, while people with physical limitations are less likely than those without to feel safe riding either an e-bike or traditional bicycle, e-bikes reduce the gap in safety perceptions between those with and without physical limitations.[91] A study found that visually impaired traditional and e-bike riders in the Netherlands ride at the same speeds and distance from the curb compared to normally sighted cyclists, suggesting that e-bike use by visually impaired individuals should not be regulated on vision standards alone, but rather based on individual needs and ability level.[92]

Figure 5: The adaptive bike share program in Portland, Oregon includes e-bikes (Source: Adaptive Biketown).

Design Considerations: Older e-bike users have identified some e-bike design characteristics to enable e-bike accessibility, including lightweight construction (less than 40 pounds), step-through frame design (i.e., low sloping top tube) which can allow for easy mounting or dismounting, and e-tricycle styles that can accommodate balance challenges.[93] The higher weight of e-bikes compared to traditional bicycles has been identified as a barrier to use by older individuals.[94] E-bike designs can be adapted to target different types of riders; for example, one Canadian company produces e-bikes for older adults with cardiovascular disease—the bikes are lightweight and monitor the rider's heartrate to determine when to engage the electric motor.[95] A survey of bike share operators in the United States found that, while e-bikes are adaptive to some degree in their own right, e-tricycles were the most promising

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[90] Leger, S., Dean, J., Edge, S., Casello, J. (2019). If I had a regular bicycle, I wouldn't be out riding anymore: Perspectives on the potential of e-bikes to support active living and independent mobility among older adults in Waterloo, Canada. Transportation Research Part A, Vol. 123, 240-254. https://www.sciencedirect.com/science/article/abs/pii/S0965856418300016.
[91] MacArthur, J., Harpool, M., Scheppke, D., Cherry, C. (2018). A North American Survey of Electric Bicycle Owners. Portland State University Transportation Research and Education Center. https://trec.pdx.edu/research/project/1041.
[92] Jeljis, B., Heutink, J., de Waard, D., Brookhuis, K., Melis-Dankers, B. (2020). How visually impaired cyclists ride regular and pedal electric bicycles. Transportation Research Part F: Traffic Psychology and Behaviour, Vol. 69, 251-264. https://www.sciencedirect.com/science/article/pii/S1369847819305170.
[93] Leger, S., Dean, J., Edge, S., Casello, J. (2019). If I had a regular bicycle, I wouldn't be out riding anymore: Perspectives on the potential of e-bikes to support active living and independent mobility among older adults in Waterloo, Canada. Transportation Research Part A, Vol. 123, 240-254. https://www.sciencedirect.com/science/article/abs/pii/S0965856418300016.
[94] Ibid.
[95] Ibid.

candidate for integrating more adaptive bicycles into fleets because they meet the most common accessibility needs of riders.[96]

Research Gaps: Adaptive cycling is an under-researched area in general. Much of the literature on e-bikes and accessibility relies on surveys of e-bike users instead of more empirical or observational methods. In a survey of people with disabilities in San Francisco, about a quarter of respondents indicated that fully electric bikes would make bike share accessible to them, and a fifth of respondents indicated electric assist bicycles would make bike share accessible to them.[97] However, there are knowledge gaps regarding better integration of adaptive e-bikes into bike share fleets such as understanding the needs of users with disabilities and how to design, finance, and operate such programs viably. Furthermore, the impact of the Americans with Disabilities Act on public entities that license the operation of e-bike share programs as well as companies that operate e-bike share programs is unsettled.

3.5 Equity

There is a growing interest in understanding how the various benefits and burdens from e-bike ridership are distributed across the population.[98] E-bikes present an opportunity to expand access to transportation for disadvantaged and underserved groups, and the rise of shared e-bikes may lower barriers for access for lower income populations. However, their high upfront cost, potential safety risk to novice riders, and limited availability in low income neighborhoods often serve as barriers reducing access to e-bikes for traditionally underserved populations. Existing research in this area is limited, but tends to focus on discrepancies in gender, lack of affordability and access, and biases in the enforcement of e-bike bans and policies.

Affordability: The high upfront cost of e-bikes is a significant barrier to greater e-bike ownership and ridership. A survey of e-bike owners in the United States found e-bikes to cost $1,500 on average, although there is a large range in prices.[99] A multi-country survey conducted by the Institute for Transportation and Development Policy found that respondents in Latin America, Africa, India, and Indonesia cited affordability as the primary barrier to e-bike use.[100] In addition

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[96] MacArthur, J., McNeil, N., Cummings, A., Broach, J. (2020). Adaptive Bike Share: Expanding Bike Share to People with Disabilities and Older Adults. Journal of the Transportation Research Board. https://journals.sagepub.com/doi/full/10.1177/0361198120925079.

[97] Ruvolo, M. (2020). Access Denied? Perceptions of New Mobility Services Among Disabled People in San Francisco. UCLA Institute of Transportation Studies. https://escholarship.org/uc/item/6jv123qg.

[98] FHWA Shared Micromobility Equity Primer. https://www.fhwa.dot.gov/livability/resources/shared_micromobility_equity_primer.pdf.

[99] Shao, Z., et al. (2012). Can Electric 2-Wheelers Play a Substantial Role in Reducing CO2 Emissions? University of California Davis. https://www.researchgate.net/profile/Yan_Xing8/publication/266461342_Can_Electric_2-Wheelers_Play_a_Substantial_Role_in_Reducing_CO2_Emissions/links/55061c270cf231de077787ee/Can-Electric-2-Wheelers-Play-a-Substantial-Role-in-Reducing-CO2-Emissions.pdf.

[100] Yanocha, D., Allan, M. (2019). The Electric Assist: Leveraging E-bikes and E-Scooters for more Livable Cities. Institute for Transportation and Development Policy. https://www.itdp.org/wp-content/uploads/2019/12/ITDP_The-Electric-Assist_-Leveraging-E-bikes-and-E-scooters-for-More-Livable-Cities.pdf.

to the cost of purchasing e-bikes, additional recurring costs including charging and battery replacement limit the ability of lower income households to purchase e-bikes.[101]

Access for Underserved Groups: E-bikes may help to reduce barriers to ridership for many groups, including disadvantaged and underserved populations. Older adults, women, and people who may not consider themselves physically able to ride a bicycle may look to e-bikes for commuting or personal trips.[102] There is limited research examining the viability of e-bikes to fill the transportation gap for women. A study in Madurai City, India found that women are generally supportive of e-bikes, but would like to see models with additional carrying capacity, recharging stations around the city, and government subsidies to make e-bikes more affordable.[103] A study using survey data in Norway found an increased risk of crashes for women on e-bikes when compared with men, suggesting a potential need for improved infrastructure or educational programs to improve safety.[104] There is not strong research examining e-bike ridership among racial groups; however, studies in Portland, OR, the United Kingdom, and the Netherlands noted that e-bike users feared intimidation and harassment on the road for using an e-bike and at times felt apologetic or self-conscious due to being viewed as "cheating" for riding an e-bike.[105,106] These sentiments are not unique to certain racial groups, but the threat of targeted harassment combined with barriers of access and affordability may deter e-bike ridership among traditionally underserved groups to a greater extent.[107]

The growth of shared e-bikes has, in some ways, helped to increase access to e-bikes for traditionally underserved populations by allowing users to experiment with these modes without committing to their high upfront costs. A review of dockless e-bikes and e-scooters in Washington, DC, found that Black residents adopted dockless services at a significantly higher rate to docked services when compared to white residents.[108] However, these shared systems often require users to unlock e-bikes with a smartphone or credit card, which presents a barrier to access for low-income and unbanked individuals. Additionally, the geographical distribution of shared e-bikes may be skewed toward central business districts and tourist hotspots, which limits access for traditionally underserved groups. A 2021 study in Austin, Texas found extreme

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[101] Dill, J., Rose, G. (2012). E-Bikes and Transportation Policy: Insights from Early Adopters. Transportation Research Board. https://nacto.org/wp-content/uploads/2012/02/E-bikes-and-Transportation-Policy-Insights-from-Early-Adopters-Dill-et-al-12-4621.pdf.

[102] Jones, T., Harms, L., Heinen, E. (2016). Motives, perceptions and experiences of electric bicycle owners and implications for health, wellbeing and mobility. Journal of Transport Geography. http://doi.org/10.1016/j.jtrangeo.2016.04.006.

[103] Alamelu, R., Anushan, C. S., Selvabaskar, S. G. (2015). Preference of e-bike by women in India–a niche market for auto manufacturers. Business: Theory and Practice. http://doi.org/10.3846/btp.2015.431.

[104] Fyhri, A., Johansson, O., Bjornskau, T. (2019). Gender Differences in Accident Risk with E-Bikes – Survey Data from Norway. Accident Analysis & Prevention. https://www.sciencedirect.com/science/article/pii/S0001457519304695.

[105] Dill, J., Rose, G. (2012). E-Bikes and Transportation Policy: Insights from Early Adopters. Transportation Research Board. https://nacto.org/wp-content/uploads/2012/02/E-bikes-and-Transportation-Policy-Insights-from-Early-Adopters-Dill-et-al-12-4621.pdf.

[106] Jones, T., Harms, L., & Heinen, E. (2016). Motives, perceptions and experiences of electric bicycle owners and implications for health, wellbeing and mobility. Journal of Transport Geography. http://doi.org/10.1016/j.jtrangeo.2016.04.006.

[107] Yanocha, D., Allan, M. (2019). The Electric Assist: Leveraging E-bikes and E-Scooters for more Livable Cities. Institute for Transportation and Development Policy. https://www.itdp.org/wp-content/uploads/2019/12/ITDP_The-Electric-Assist_-Leveraging-E-bikes-and-E-scooters-for-More-Livable-Cities.pdf.

[108] Clelow, R. (2018). DC is growing its dockless bike and scooter program: We partnered with them to evaluate how it's expanding access in underserved communities. Populus. https://medium.com/populus-ai/measuring-equity-dockless-27c40af259f8.

inequity in access to shared micromobility services, including e-bikes and scooters. The study found that 80 percent of residents had no access, and transit-dependent people and majority-Black neighborhoods had less access than the general population.[109] A growing list of cities including Washington, DC and Santa Monica, CA, have compelled bike share operators to station devices in underserved areas and offer alternative means of access for unbanked individuals or those without a smartphone; however, this topic remains an equity concern and a need for further research.[110]

E-Bike Bans and Enforcement: A number of cities and municipalities across the United States have instituted bans on e-bikes due to concerns that their higher speeds create safety issues for pedestrians, motorists, and other cyclists. Delivery workers, who are often lower-income and make up a substantial portion of e-bike users in urban areas, are often disproportionately burdened by these policies.[111] A study in New York City found that Latino and Chinese delivery workers were likely to receive more frequent and higher fines for e-bike use than other delivery workers.[112] New York City suspended the enforcement of the city's e-bike ban in March 2020 due to increased protest over the policies restricting workers from delivering food to residents during the COVID-19 pandemic and in June 2020, it overturned the ban entirely, legalizing e-bikes and electric scooters on city streets.[113,114] Cities have also created partial bans that prevent individuals from unlocking and operating shared devices after dark. These policies may disproportionately burden late-night workers who rely on shared e-bikes as an affordable transportation option to reach their workplace or home when transit services are offering limited service.[115]

Research Gaps: More research is needed to understand the discrepancy in attitudes towards e-bikes and safety outcomes among different demographic groups. Future research could also look into ridership by racial groups to better determine why ridership is often lower among certain underserved groups. Existing research suggests that there may be stigmas or fears of harassment that decrease ridership among certain groups; future studies may help to identify strategies to guide policy and decision making in a manner that will support greater e-bike ridership among all traditionally underserved groups. Lastly, there is a need to analyze the effectiveness of policies that encourage greater e-bike ridership among traditionally underserved groups. As

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[109] Aman, Javad J. C., Myriam Zakhem, and Janille Smith-Colin. 2021. "Towards Equity in Micromobility: Spatial Analysis of Access to Bikes and Scooters amongst Disadvantaged Populations" *Sustainability* 13, no. 21: 11856. https://doi.org/10.3390/su132111856.

[110] Stowell, H. (2020). Making Micromobility Equitable for All. Institute of Transportation Engineers.

[111] Yanocha, D., Allan, M. (2019). The Electric Assist: Leveraging E-bikes and E-Scooters for more Livable Cities. Institute for Transportation and Development Policy. https://www.itdp.org/wp-content/uploads/2019/12/ITDP_The-Electric-Assist_-Leveraging-E-bikes-and-E-scooters-for-More-Livable-Cities.pdf.

[112] Lee, D. (2018). Delivering Justice: Food Delivery Cyclists in New York City. City University of New York Academic Works. https://academicworks.cuny.edu/cgi/viewcontent.cgi?article=3854&context=gc_etds.

[113] Cuba, J., Colon, D. (2020). Mayor Suspends E-Bike Crackdown During Coronavirus Outbreak. StreetsblogNYC. https://nyc.streetsblog.org/2020/03/16/council-members-to-mayor-stop-crackdown-against-delivery-cyclists-amid-coronavirus-crisis/.

[114] Council Votes to Legalize the Use of E-Bikes and Scooters. New York City Council. June 25, 2020. https://council.nyc.gov/press/2020/06/25/1997/.

[115] Dupois, N., Griess, J., Klein, C. (2019). Micromobility in Cities: A History and Policy Overview. National League of Cities. https://www.nlc.org/resource/micromobility-in-cities-a-history-and-policy-overview.

previously mentioned, many bike share operators are working with cities to expand access, but there is a need to analyze whether these policies are effective in equitably expanding ridership.

3.6 Trail Infrastructure and Environment

Although e-bikes share many similar characteristics to traditional bicycles, their additional components may impact trail surfaces and the environment in different ways. Natural surface trails are susceptible to damage from the tires of bikes, and it is possible that these trails are more vulnerable to the additional torque of an e-bike's electric motor. Furthermore, the presence of e-bikes may impact wildlife behavior differently than other authorized uses of natural environments, such as hiking or traditional mountain biking. As e-bike access to Federal lands expands, there is a need to better understand how their usage affects trail infrastructure and the overall ecological system.

Trail Infrastructure Impacts: Primary research on the impact of e-bikes on natural surface trails is limited. Research on similar products, such as mountain bikes, may provide insight and direction for future studies. Traditional bikes, in particular mountain bikes, can cause degradation of natural surface trails. Research suggests that bikes can decrease the useful life of a trail and may exacerbate degradation in specific areas prone to erosion.[116] In addition, mountain bikes have been shown to cause surface area damages such as trail erosion, reduction in water quality, and increased runoff.[117,118] E-MTBs have some similar characteristics to traditional mountain bikes, and the additional torque provided by an electric motor may produce similar, if not more, damage to natural surface areas. Therefore, it is important to determine the impacts of e-bikes on natural surface areas.

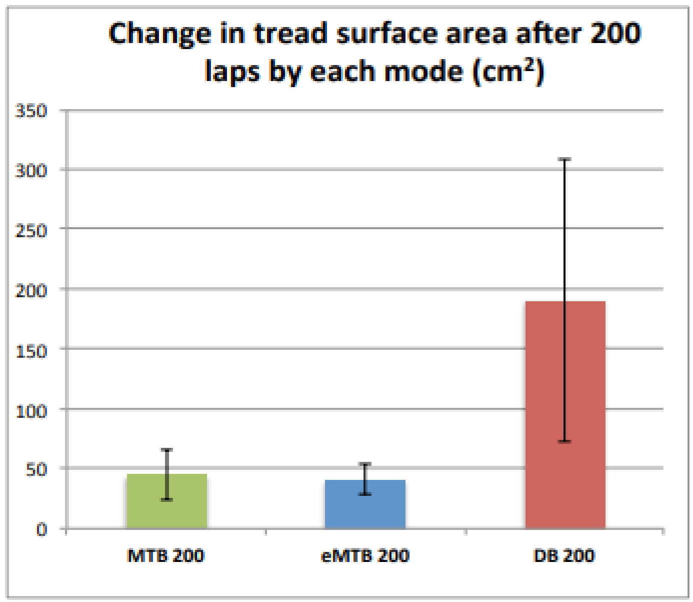

Figure 6: A small study on soil displacement of trails showed that traditional mountain bikes and e-MTBs had similar impacts to natural surfaces, while gas-powered off-road motorcycles had much greater impacts. Source: IMBA

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[116] Chavez, et al. (1993). Recreational Mountain Biking: A Management Perspective. Journal of Park and Recreation Administration. https://www.fs.fed.us/psw/publications/chavez/psw_1993_chavez001.pdf.
[117] Nielsen, et al. (2019). Literature Review: Recreation Conflicts on Emerging E-bike Technology. Boulder County Parks & Open Space. https://assets.bouldercounty.org/wp-content/uploads/2020/01/e-bike-literature-review.pdf.
[118] The quality of water resources can be diminished by the introduction of soils, nutrients, and pathogenic organisms. Furthermore, increased runoff occurs when the integrity of surface water drainage, such as tires loosening rock formations, is damaged.

This literature review identified only one comparison study on soil displacement that includes e-MTBs. The study, conducted by the International Mountain Bicycling Association (IMBA), a nonprofit mountain bike advocacy group, compared the soil displacement (a measurement of natural surface degradation) of a mountain bike, a pedal-assisted e-MTB (Class 1), and a gas-powered off-road motorcycles. The results indicated that there was not a significant difference in soil displacement between e-MTBs and traditional mountain bikes except for some observed differences at grade changes and turns (see Figure 6).[119] Depending on the weight of the bike, e-MTBs were shown to cause different levels of soil displacement in grade changes and turns than mountain bikes. Gas-powered off-road motorcycles showed significantly more soil displacement than both e-MTBs and mountain bikes. [120] Although informative, this was a small-scale field study limited in scope.

Impacts on Wildlife and Ecological Systems: E-MTBs may have ecological impacts. Wildlife can be negatively affected by the presence of humans within their natural environment. In one study estimating the associated impacts of mountain bikes in Western Australia, evidence suggested that nonmotorized activities had a larger negative effect on wildlife than motorized activities on trails.[121,122] A literature review for the Boulder County Parks and Open Space speculated that this was because motorized trails tend to be more prominent and placed outside wildlife areas while nonmotorized paths are closely located to wilderness areas and can create opportunities to travel off the beaten path, resulting in a less predictable travel pattern and more contact with areas where wildlife are located.[123]

A 2004 study in the Oregon Starkey Experimental Forest and Range found that motorized activities have negative impacts to wildlife compared to nonmotorized activities. Elk and deer populations were monitored to measure the 'disturbance' effect caused by hiking, horseback riding, mountain biking, and ATVs. Mountain bikes were found to disturb wildlife up to 750 meters from the rider. In comparison, the disturbance effect for ATVs, horse riders, and hikers, were observed at 1,350, 550 and 400 meters respectively.[124] Further research should be conducted to determine the disturbance effect on wildlife of e-MTBs and whether or not they have similar impacts to other motorized or nonmotorized activities. If e-MTBs disturb wildlife

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[119] The International Mountain Bicycling Association. (2016). A Comparison of Environmental Impacts from Mountain Bicycles, Class 1 Electric Mountain Bicycles, and Motorcycles: Soil Displacement and Erosion on Bike-Optimized Trails in a Western Oregon Forest. IMBA. https://www.americantrails.org/resources/a-comparison-of-environmental-impacts-from-mountain-bicycles-class-1-electric-mountain-bicycles-and-motorcycles-1.
[120] The International Mountain Bicycling Association. (2016). A Comparison of Environmental Impacts from Mountain Bicycles, Class 1 Electric Mountain Bicycles, and Motorcycles: Soil Displacement and Erosion on Bike-Optimized Trails in a Western Oregon Forest. IMBA. https://www.americantrails.org/resources/a-comparison-of-environmental-impacts-from-mountain-bicycles-class-1-electric-mountain-bicycles-and-motorcycles-1.
[121] Newsome, D., Davies, L. (2009). A case study in estimating the area of informal trail development and associated impacts caused by mountain bike activity in John Forrest National Park, Western Australia. Journal of Ecotourism. https://core.ac.uk/download/pdf/11233185.pdf.
[122] Larson, et al. (2016). Effects of Recreation on Animals Revealed as Widespread through a Global Systematic Review. PLoS One. https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0167259.
[123] Nielsen, et al. (2019). Literature Review: Recreation Conflicts on Emerging E-bike Technology.
[124] Wisdom, J., et al. (2004). Effects of Off-Road Recreation on Mule Deer and Elk. Transactions of the 69th North American Wildlife and Natural Resources Conference. https://www.fs.fed.us/pnw/pubs/journals/pnw_2004_wisdom001.pdf.

more than traditional biking and hiking, then their presence may contribute to wildlife vacating trail areas, which may negatively impact the ecological system in surrounding areas.

Bicycles, as well as hikers, may veer off paths and damage vegetation along trails. This is more likely when there is an obstruction in the way such as a dirt rut or puddle. Trampling of vegetation along a trail could consequentially widen the trail and lead to erosion, but it may also allow trample-resistant plants, such as tall grass, to grow in place. A study from Canada comparing the impacts of hiking and mountain biking on vegetation along trails found no statistically significant difference between the two activities.[125] A possible greater concern to vegetation is the spread of invasive plant species. Both hikers and bikers share the same ability to transmit invasive species; however, the farther a user travels on a trail the higher the probability of encountering, picking up and distributing the invasive species.[126] This is a particular concern for e-MTB riders because their electric motors allow them to travel greater distances.

Research Gaps: As previously mentioned, the literature on e-MTB impacts is limited and further research is needed to better understand how they affect both natural surface areas and ecological systems. Primary research that studies degradation of natural surfaces by measuring cross-sectional areas, depth of loose soil and tire rutting, and other metrics that illustrate erosion is needed. In an IMBA administered survey of land management staff that gauged their experiences and concerns regarding e-MTB use on natural surface and/or single-track trails, IMBA recommended several actions be taken to better understand e-MTB trail impacts:[127]

- Develop a comparison of e-MTBs alongside mountain bicycles and motorcycles to help understand how e-MTBs perform and are used on trails, what the user experience is, and how they might affect other trail users;
- Use test trails to measure the effects on trails directly and to the surrounding environment; and
- Focus future efforts on developing and testing e-MTB-specific trails; and test a range of trail and user conditions, including differing soil types, soil moisture, use levels, and trail grade.

FHWA is pursuing field studies that will delve into the potential impacts of e-MTB on soft- or natural-surface trail systems to improve understanding of e-MTBs and soft surface trail condition and consider whether specific soft-surface trail design standards are necessary to sustainably meet the needs of e-MTB riders and other trail users.

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[125] Thurston & Reader. (2001). Impacts of experimentally applied mountain biking and hiking on vegetation and soil of a deciduous forest. Environmental Management. v. 27.

[126] Cushman, J., Cooper, M., Meentemeyer, K., Benson, S. (2008). Human activity and the spread of Phytophthora ramorum. United States Department of Agriculture. https://www.fs.fed.us/psw/publications/documents/psw_gtr214/psw_gtr214_179-180_cushman.pdf.

[127] The International Mountain Bicycling Association. (2016). Trail Use and Management of Electric Mountain Bikes: Land Manager Survey Results. IMBA. https://b.3cdn.net/bikes/8834549e2b0ec018d0_qum6b48z6.pdf.

Furthermore, research on plant trampling is limited and could be expanded to determine if trample-resistant plants grow after vegetation has been destroyed by the motorized force of an e-bike.

Finally, another consideration that needs to be further studied are the risks associated with e-bike batteries. Given the devastation of wildfires, if battery combustion were to occur in a natural area it could pose a significant hazard not only to wildlife and natural resources, but also to the health and safety of surrounding populations. Further research needs to be done to better understand the probability of a combustion and the possible scenarios of one occurring within forested environments.

3.7 Energy and Emissions

Compared to traditional internal combustion engine vehicles, e-bikes "consume less energy, emit less carbon dioxide (CO_2), and decrease exposure to pollution" because e-bike related air pollution is primarily due to their production and electricity generation that typically occur away from population centers.[128] However, the extent of environmental benefits of e-bikes depends on several factors including mode shift behavior, degree of e-bike market penetration, and attributes of electricity generation (i.e., electricity blend and electrical system efficiency) used to charge the e-bikes. Most environmental impacts of e-bikes are associated with their production and end-of-life management, not their use/operation.

Greenhouse Gas Emissions: Greenhouse gas (GHG) emissions impacts of e-bikes are driven by emissions associated with both producing and using/charging e-bikes. These effects, like other air pollution impacts, depend on the source of electrical power (e.g., renewables or fossil fuels) used and extent of efficiency losses during extraction, conversion, and energy transport.[129] The lifecycle GHG emissions of an e-bike are approximately five times higher than that of a traditional bicycle.[130]

Studies have modeled how an increase in e-bike mode share would yield GHG emission reductions due to mode shift from cars to bicycles. One such study found that a 15-percentage point increase in e-bike mode share in Portland, OR would result in an 11 percent decrease in GHG emissions because of reduced person-miles traveled by car, a result that held even when modeling the most carbon-intensive electricity generation profile.[131] Another study found that for a given increase in the proportion of the English population who cycle regularly, access to e-bikes can reduce car miles more than traditional bikes.[132] These models are subject to the

[128] Weiss, M., Dekker, P., Moro, A., Scholz, H., & Patel, M. (2015). On the electrification of road transportation – A review of the environmental, economic, and social performance of electric two-wheelers. Transportation Research Part D, 41, 348-366. https://pubmed.ncbi.nlm.nih.gov/32288595/.
[129] Cazzola, P., Crist, P. (2020). Good to go? Assessing the Environmental Performance of New Mobility. International Transport Forum. https://www.itf-oecd.org/good-go-assessing-environmental-performance-new-mobility.
[130] Ibid.
[131] McQueen, M., MacArthur, J., & Cherry, C. (2019). The E-Bike Potential: Estimating the Effect of E-Bikes on Person Miles Travelled and Greenhouse Gas Emissions. Transportation Research and Education Center. https://pdxscholar.library.pdx.edu/cgi/viewcontent.cgi?article=1193&context=trec_reports.
[132] Woodcock, J., Abbas, A., Ullrich, A., Tainio, M., Lovelace, R., Sa, T., Westgate, K., & Goodman, A. (2018). Development of the Impacts of Cycling Tool (ICT): A modelling study and web tool for evaluating health and environmental impacts of cycling uptake. PLOS Medicine. https://journals.plos.org/plosmedicine/article?id=10.1371/journal.pmed.1002622.

limitations of self-reported travel survey data to inform mode shift scenarios. The scenarios modeled explore the relationship between e-bike mode share and GHG emission reductions; however, the studies do not make claims about the likelihood or policy conditions required to bring about such mode shift.

Air Pollution Impacts: E-bikes do not emit the tailpipe air pollutants associated with traditional internal combustion engine vehicles. An Italian study modeled carbon monoxide, hydrocarbon, and nitrogen oxide emissions of an internal combustion engine moped matching the speed performance of an e-bike in real-world driving conditions to illustrate local air pollution benefits of e-bikes.[133] Because e-bikes do not have tailpipe emissions, air pollution associated with e-bikes occurs at facilities where e-bikes are manufactured, locations where raw materials for e-bikes are extracted and refined, and power plants that provide electricity to manufacture and charge e-bikes rather than in urban centers. Since power plants are typically located in areas with lower population density, studies have found that e-bikes decrease human exposure and intake of pollutants, including carbon monoxide, nitrogen oxides, and hydrocarbons.[134] The degree of pollution around these power plants depends on their electricity source.

From a lifecycle perspective, considering electricity generation and emissions associated with production, e-bikes generate significantly less air pollution than internal combustion engine vehicles. A study synthesized estimates from several analyses of carbon monoxide, nitrogen oxide, volatile organic compounds, and particulate matter pollution to determine that a typical e-bike generates 1-2 kilotons/year relative to 10 kilotons/year for a representative motorcycle, big scooter, or moped and 4-30 kilotons/year for a characteristic car, train, tram, truck, or bus.[135]

Materials and Resource Impacts. Some e-bikes rely on lead-acid battery technology that generates more severe environmental impacts than other battery technologies. Lead losses to the environment during mining, smelting, and manufacturing of the battery contribute to 6.4 to 6.6 pounds of lead emissions per e-bike battery associated with production and up to 3.3 pounds of lead disposed as solid waste, more lead than is associated with motorcycle battery production.[136] While e-bikes in Europe tend to rely on other battery technologies (e.g., lithium ion), e-bikes in China more frequently used lead-acid batteries until the last decade.[137] The lifespan of lithium ion batteries varies from 500-20,000 recharge cycles, or 5-16 years, a concern given limited lithium reserves and the environmental impacts associated with extraction.[138] A lifecycle

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[133] Abagnale, C., Cardone, M., Iodice, P., Strano, S., Terso, M., & Vorraro, G. (2015). A dynamic model for the performance and environmental analysis of an innovative e-bike. Energy Procedia, 618-627. https://www.sciencedirect.com/science/article/pii/S1876610215026958.
[134] Ibid.
[135] Machedon-Pisu, M. & Borza, P. (2020). Are Personal Electric Vehicles Sustainable? A Hybrid E-Bike Case Study. Sustainability, 12, 32. https://www.mdpi.com/2071-1050/12/1/32.
[136] Ibid.
[137] Weiss, M., Dekker, P., Moro, A., Scholz, H., & Patel, M. (2015). On the electrification of road transportation – A review of the environmental, economic, and social performance of electric two-wheelers. Transportation Research Part D, 41, 348-366. https://pubmed.ncbi.nlm.nih.gov/32288595/.
[138] Machedon-Pisu, M. & Borza, P. (2020). Are Personal Electric Vehicles Sustainable? A Hybrid E-Bike Case Study. Sustainability, 12, 32. https://www.mdpi.com/2071-1050/12/1/32.

assessment found that e-bike production/manufacturing processes result in more wastewater and solid waste relative to motorcycles and traditional bicycles.[139]

Research Gaps: There is disagreement in the literature about the longevity (i.e., number of recharge cycles) of lithium ion batteries, which has implications for environmental impacts associated with the production and disposal of e-bikes that use these batteries. Research on novel energy storage and battery recycling approaches is also needed to improve battery performance and minimize environmental impacts. More research is also needed to validate modeled increases in e-bike mode share and to understand what interventions yield the most cost-effective realization of environmental benefits. Finally, attributes driving environmental impacts of e-bikes, such as the electrical system efficiency and electricity blend, vary geographically and require localized analysis.

3.8 Freight Use Cases

E-bikes show promise for urban freight applications, particularly as a last-mile solution for deliveries. This section focuses on commercial cargo e-bikes; see *Section 3.1, Ridership Trends* for discussion of individually-owned cargo e-bikes. Cargo e-bikes have several advantages relative to traditional means of urban delivery, including reducing noise and air pollution; navigating narrow, congested streets more easily; saving time and money by reducing searching for parking and the likelihood of parking illegally; improving delivery reliability; and improving safety for vulnerable road users. European studies suggest that 25 percent of goods and 50 percent of light goods could be delivered by cargo e-bike, 32 percent of delivery miles driven could be replaced by cargo e-bikes, and 85 percent of car delivery trips could be made my cargo e-bike; however, these results may not be generalizable to the United States due to the higher population density of European cities.[140]

Though cargo e-bikes have many benefits and may be able to optimize certain supply chain applications, they are not an urban freight panacea. Cargo e-bikes are limited by their lower cargo capacity and associated higher costs of trans-loading (i.e., moving parcels from trucks to e-bikes) at consolidation/distribution centers, local topography and weather, battery range and recharge times, courier fatigue, and regulations regarding e-bike use.

Empirical evidence demonstrates benefits of replacing conventional delivery vehicles with e-bikes. For example, a study reviewed pilot projects in Italy that analyzed replacing vans with e-bikes for the delivery of goods in urban areas and found absolute reductions in costs and CO_2 emissions, as well as reductions on a per mile basis and on a per day per e-bike basis.[141] Another study detailed the results of a pilot project involving distribution centers and e-bikes: a Parisian company replaced delivery by conventional vehicles directly from suppliers to recipients with

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[139] Ibid.
[140] Choubassi, C., Seedah, D., Jiang, N., & Walton, C. (2016). Economic analysis of cargo cycles for urban mail delivery. Transportation Research Record Journal of the Transportation Research Board, 2547, 102-110. https://journals.sagepub.com/doi/abs/10.3141/2547-14.
[141] Nocerino, R., Colorni, A., Lia, F., & Lue, A. (2016). E-bikes and E-scooters for smart logistics: environmental and economic sustainability in pro-E-bike Italian pilots. Transportation Research Procedia, 14(2016), 2362 – 2371. https://cyberleninka.org/article/n/1412748.pdf.

cargo e-trikes and microdistribution centers, resulting in a 30 percent reduction in total distance traveled. [142]

A few pilot programs in the United States are currently demonstrating the viability of cargo e-bikes as an urban freight solution, but they are ongoing and limited data is available. New York City announced a cargo e-bike pilot program in partnership with Amazon, DHL, and UPS to allow delivery throughout lower Manhattan. The goals of the pilot program are to understand how cargo e-bikes can operate on the city's roadways and how to consider changes to cargo e-bike regulations on speed, parking rates, and size. Miami is implementing a similar, but smaller scale, pilot program working with DHL.

Figure 7: City of Miami cargo e-bike pilot program (Source: City of Miami)

Modeling studies have aimed to determine under what conditions cargo e-bikes make economic sense relative to traditional delivery means. One study considered the cost implications of replacing U.S. Postal Service trucks in Austin, TX with cargo e-bikes or e-trikes, and found that cargo e-trikes had the lowest lifecycle costs and were most competitive with other delivery approaches under congested conditions, when distribution centers were located relatively close to delivery areas, and in higher density areas, like central business districts.[143] Another study modeled replacing delivery trucks with cargo e-bikes in Seattle, WA, with similar findings: cargo e-bikes are more cost-effective than trucks when deliveries are: 1) close to distribution centers; 2) to high-density areas; and 3) low-volume. The studies assume the availability of distribution centers that consolidate and transfer parcels to cargo e-bikes for delivery, an essential part of an e-bike urban freight system.[144]

Research Gaps: There are limited cargo e-bike pilot programs in the United States, and successes in European case studies may not be generalizable due to differences in population densities and availability of bike infrastructure. More research is needed on effective financial models for consolidation/distribution centers, a necessary component e-bike urban freight systems. Further research on user conflicts with cargo e-bikes and potential safety impacts to

[142] Clausen, U., Geiger, C., & Pöting, M. (2016). Hands-on testing of last mile concepts. Transportation Research Procedia, 14(2016), 1533-1542. https://www.researchgate.net/publication/304530124_Hands-on_Testing_of_Last_Mile_Concepts.
[143] Choubassi, C., Seedah, D., Jian, N., & Walton, C. (2016). Economic analysis of cargo cycles for urban mail delivery. Transportation Research Record Journal of the Transportation Research Board, 2547, 102-110. https://journals.sagepub.com/doi/abs/10.3141/2547-14.
[144] Sheth, M., Butrina, P., Goodchild, A., McCormack, E. (2019). Measuring delivery route cost trade-offs between electric-assist cargo bicycles and delivery trucks in dense urban areas. European Transport Research Review. https://www.researchgate.net/publication/331077167_Measuring_delivery_route_cost_trade-offs_between_electric-assist_cargo_bicycles_and_delivery_trucks_in_dense_urban_areas.

other vulnerable road users is needed (e.g., cargo e-bikes may be larger and heavier than standard e-bikes and they share space with other vulnerable road users on the roadway). While there are several potential benefits to using e-bikes for urban freight (e.g., noise and air pollution abatement; ease of navigation and parking; improved delivery reliability; and improved safety for vulnerable road users), existing literature has focused primarily on time and money savings.

4. Research Gaps and Needs

Throughout each topic area of this literature review, specific gaps and research needs are identified. This section highlights overarching trends regarding research availability and direction for future study.

While there is a significant body of research concerning use of e-bikes and their impacts in Europe and Asia, additional studies are needed in the United States context. For example, cities in the United States are less dense than their Eurasian counterparts, consumer preferences and travel patterns differ between countries, and the availability of quality bicycle infrastructure varies substantially internationally.

Many studies rely on surveys of e-bike riders which, while helpful for establishing a baseline understanding of the e-bike landscape, are limited in ways all survey data is limited (e.g., data may be unreliable due to subjective responses and reflect biased or otherwise nonrepresentative samples). There is a need for more observational and/or experimental research to more rigorously understand causal impacts of e-bikes, e-bike rider behavior, and mode shift associated with e-bikes.

Finally, more research is needed on e-bikes and public lands, particularly the potential for e-bikes to impact infrastructure and natural resources and to better understand how e-bikes should be regulated and managed in those contexts.

Federal, State, and local agencies may consider how they can integrate e-bikes into transportation and recreation infrastructure and share best practices.

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FHWA Shared Micromobility Equity Primer. https://www.fhwa.dot.gov/livability/resources/shared_micromobility_equity_primer.pdf

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