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EEMS097

U.S. DEPARTMENT OF ENERGY SMARTMOBILITY
Systems and Modeling for Accelerated Research in Transportation

MICROMOBILITY INTEGRATED TRANSIT AND INFRASTRUCTURE FOR EFFICIENCY (MITIE)

ANDREW DUVALL (PI), TOM WENZEL, SIMEON ILIEV, VENU GARIKAPATI, BINGRONG SUN, ALANA WILSON, ALEJANDRO HENAO, AND ELLIOT MARTIN

Energy Efficient Mobility Systems (EEMS)
Vehicle Technologies Office
U.S. Department of Energy

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Argonne NATIONAL LABORATORY · BERKELEY LAB · INL Idaho National Laboratory · NREL · OAK RIDGE National Laboratory · Pacific Northwest

OVERVIEW

Timeline

- Project start date: 09/01/2020
- Project end date: 09/30/2023
- Percent complete: 49%

Budget

- Total project funding: $2,680,000
  - DOE share: $2,680,000
- Funding for FY 2021: $894,000
- Funding for FY 2022: $1,064,000

Barriers

- Barriers addressed:
  - Vehicle-Mobility Systems Analysis Tech Team (VMSATT) future mobility systems scenarios
  - VMSATT evaluation and augmentation of capabilities for mobility energy productivity (MEP) at scale

Partners

- Interactions/collaborations
  - Tom Wenzel, Lawrence Berkeley National Laboratory (LBNL)
  - Elliot Martin, University of California, Berkeley (UCB)
  - Simeon Iliev, Argonne National Laboratory (ANL)
- Project lead
  - Andrew Duvall, National Renewable Energy Laboratory (NREL)

RELEVANCE: OBJECTIVES

- **Overall Project Objectives (April 2021–March 2022):**
  1. A comprehensive set of micromobility scenarios to be integrated into Workflow
     - Initial scenarios delivered to modeling team
  2. Estimated energy impacts for low-, medium-, and high-adoption scenarios
     - Estimation framework encapsulated in scenarios
  3. Analysis of interconnected transit/micromobility use
     - Scenario exploration, coordinated with LBNL and U.S. Environmental Protection Agency (EPA)
  4. Behavioral models of current and hypothetical micromobility, induced demand
     - Behavioral model baseline; Fundamental Influencing Factors (FIF) model
  5. Energy optimization estimates of micromobility operations
     - Engagement with stakeholders; energy intensity data collection
  6. Quantitative energy estimation of microfreight
     - Characterize microfreight use cases; identify microfreight vehicle types.

RELEVANCE: MITIE CONTRIBUTIONS

- The MITIE project supports Energy Efficient Mobility Systems (EEMS):
  - Advancing technologies and systems to improve MEP when adopted at scale
  - Exploring modes that have not been well studied in the context of energy impacts
- The MITIE project is relevant to:
  - **Reduction of energy costs** by replacing large vehicles, improving transit and delivery
  - **Increased energy security** by reducing fossil fuel dependence
  - **Clean energy technology to move people and goods** by using highly efficient vehicles with simple and proven electric vehicle (EV) technologies
- MITIE addresses research barriers by defining future mobility scenarios and integrating equitable options
  - Micromobility options per trip are affordable; introductory experience to EVs.

MILESTONES

FY 2022

Q1 (Completed) Summary of mature FIF behavior modeling framework; summary of data and methods to validate micromobility functions in four BEAM[1] cities

Q2 (Completed) Summary of microfreight scenarios for BEAM; report from BEAM simulations of micromobility as first/last mile to transit scenarios in BEAM cities; research new vehicles with high-value data gaps

Q3 Summary of operational energy optimization and scenarios for shared micromobility operations

Q4 Micromobility scenarios for representative cities from other size cohorts

Go/No-Go: Integration of output from micromobility modeling and simulation tasks to inform Workflow scenarios.

FY 2023

Q1 Presentation outlining micromobility advances since project start to inform Workflow efforts in final year of project

Q2 Research new vehicles with high-value data gaps related to DOE simulation and analysis efforts and select additional vehicle to test

Q3 Draft comprehensive final report

Q4 Comprehensive project final report; report estimating the net energy use of micromobility services based on analysis of trip-level data, including shift from other travel modes and device rebalancing/recharging; final energy consumption and sensitivity analysis report on the tested micromobility vehicles.

[1] *Behavior, Energy, Autonomy, and Mobility model*

Any proposed future work is subject to change based on funding levels.

APPROACH: PROJECT EMPHASIS AREAS

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1. Energy estimates of micromobility for Workflow scenarios

– Augment the Workflow approaches to model urban travel

2. Multimodal connection with transit

– Evaluate multimodal travel patterns enabled by micromobility, including assessing how to reduce barriers of inequity of access to mobility options and destinations

3. Mode choice, induced demand, and infrastructure

– Understand the mode shift induced through micromobility, supportive infrastructure

4. Energy optimization of micromobility operations

– Evaluate micromobility operation parameters and energy intensity

5. Microfreight

– Characterize microfreight activities, energy effects, and geospatial analyses.

APPROACH: CONTRIBUTIONS TO SMART MOBILITY EFFORTS

Unique aspects of this work augment SMART Mobility:

- Enhancement of Workflow models to include micromobility scenarios for agents in the models based on real-world data and observations
- Behavioral model that is mode-agnostic—meaning that as-yet unknown modes can be modeled by characteristics

Addresses technical barriers by:

- Working toward ranges of generalizable and transferrable micromobility assumptions and transit interconnection
- Accounting for specifics of location and demography in micromobility use

Integration within SMART Mobility:

- BEAM CORE: Closely working with modelers to inform scenario integration
- Freight: Microfreight as a component of overall freight
- Curb space: Micromobility and microfreight impacts on curb activity.

TECHNICAL ACCOMPLISHMENTS: ENERGY ESTIMATION/SCENARIO DEVELOPMENT (TASK 1)

Scope: Energy estimates of micromobility for Workflow scenarios

- "Estimating Energy Bounds for Adoption of Shared Micromobility" published in *Transportation Research Part D*
- Three primary levers (adoption level, energy intensity for fleet repositioning, and vehicle technology) identified for implementation in the BEAM workflow

Summary:

- First publication to our knowledge in energy bounds estimation for shared micromobility (plans to do a follow-up paper that includes personal micromobility)
- Continued conversations with BEAM and POLARIS teams in reflecting micromobility (passenger and freight) in their respective workflows.

Table 1. Energy Impacts from Micromobility Adoption at the National Level

Scenario	Mode	Energy Change as % of Energy Consumption from All NHTS Trips	Gasoline-Equivalent Energy Change (Million Gallons)
1. Low micromobility adoption	M-bikes	−0.03%	−21.8
	E-bikes	−0.04%	−34.4
	E-scooters	−0.02%	−13.5
	Seated scooters	−0.03%	−29
2. Moderate micromobility adoption	M-bikes	−0.11%	−93
	E-bikes	−0.17%	−147
	E-scooters	−0.07%	−56.5
	Seated scooters	−0.15%	−125.9
3. High non-motorized trip adoption	M-bikes	0.05%	43.8
	E-bikes	0.07%	60.3
	E-scooters	0.03%	24.9
	Seated scooters	0.10%	80.8
4. High motorized trip adoption	M-bikes	−0.61%	−513.6
	E-bikes	−0.96%	−805
	E-scooters	−0.36%	−305.6
	Seated scooters	−0.86%	−721.5

TECHNICAL ACCOMPLISHMENTS: ANALYSIS OF TRIP-LEVEL DATA FOR MICROMOBILITY (TASK 2)

Scope: Analyze micromobility trip data

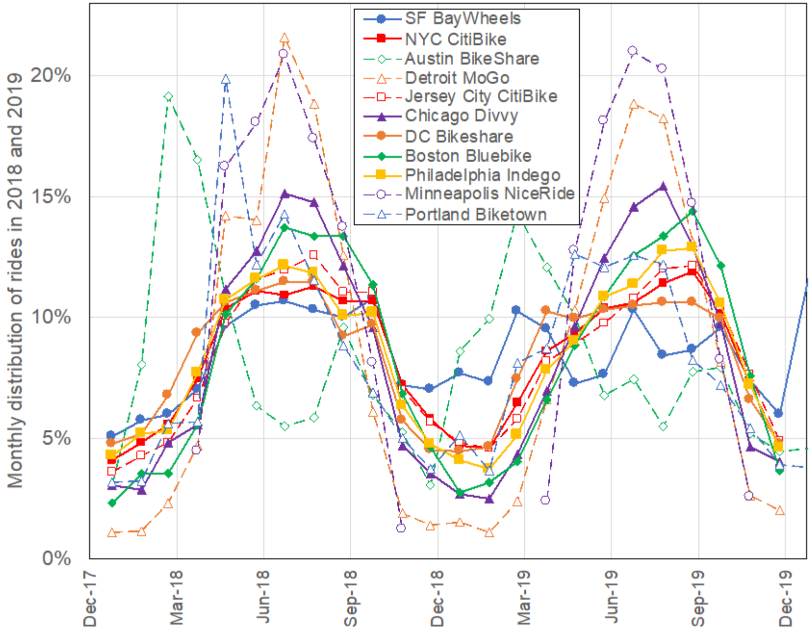
- — LBNL analysis of docked bikeshare data in 11 cities
- — General bikeshare feed specification (GBFS) persistent bike identification allows estimation of the fraction of all trips and vehicle miles traveled (VMT) that are repositions
- — Analyzed average trip distance, duration, and speed by type of day (weekday vs. weekend) and hour, user age/gender, casual user/subscriber, and pedal/electric bike.

Summary:

- – Rides vary seasonally and were initially negatively affected by the pandemic
- – Large, high-density systems appear to experience higher use and shorter, faster trips
- – E-bikes used for longer distances, at higher speeds, and more frequently than pedal bikes
- – Trip data used to validate BEAM agent-based model in San Francisco Bay Area and Austin.

Docked bikeshare data from 11 cities

(Austin peak in spring 2018 due to short-term pilot of free rides to UT students)



TECHNICAL ACCOMPLISHMENTS: ANALYSIS OF TRIP-LEVEL DATA FOR MICROMOBILITY (TASK 2)

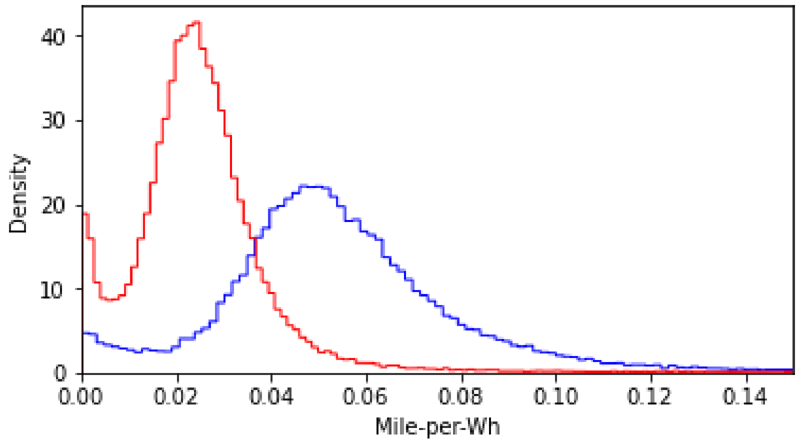
Scope: Analyze *dockless* micromobility trip data

- UCB analysis of dockless bike/scooter share data in 10 cities.
- Data were collected from the GBFS containing origin-destination location and time stamps, as well as state of charge change.
- Data augmented with an estimation of route length, elevation change, temperature, and wind speed and direction.
- Analyzed and modeled battery state of charge and energy use for electric bikes/scooters as function of trip distance, speed, change in grade, and other augmented trip attributes.

Summary:

- Completed FY 2021 Q2 milestone; progress toward FY 2021 Q4 milestone.

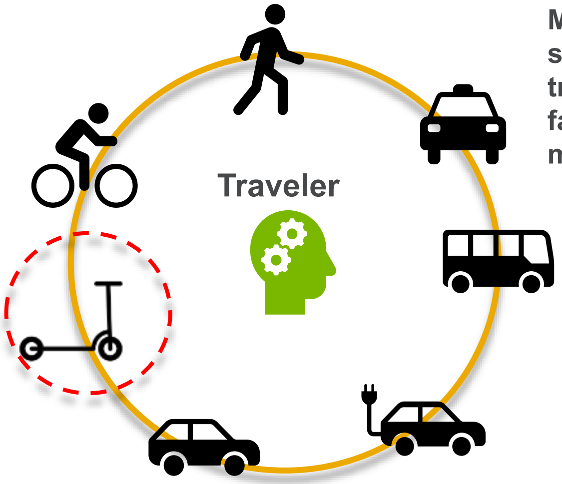
Empirically derived distribution of energy efficiency of e-scooters (red) and e-bikes (blue) in San Francisco



TECHNICAL ACCOMPLISHMENTS: MODE CHOICE, INDUCED DEMAND, AND INFRASTRUCTURE (TASK 3)

Scope: Establish a mode choice model considering micromobility

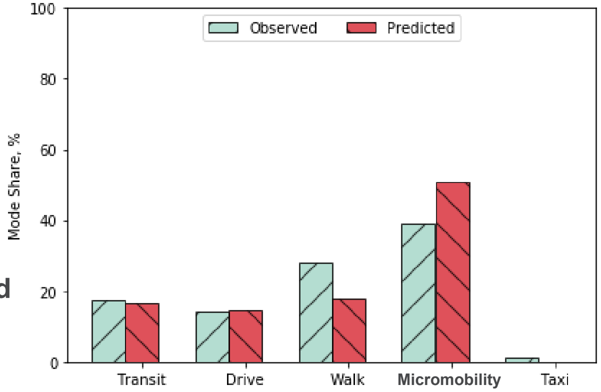
- Travel demand data and micromobility trip data in Washington, D.C., were processed and used for mode choice model estimation
- Established a behavior model that estimates and predicts how people choose between traditional modes and emerging micromobility modes
- Influencing factors in the model include cost, in-vehicle travel time, access time, and egress time



Mode choice scenario travelers are facing in the modeling

Summary:

- The established mode choice model captures well the micromobility adoption behavior in Washington, D.C.
- More advanced model structure (i.e., nested logit) is under development to improve the overall model fitness.



Comparison between observed and predicted mode shares with estimated model

TECHNICAL ACCOMPLISHMENTS: ENERGY OPTIMIZATION OF MICROMOBILITY OPERATIONS (TASK 4)

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Scope: Evaluation of micromobility operations

- Many vendors consider repositioning practices to be proprietary, and use ad hoc strategies with independent management
- LBNL analysis of GBFS data from 11 docked bikeshare programs:
  - Repositions are 7%–19% of trips, 8%–18% of VMT (2.7% and 4.7%, respectively, in NYC)
  - Monthly rides per bike range from 18 to 69 (118 in NYC)

Summary:

- Repositioning/maintenance practices vary widely, and by systems of different sizes and in different geographies
- Cities seek info on optimized number of stations, vehicles, and operators
- Large, dense systems may require less repositioning.

Program	Percent trip/VMT repositions		Average distance (miles)*		Average ride duration (mins)*	Average ride speed (miles/hour) *†	Percent round trips to same station	Average monthly rides per bike
	Trips	VMT	Rides	Repos				
NYC CitiBike	2.7%	4.7%	1.12	1.99	14	4.9	1.5%	118
SF Bay Wheels	10%	14%	1.08	1.63	12	5.3	1.4%	46
Jersey City CitiBike	14%	15%	0.64	0.78	8	4.5	2.7%	68
Detroit MoGo	18%	18%	0.99	1.26	17	3.4	11.8%	18
Austin MetroBike	10%	11%	0.78	0.96	19	2.4	13.1%	19**
Chicago Divvy	7%	8%	2.38	2.70	17	8.2	2.3%	61
DC Capital Bikeshare	11%	16%	1.15	2.01	16	4.3	2.6%	56
Boston Bluebike	7%	9%	1.29	1.83	16	4.9	2.4%	69
Philadelphia Indego	7%	9%	1.05	1.43	17	3.7	5.2%	41
Minneapolis NiceRide	9%	12%	1.13	1.66	19	3.5	15.5%	18
Portland Biketown	19%	14%	0.99	0.89	20	3.0	4.8%	27

*Includes only rides between 30 sec and 5 hours, and one-way rides to a different docking station
†Calculates MPH by dividing average distance by average duration
**Average monthly rides per bike in Austin were 62 in 2018

TECHNICAL ACCOMPLISHMENTS: ASSESSMENT OF MICROMOBILITY OPTIONS (TASK 4A)

Scope: Collection and dissemination of micromobility energy use and performance data

- Laboratory and in-field testing
- Overall watt-hours/mile energy consumption of multiple micromobility vehicles in various conditions
- Component-level efficiencies

Micromobility vehicle focus

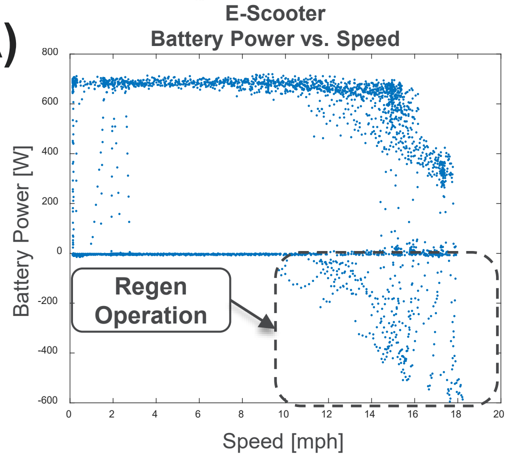
- E-scooters (testing completed at ANL)
- E-assist personal bicycles (upcoming testing at ANL) and microfreight vehicles (in-field instrumentation)

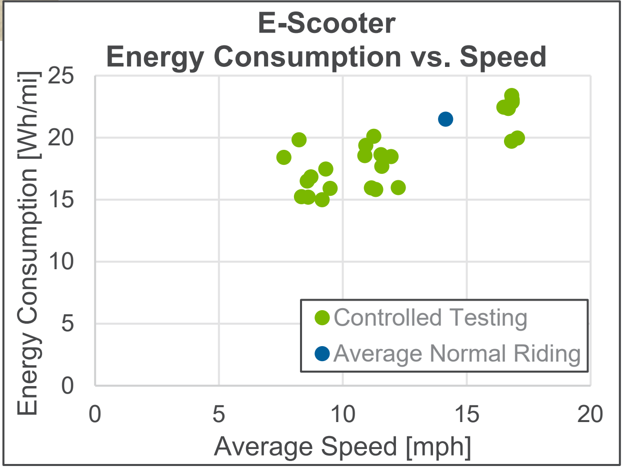
Summary:

- Developed small-scale data acquisition box for in-field data collection from micromobility vehicles
  - Battery voltage and current, GPS (distance and speed), and inertial measurement unit (IMU)-based acceleration data
- Bird One e-scooter testing and data analysis completed at ANL
- Charge Bikes Comfort e-assist bicycle to be tested in FY 2022
- Data and analysis to be shared for EEMS modeling efforts.

Bird One e-scooter

Photo by Simeon Iliev, co-PI, with permission





TECHNICAL ACCOMPLISHMENTS: MICROFREIGHT (TASK 5)

Scope: Evaluate microfreight energy, behavior potential

- Initial scenarios for microfreight

Summary:

- Scenarios drawn from cargo bike pilots in Seattle and NYC.

Core scenario trajectory and potential elements

Microfreight

	Conservative trajectory	Core scenario trajectory	Aggressive trajectory
Main scenario	~5% of viable freight deliveries via microfreight by 2040	~25% of viable freight deliveries via microfreight by 2040	~75% of viable freight deliveries via microfreight by 2040
Congestion impact scenario	No change	Eliminate 10% of large delivery vehicles (traffic, double parking)	Eliminate 50% of large delivery vehicles
Replacement ratio (cargo bikes : medium-duty trucks)	1 : 1	2.5 : 1	4 : 1
Operating radius (from microfreight hub)	1 mile	3 miles	5 miles
VMT reduction	0% fewer miles per package	25% fewer miles per package	50% fewer miles per package

Core scenario trajectory
Aggressive trajectory
Conservative trajectory

RESPONSES TO PREVIOUS YEAR REVIEWERS' COMMENTS

- Appreciation for topic, approaches, design, importance, and relevance. **Thanks!**
- May be useful to add an analysis of the possible correlation, dependencies, and orthogonality relationships of the scenario independent variables; weather parameters. **Thanks, we have incorporated these into scenario factors.**
- Agree with challenge of data access, plan to mitigate. **The MITIE team continues to engage with stakeholders and identify data sources and complementary partners.**
- Reviewer recommended that the research team approaches some of the corporate partners to develop a phone-based market survey that could help support some of the Fundamental Influencing Factor (FIF) data. **We are working with CEO, Mass CEC, and NABSA for data acquisition.**

COLLABORATION AND COORDINATION

National lab research partners

NREL NATIONAL RENEWABLE ENERGY LABORATORY

BERKELEY LAB

Argonne NATIONAL LABORATORY

Pacific Northwest NATIONAL LABORATORY

Non-lab research partners

EPA

U.S. Department of Transportation

University of Colorado Boulder

Massachusetts Institute of Technology

The University of Tennessee

Arctic Energy Office

Portland State University

Industry Stakeholders: inform approach, data, insights

Colorado Energy Office

The City of Columbus

Seal of the City and County of San Francisco

City of Boulder

Massachusetts Clean Energy Center

City of Fort Collins

Denver The Mile High City

NYC

North American Bikeshare and Scootershare Association

Forth Mobility

Bird Mobility

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- Collaborative relationships are essential to gain access to data and to understand needs and trends
- High-quality relationships with research and industry partners have yielded access to critically important data and insights
- Collaborations have led to publication opportunities
- Additional partners continue to emerge.

REMAINING CHALLENGES AND BARRIERS

Acquisition of micromobility data continues to be a challenge

- The pandemic posed disruptions from supply chains to operations
- Wariness of data-sharing in competitive commercial environment

Building collaboration with stakeholders remains important

- Continued interaction is critical for refining and understanding how micromobility adoption and use occurs

Micromobility continues to evolve

- New vehicles, use cases, and practices must be identified to inform Workflow models and derive accurate energy estimates
- Relative low cost and ease of access of micromobility for underrepresented communities is an opportunity to expand mobility electrification and address equity concerns.

PROPOSED FUTURE RESEARCH

- FY 2022:
  - Revisit micromobility energy bounding analysis paper (Sun et al. 2021) to include private ownership
  - **Key milestone:** Scenarios for Workflow of micromobility scenarios for smaller representative cities
  - Energy use instrumentation for in-field data collection for high-value data gap micromobility and microfreight vehicle variants.

- FY 2023:
  - Research new vehicles with high-value data gaps related to DOE simulation and analysis efforts
  - **Key milestones:**
    - Comprehensive project final report
    - Report estimating the net energy use of micromobility services based on analysis of trip-level data, including shift from other travel modes and device rebalancing/recharging
    - Final energy consumption and sensitivity analysis report on the tested micromobility vehicles
  - The project undergoes constant refinement and review from DOE technology managers and partners to address barriers and mitigate risk to ensure milestones are met.

Any proposed future work is subject to change based on funding levels.

SUMMARY

Micromobility continues popularity and rapid evolution

- This project contributes to characterization of micromobility use cases and behavioral adoption for Workflow modeling

Findings suggest micromobility returns energy benefits

- Energy benefits range depending on mode replaced, trip distance
- Net benefits are positive, contributing to increased mobility options
- Private ownership micromobility appears to be alternative to car use
- Behavioral models suggest opportunities for additional uptake

Additional potential benefits are identified

- Micromobility mitigates some equity barriers to mobility
- E-bikes, e-scooters are low-cost introductory pathway to EV adoption
- Supportive infrastructure encourages use through convenience, safety

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OAK RIDGE National Laboratory

Pacific Northwest NATIONAL LABORATORY

TECHNICAL BACKUP SLIDES

GUIDING RESEARCH QUESTIONS

- What are the potential energy savings from low, medium, and high market penetration of micromobility (in passenger, multimodal, and freight domains)?
- Which scenarios for micromobility use and related enablement of increased public transit use should be modeled/considered in the SMART 2.0 Workflow?
- To what degree can micromobility supplement/complement transit system operations?
- What are people's preferences toward micromobility? How do preferences vary across sociodemographic segments? How can this knowledge inform operations?
- What are optimal strategies to attain high user adoption and shift users toward more energy-efficient mode choices in terms of micromobility operation? How do these strategies affect energy savings, person-miles traveled, life cycle energy use, and adoption rates?

COLLABORATION AND COORDINATION

National lab research partners

- Lawrence Berkeley National Laboratory: co-PI partner
- Argonne National Laboratory: co-PI partner
- Pacific Northwest National Laboratory: complementary research
- NREL Director's Fellowship: complementary research

Non-lab research partners

- EPA: complementary research led by LBNL
- DOE Arctic Energy Office: complementary research
- University of Colorado, Boulder: complementary research
- Massachusetts Institute of Technology (MIT): complementary research
- Portland State University: complementary research
- University of Tennessee: complementary research

Industry Stakeholders: inform approach, data, insights

- Colorado Energy Office
- Massachusetts Clean Energy Center
- Washington, D.C., Department of Transportation
- City of Columbus, Ohio
- City of San Francisco
- City of Denver
- City of Boulder, Colorado
- City of Fort Collins, Colorado
- North American Bikeshare and Scootershare Association
- Forth Mobility
- Bird Mobility
- City of New York

- Collaborative relationships are essential to gain access to data and to understand needs and trends
- High-quality relationships with research and industry partners have yielded access to critically important data and insights
- Collaborations have led to publication opportunities
- Additional partners continue to emerge.

REVIEWER-ONLY SLIDES

RELATED WORK:
MICROMOBILITY-TO-TRANSIT SCENARIOS IN BEAM

Scope: Micromobility simulations in BEAM, in San Francisco Bay Area and Austin (funded by EPA)

- Baseline: 455 stations, 10,441 docks, 7,000 bikes (23 docks/station); $2 for first hour + $0.30 for every additional minute
- Sensitivities
  - Number of docks: 73 stations, 1,095 docks (15 docks/station; 10%) to infinite (dockless, assumes no restriction on bikes stored on street)
  - Number of bikes: 700 (10%), 14,000 (2x), 70,000 (10x)
  - Cheaper bikes: $1 for first hour + $0.02 for every additional minute
  - No bikeshare
- Scenarios
  - No light-duty vehicle/ride-hail modes available to agents who start and end trip within 400 (or 1,600) meters of BART/Caltrain station (0.25 or 1.0 miles)
  - No light-duty vehicle/ride-hail within 400/1,600 meters + 14,000 bikes
- Run with 30% and 50% population to test sensitivity to sample size

Summary:

- Forthcoming.

PUBLICATIONS AND PRESENTATIONS

B. Sun, V. Garikapati, A. Wilson, and A. Duvall. 2021. “Estimating energy bounds for adoption of shared micromobility.” *Transportation Research Part D: Transport and Environment* 100: 103012. https://doi.org/10.1016/j.trd.2021.103012.

K. Shankari, Leidy Boyce, Ethan Hintz, and Andrew Duvall. 2021. *The CanBikeCO Mini Pilot: Preliminary Results and Lessons Learned*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5400-79657. https://www.nrel.gov/docs/fy21osti/79657.pdf.

Alana Wilson and Andrew Duvall. 2021. “A review of the literature on cargo bikes as a microfreight mode with a focus on the United States.” Presented at the World Symposium on Transport and Land Use Research (WSTLUR) 2021, Portland, Oregon, August 9–13, 2021.

CRITICAL ASSUMPTIONS AND ISSUES

The MITIE project assumes some level of data availability and acquisition

– Most vendors greatly limit or exclude data access to researchers, though many cities are willing to share data required to be provided by vendors
– The MITIE team is working to migrate micromobility data to the DOE Livewire Data Platform, when possible, to ensure researcher access

Integration into Workflow models

– Current models may not be optimized for inclusion of micromobility and its range of forms. The team continues to coordinate with Workflow modelers to devise integration plans
– Prioritization of scenario implementation is determined by Workflow teams

Effects of the pandemic

– The pandemic dramatically affected micromobility, including disrupted supply chains, increased demand for vehicles, and financial collapse of some vendors and systems
– Micromobility is likely to persist but is in a state of flux for operations. The team continues to engage with key stakeholders to monitor and adapt to changes.