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

MULTIMODAL TRAVEL: MICROMOBILITY AND DELIVERY DRONES

April 11, 2023

SMART Webinar Series
Webinar #3

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

Argonne National Laboratory · Berkeley Lab · Idaho National Laboratory · NREL National Renewable Energy Laboratory · Oak Ridge National Laboratory · Pacific Northwest National Laboratory

TODAY'S SPEAKERS

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PREVIOUS & UPCOMING WEBINARS

FEBRUARY
OVERVIEW, KEY METRICS AND INSIGHTS SNEAK PEEK

MARCH
MULTIMODAL TRAVEL
Transit & Ridehail

APRIL
MULTIMODAL TRAVEL
Micromobility
Drones

TODAY

MAY
CONNECTED & AUTOMATED VEHICLES (CAVs)
Vehicle and powertrain control
Traffic signal control

JUNE
CAVs and Intelligent Transportation Systems
Transportation system impact, induced VMT, parking, curb management, land use, policies

JULY
FREIGHT
Last mile delivery

AUGUST
ELECTRIFICATION
EV charger deployment
Grid impact

2023

Webinar Materials

WHAT IS INCLUDED IN MICROMOBILITY?

Human powered, electric assisted vehicles

- E-scooters
- E-bikes
- Manual bikes
- Electric seated scooters/mopeds

Access variants

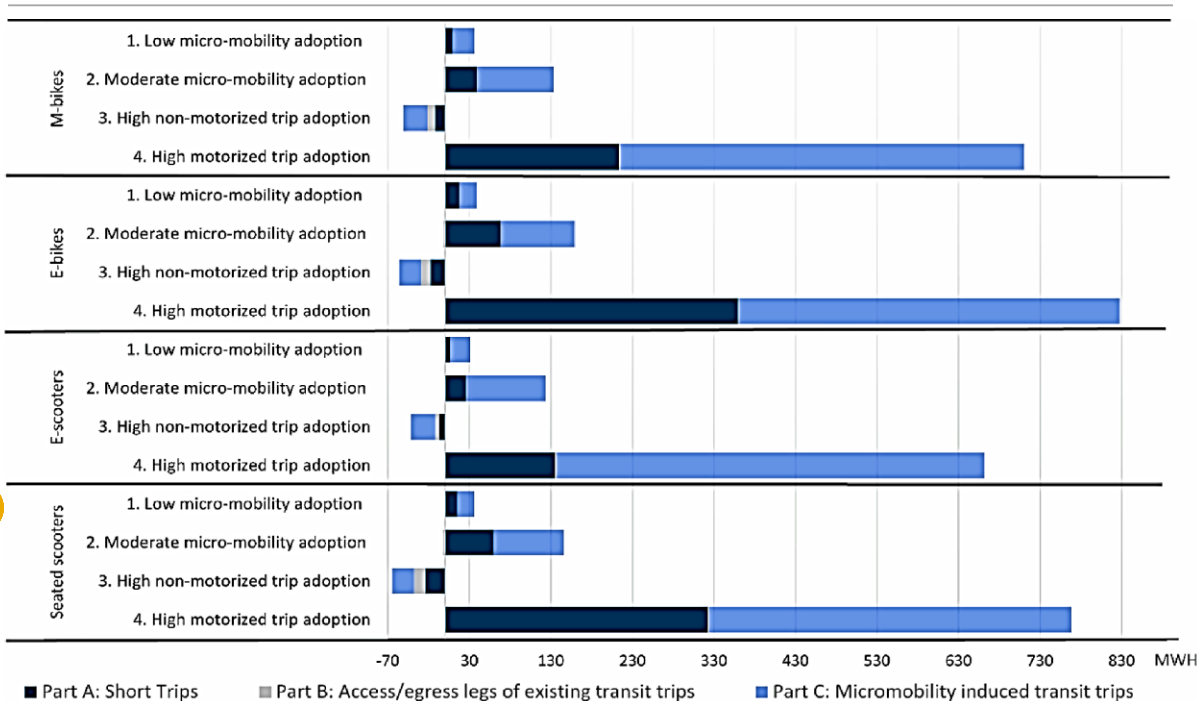
- Shared docked and dockless systems
- Privately owned (the bike in your garage)

Images: Andy Duvall

ESTIMATED ENERGY IMPACTS OF SHARED MICROMOBILITY

- **Micromobility replacement of motor vehicles reduces transportation energy**
- **High national adoption could save 805M gallons of gasoline annually**
- **Shared micromobility is a viable replacement for many trip types**

- **Cities could support shared micromobility to gain transportation energy benefits**

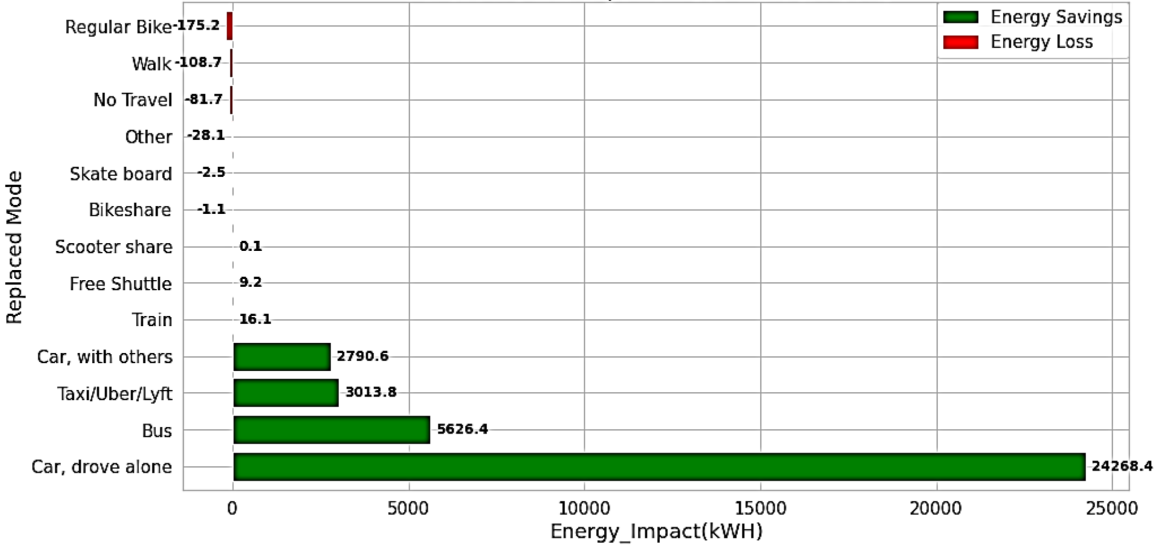


E-BIKE PROGRAMS PROVIDE EFFICIENT MOBILITY FOR LOW-INCOME POPULATIONS

- **Energy benefits (replacing motorized modes) outweigh energy costs (replacing non-motorized modes)**
- **Single occupancy car trips are the most replaced mode**
- **Travel time benefits can improve quality of life**

- **E-bike rebate programs could be implemented to facilitate motor vehicle trip replacement**

Sketch of Energy Impact of E-Bike trips
Contribution by replaced mode towards a total of 35,327 (kWH)
Based on 50,395 confirmed trips from 146 users of 13,5471 total trips from 219 users (37%)

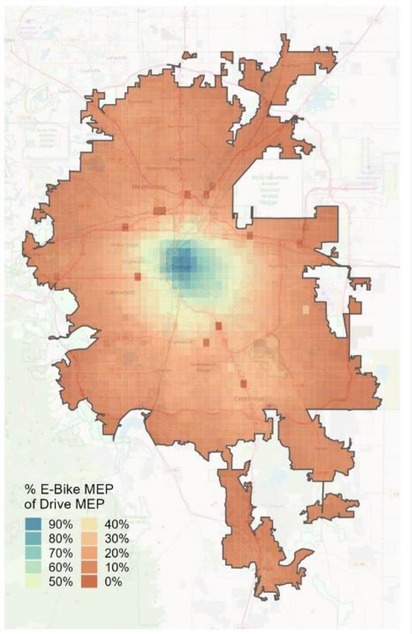


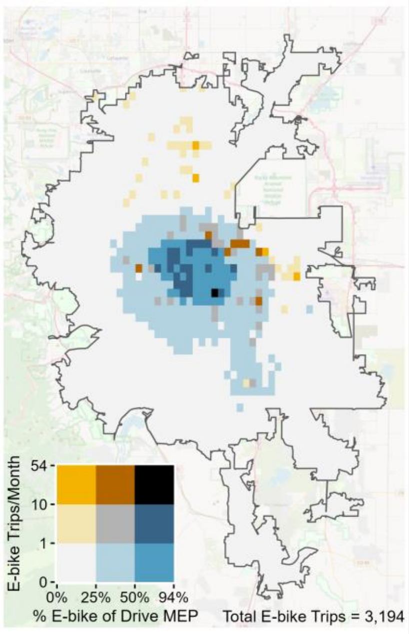
E-BIKES APPROACH ACCESSIBILITY BENEFITS OF CARS

- **The ratio of e-bike MEP to drive MEP reveals e-bikes score ≥50% the magnitude of driving in some settings**
- **E-bikes can provide as much as 80% of the quality of mobility provided by a much faster mode such as driving**

MEP = Mobility Energy Productivity

- **Cities could continue encouraging e-bike deployment in dense urban areas to replace driving for certain trips**

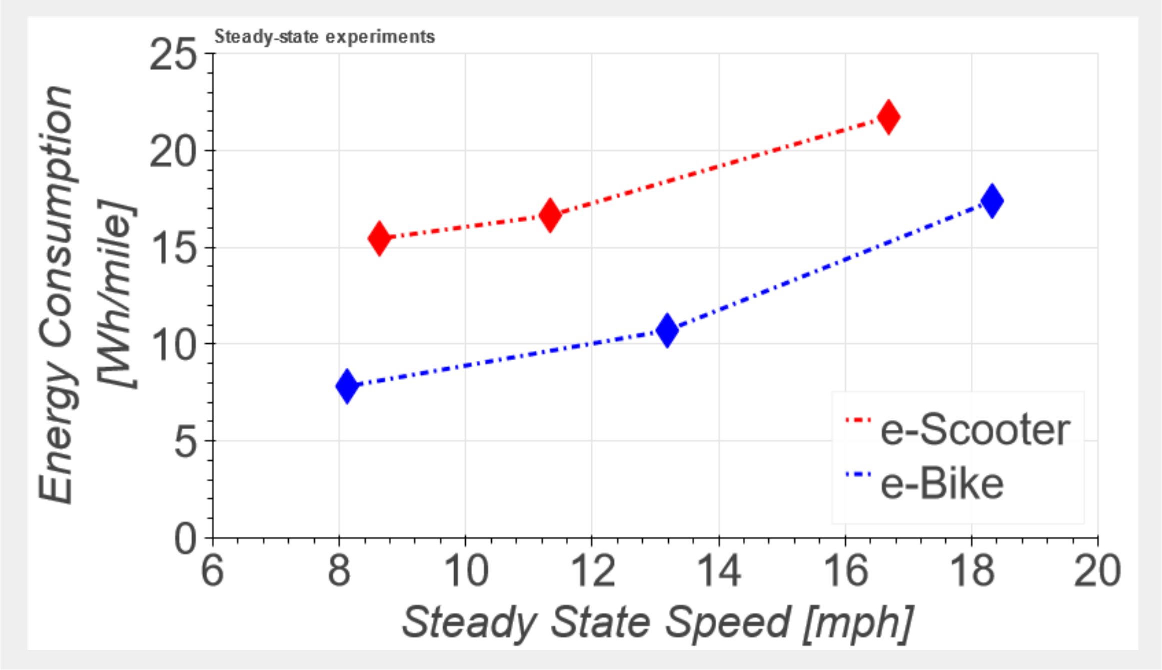




MICROMOBILITY ENERGY CONSUMPTION VARIES BY OPTION AND USAGE

- **Steady-state experiments with both vehicles in throttle mode**
- **Experiments confirm energy differences seen in nominal ranges**
- **E-bike more efficient compared to e-scooter, though both are much more efficient than cars**

- **Industry standardization for energy consumption could assist buyers in selecting micromobility vehicles**



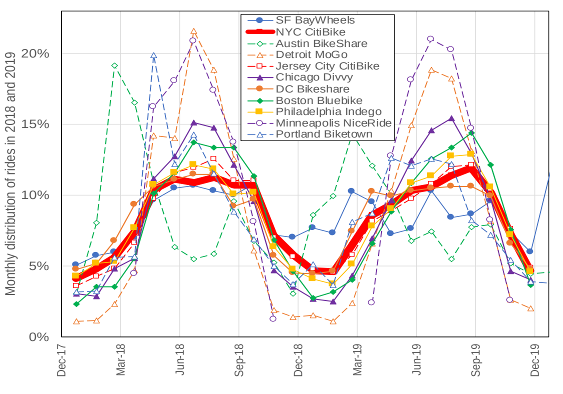
SHARED BIKE/SCOOTER USE VARIES BY SEASON AND HOUR

- **Number of rides increases in warmer and drier weather**
- **Seasonal variation bigger in colder cities (Detroit, Minneapolis, Chicago, Boston); less variation in milder cities (SF, Austin)**
- **Pre-COVID, use peaked during commute hours on weekdays, and at midday on weekends**

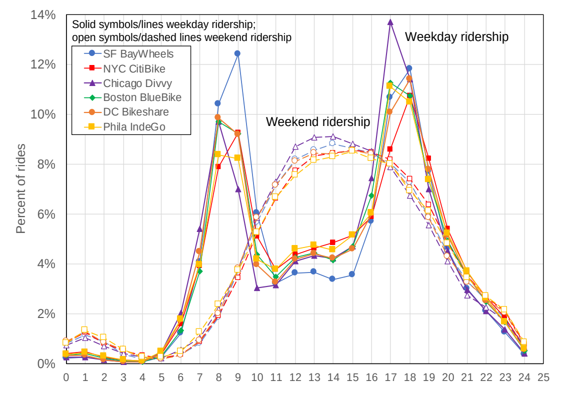
- **Cities should consider seasonal variation when determining program size, and how hourly variation can influence siting of docks, when contracting with service providers**

Docked bikeshare programs in 11 U.S. cities

Monthly distribution of rides



Hourly distribution of rides

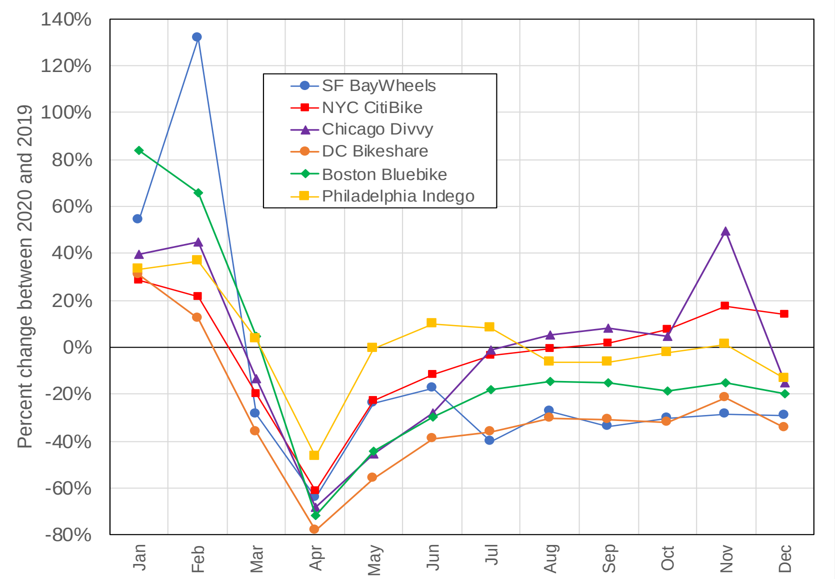


RIDERSHIP RECOVERED QUICKLY FROM PANDEMIC IN SOME CITIES

- **Bikeshare use down 50% to 80% at start of pandemic**
- **But recovered by end of 2020 in half of the largest cities (New York, Chicago, Philadelphia)**
- **Low ridership in other large cities (SF, Boston, DC) likely due to continued working from home**

- **Bikeshare provided safe travel mode and flexibility relative to transit/rideshare during pandemic**

Percent change in ridership between 2020 and 2019

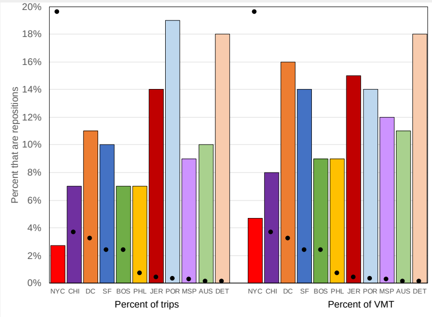


REPOSITIONS CAN ACCOUNT FOR LARGE FRACTION OF TRIPS AND VMT

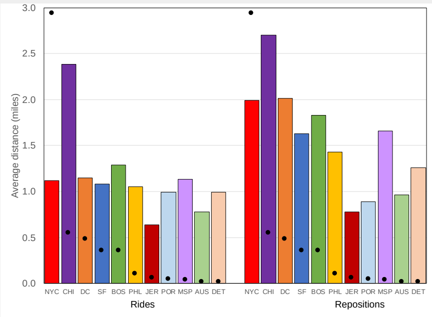
- **Wide range in use patterns by city (sorted by program size)**
- **Repositions are 7% to 19% of trips, 8% to 18% of VMT (2.7% and 4.7% in NYC)**
- **Repositions tend to be longer distance than rides**
- **Average trip speed and number of daily rides per bike tend to decrease as program size decreases**

- **Stakeholders should keep in mind the impacts of repositioning on the net system performance**

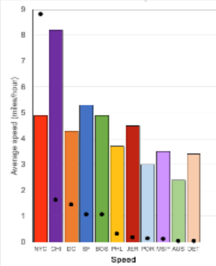
Pct of trips/VMT that are repositions

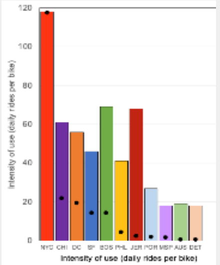


Average distance ride/reposition



Average speed





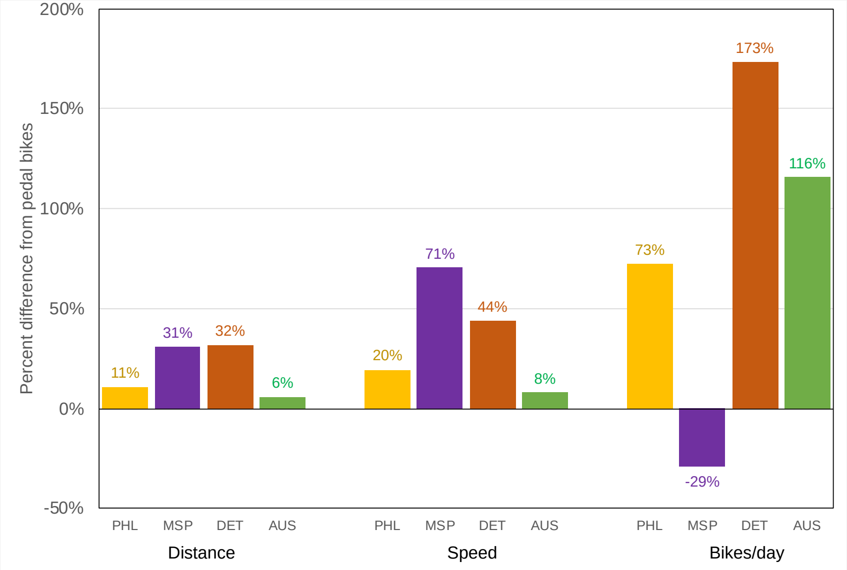
Daily rides per bike

E-BIKE RIDES ARE LONGER AND FASTER THAN PEDAL BIKE RIDES

- **E-bike rides are 6% to 32% longer and 8% to 71% faster than pedal bike rides**
- **E-bikes tend to be used more intensively (daily rides per bike), except in Minneapolis**
- **In some locations, e-bikes may require fewer repositions than pedal bikes**

- **Cities could consider deploying more e-bikes vs. pedal bikes**

Percent e-bike difference from pedal bikes

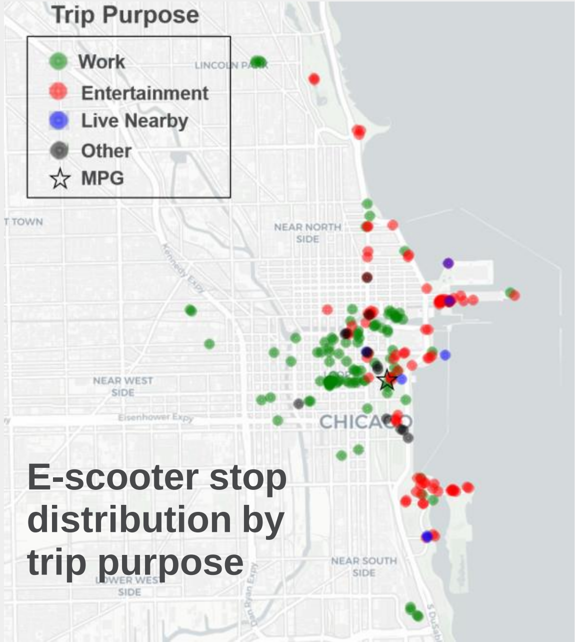


MICROMOBILITY TRANSFER SERVICE CAN HELP REDUCE PARKING CONGESTION AND USE OF TAXI/TNC IN URBAN AREAS

- Pilot study in Millennium Park Garage (MPG) show promising use of e-scooter service as a FMLM solution to parking in downtown area
- The service provided increased coverage area for parking users
- High demand for work and entertainment purposes

TNC = transportation networking company
FMLM = first mile, last mile

- Cities & parking managers could work together to provide micromobility options to parking users



E-scooter stop distribution by trip purpose

90% of destinations are beyond typical walking distance (0.25 miles) from MPG

- Average stop is 0.72 miles from MPG
- Users traveled up to 5 miles from MPG using e-scooters

WHAT IS THE IMPACT OF DRONE DELIVERY?

Provides a solution for “Microfreight”

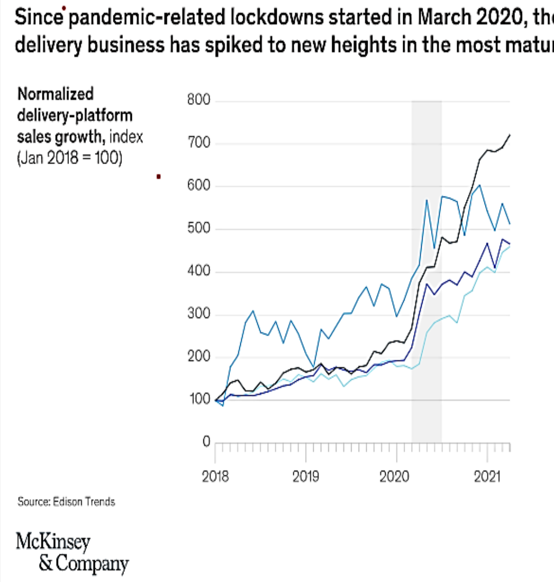
- Localized delivery of prepared food, groceries, prescriptions, Cheez-Its
- Business to Consumer or Business to Business

Solution offers “air advantages” to local delivery

- More direct routing without road network
- Faster local speeds with reduced congestion
- Increased automation

- **Drone delivery can apply to urban and rural environments**

Food delivery demand has grown more than 500% since 2018 (*McKinsey)



Inhibiting S’s:

- Standards (Regulation)
- Safety
- Secrecy (Privacy)
- Sound

DIFFERENT TYPES OF DRONES CAN SERVE DIFFERENT PURPOSES

Drone 1 – Large Rotary

Payload: 13 lbs.
Speed: up to 40 mph
Range: ~10 Mile

5.4 x 5.0 x 2.4 ft / ~20 lbs/$$

Drone 2 – Small Rotary

Payload: 3 lbs.
Speed: up to 30 mph
Range: ~2.5 miles

1.7 x 1.7 x 1.1 ft / ~8 lbs./$

Drone 3 – Large VTOL

Payload: 13 lbs.
Speed: ~60 mph
Range: ~60 miles

6.5 x 5.0 ft / ~40 lbs./$$$$

Drone 4 – Small VTOL

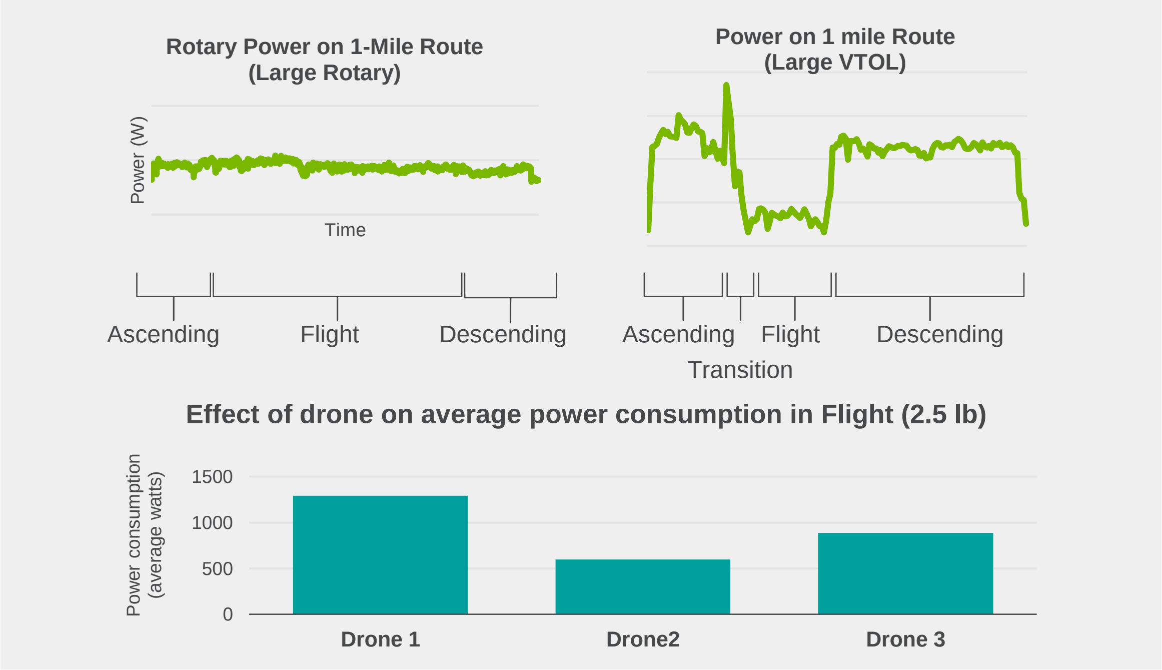
Payload: 3 lbs.
Speed: 55 mph
Range: ~12 miles

4.3 x 3.3 ft / ~11 lbs./$$$

DRONE SIZE AND TYPE HAVE SIGNIFICANT IMPACTS ON POWER

- **VTOL and Rotary drones have different energy profiles**
- **Lighter drones use much less energy in hover**
- **In flight, Large VTOL uses less energy than Large Rotary at twice the speed**

- **Providers could use different drone types to optimize range and energy for different deliveries**

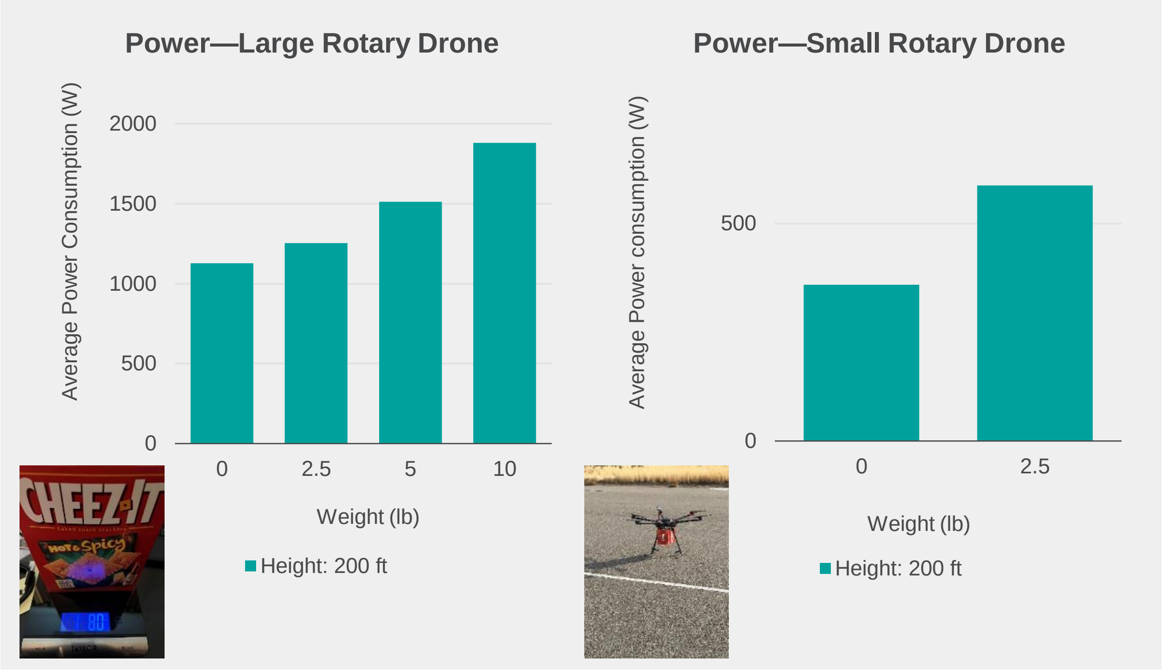


PACKAGE WEIGHT HAS NEAR LINEAR INCREASE IN ENERGY

Package weight increases energy and decreases range

- **Weight of packages increases power consumption consistently**
- **Large rotary increase:**
  - **2.5 lb: 12–20%**
  - **5 lb: 34–40%**
  - **10 lb: 67–80%**
- **Small rotary increase:**
  - **2.5 lb: 63–67%**

- **Drone users could consider the weight of their deliveries when deciding range and which drones to use**



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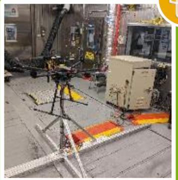
EFFICIENCIES IN LARGER DRONES DO NOT OFFSET HEAVIER WEIGHTS

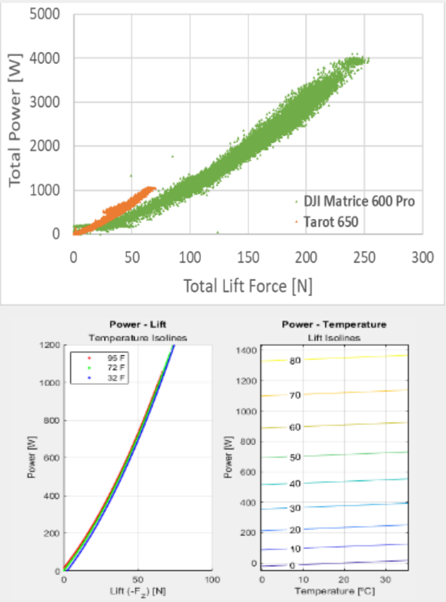
Physics of weight and temperature affect range and payload

- Large rotary drone has significantly higher maximum lift force and efficiency but uses more power per unit of payload
- Temperature increases power use by 10–15% from 32–95 °F

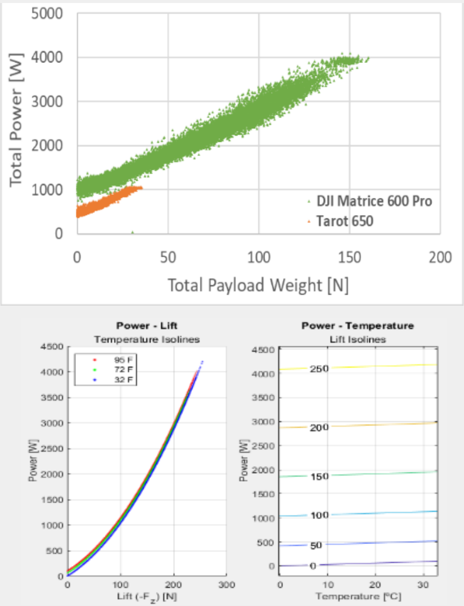
- Drone users could better plan range using drone size and temperature



Power vs. Lift Force 72°F



Power vs. Payload Weight 72°F



SERVICE WINDOW CHANGES DRONE FLEET NEEDS

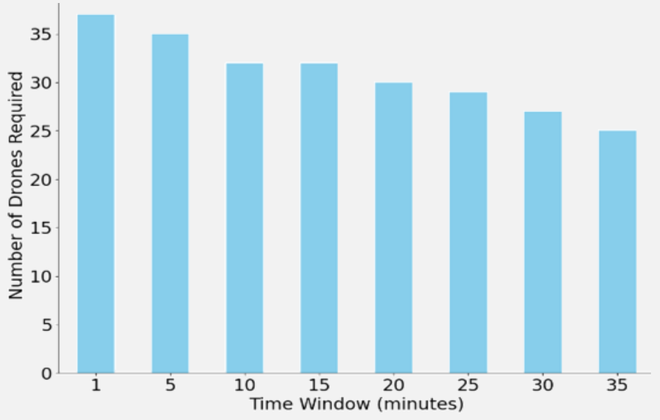
Large number of drones needed for full-service offering

More responsive delivery windows require significant number of drones

(Based on large rotary drone deliveries)

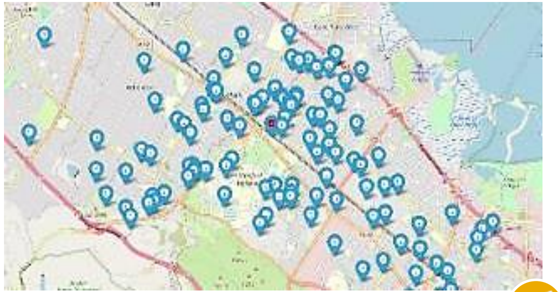
Effect of Time Window on Number of Drones Required

30 mph / 2.5 lbs payload / 126 deliveries



Percentage reduction in the number of drones required

Time Window	% Reduction
5 minutes	5%
10 minutes	14%
15 minutes	14%
20 minutes	19%
25 minutes	22%
30 minutes	27%
35 minutes	32%



- **Service providers will need to balance fleet management with speed of service**
- **Fresh products likely require more drones**

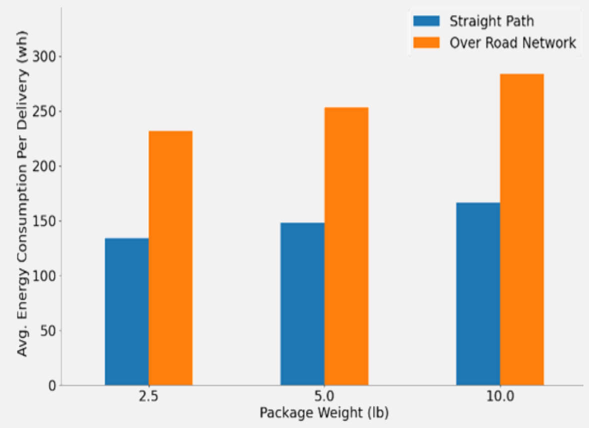
ROUTING RESTRICTIONS CAN LIMIT RANGE

Following road networks increases energy dramatically

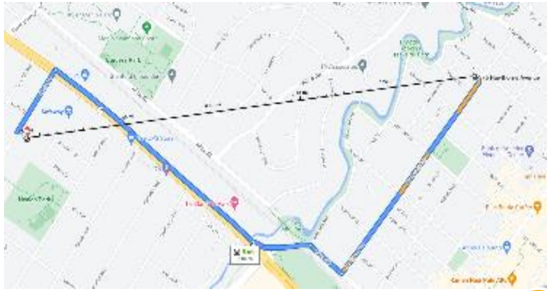
Restrictions to road network eliminates 60% of delivery options

Remaining deliveries have 70% higher energy

Effect of Flight Path and Package Weight on Average Energy Consumption



- **Large rotary Drone**
- **Speed: 30 mph**
- **Number of deliveries: 44 (excluding 82 out of range)**
- **Average distance**
  - Straight path: 0.93 miles
  - Over road: 1.47 miles



- **Regulators could consider the impacts of flight restrictions on the capabilities for drone deliveries**

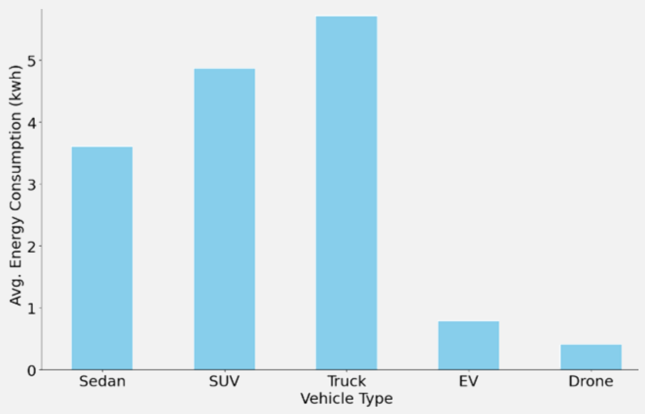
DRONES SAVE SIGNIFICANT ENERGY OVER LARGER VEHICLES

Even EVs consume twice the energy with single deliveries

Even in the most energy-intensive scenario (15 mph, 10 lbs), drones save energy over ground vehicles

(Drones offer limited application here due to poor energy scenario)

Effect of Vehicle Type on Avg. Energy Consumption



Percentage increase in average energy consumption compared to using drone

Vehicle Type	% Increase in Energy Consumption
EV	92%
Sedan	782%
SUV	1091%
Truck	1300%

- Large rotary / 15 mph / 10 lb. payload
- Over road-network
- Number of deliveries: 44 (excluding 82 out of range)

- **Providers could save significant energy using drones for single deliveries of small payloads**

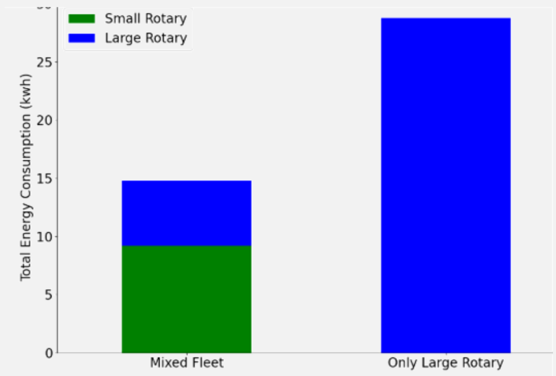
MIXED FLEETS OF DRONES COULD BE MORE EFFICIENT

Using small and large drones together can save significant energy

Small rotary drone has lower energy for smaller packages but has limited range

Mixing drones to serve different deliveries can reduce total energy significantly (49% reduction)

Comparison of Energy Consumption Between Different Fleet Types



2.5 lbs. package
Full set of deliveries at 30 mph / Reduced to 98 deliveries at 15 mph

Mixed Fleet: Large and Small Rotary	Drone Speed (mph)	
	30	15
Number of Locations	126	98
% Energy Reduction	49%	38%

- **Providers could save total energy by using the smallest drone for the range and payload**

SMALLER BATTERY SIZE COULD INCREASE MANAGEMENT NEEDS

Lighter batteries reduce energy needs but also reduce range

- **Small drones take less energy but have limited battery and range**
- **Range and speed can impact number of drones needed**
- **Battery management can actually increase overall time and labor**

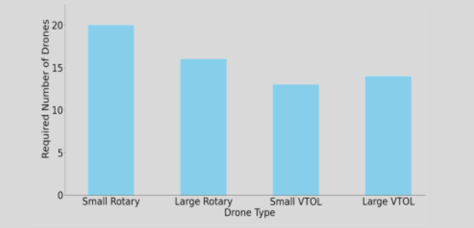
- **Fleet managers could balance total energy with labor and management costs**

Drone types	Total energy (kWh)	# of Drones	Delivery time (min)	Battery change time
Small Rotary	4.6	20	1,071	115
Large Rotary	12.6	16	1,021	65
Small VTOL*	6.5	13	809	90
Large VTOL	14.9	14	752	20

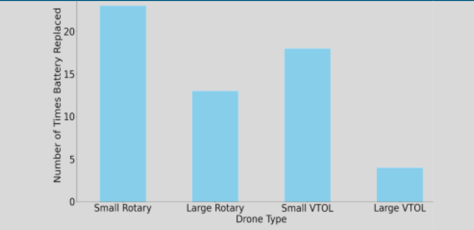
- **Number of deliveries: 58**
- **The same number of deliveries made by all drone types**
- **Time window: 20 minutes**

* Average values used for small VTOL

Effect of Drone Types on Required Number of Drones



Effect of Drone Types on Number of Battery Replacements



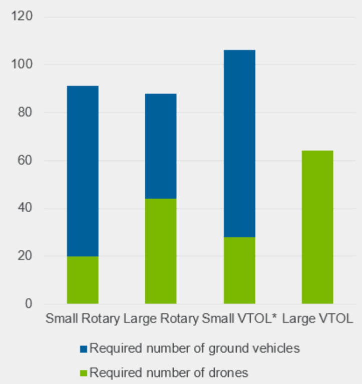
DRONES COULD WORK WITH GROUND FLEETS TO FULFILL FULL RANGE

- **Drones can have range and weather restrictions**
- **Many services would require ground vehicles as well**
- **Practical management of both fleets can improve throughput**
- **Fleet managers can optimize their deliveries with drones and ground vehicles**
- **Drones still use less energy**

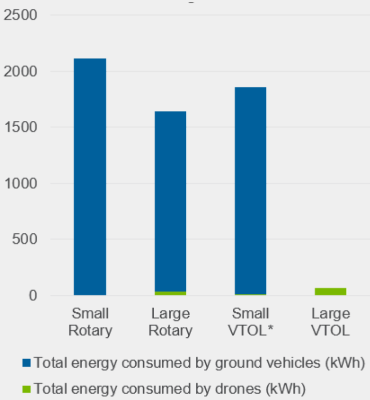
Expanded to total deliveries in full range (up to 20 miles away)

- **Total number of deliveries:** 207
- **Time window:** 20 minutes
- **Ground vehicle type:** Hyundai Accent (2022)

Vehicle Mix by Drone Type



Total Energy by Vehicle Type

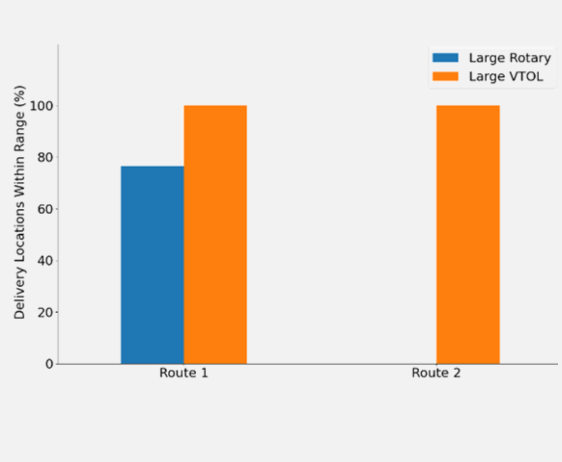


LARGE VTOL ENABLES RURAL DELIVERY OPTIONS

Charging at destination can double range
Larger VTOL can extend to further distance
Larger VTOL saves energy over distances

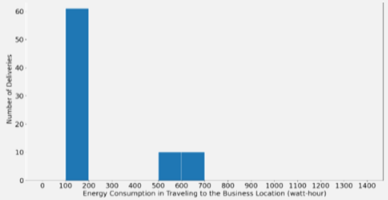
Drone speed:
- **Large Rotary:** 30 mph
- **Large VTOL:** 55 mph

Delivery Range of Different Drones



Histogram of Energy Consumption of Large Rotary in Route 1

Histogram of Energy Consumption of Large VTOL in Route 1

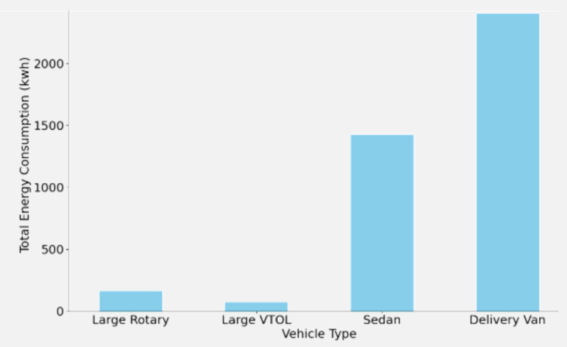


- **Businesses can look at large VTOLs with longer range to provide services to more remote locations**
- **Businesses can perform**

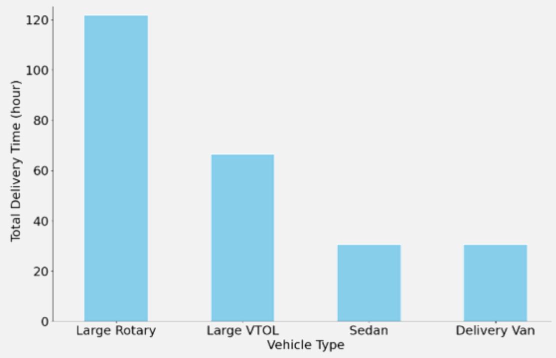
DRONES COULD USE LESS ENERGY THAN GROUND ROUTE VEHICLES BUT TAKE MORE TOTAL TIME

Even compared to a vehicle on a delivery route (visiting multiple locations) the drones save significant energy

Comparison of Drone and Ground Vehicle Energy Consumption in Route 2



Comparison of Drone and Ground Vehicle Delivery in Route 2



Drones visit just one location per trip

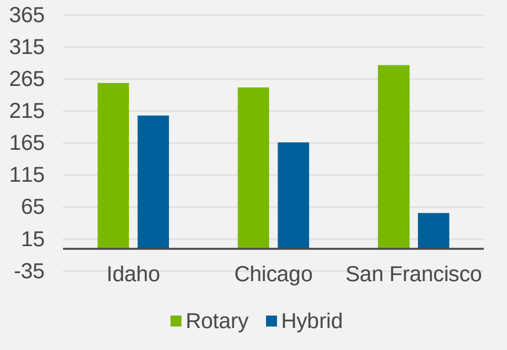
Vehicles visit multiple locations in a route

*Assuming rotary drone could charge to complete routes

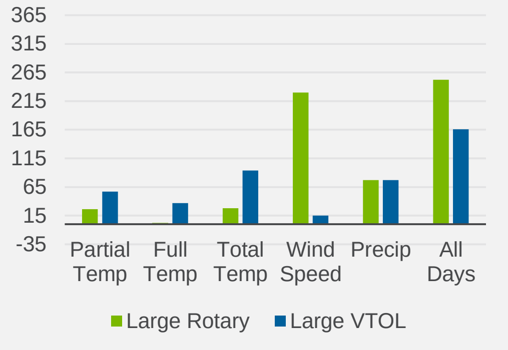
- **Providers could reduce energy for less dense, longer routes with drones, but will balance with time**

WEATHER COULD IMPACT USE OF DRONES AND DRONE CHOICE

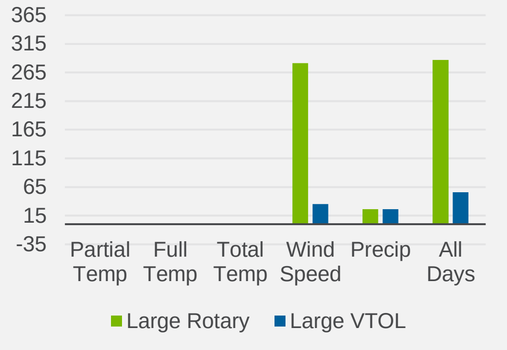
Total Days with Drone Impact
2022



Days with Drone Impacts
2022 | Chicago



Days with Drone Impacts
2022 | San Francisco



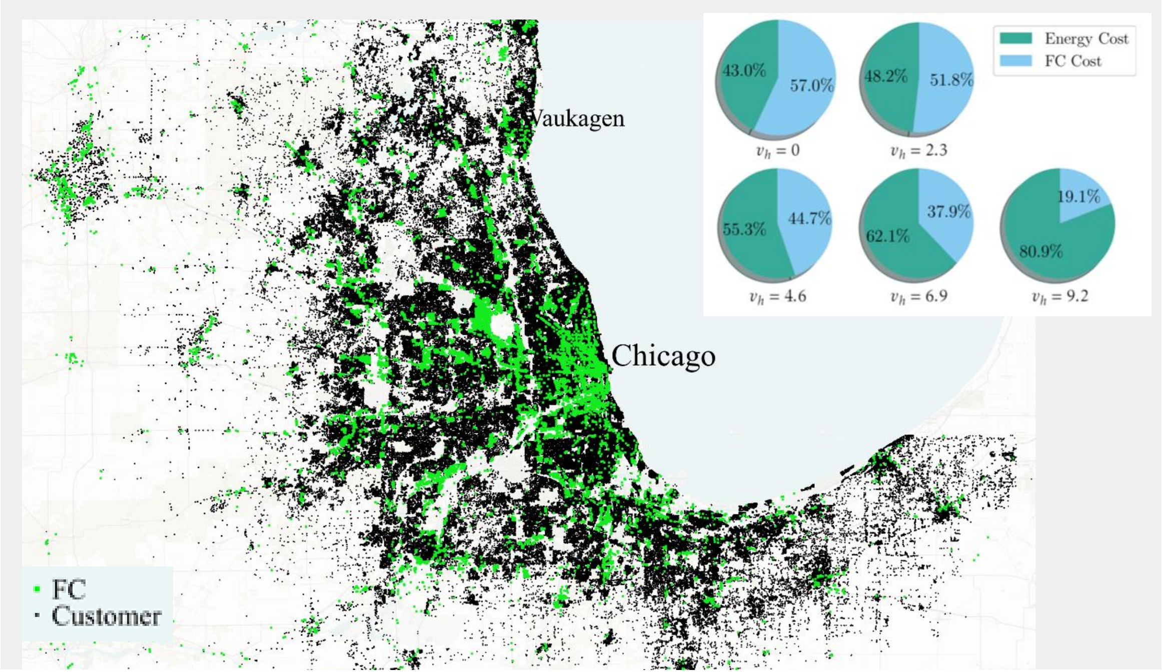
- **Drone users could improve reliability and use by considering drones for the local weather (VTOLs are better in wind but worse in cold)**
- **Businesses could consider plans to integrate with ground solutions for bad weather**

DRONE DELIVERY CAN REPLACE TRUCKS, BUT WIND GREATLY AFFECTS EFFICIENCY

Wind also makes energy costs dominate facility costs

- **Optimization modeling for connecting a set of fulfillment centers (FC) to customers can find optimal number of FCs and drones required**
- **Wind increases the number of FCs needed by reducing range, and increases energy cost**
- **Cost of energy use predominates over the cost of FC construction above 10 mph**

- **Industry should explore wind patterns before deploying drones, prioritizing low wind environments**

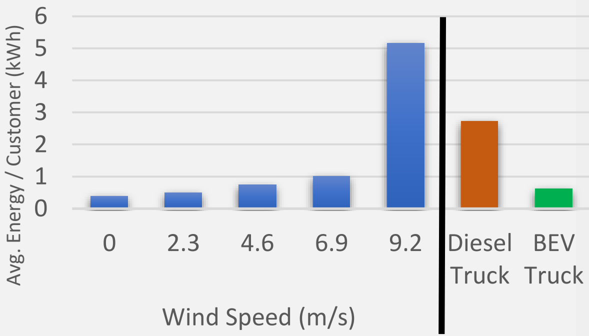


DRONE DELIVERIES LESS EFFICIENT THAN BEV TRUCK AT 10MPH AND DIESEL TRUCKS AT 20MPH WIND SPEED

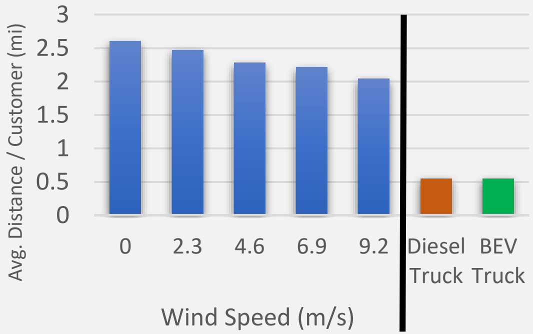
- Wind is detrimental to drone performance, especially above 10 mph
- In a 20-mph wind, a drone will use twice the energy per customer than a diesel truck
- High winds also reduce the avg. distance to a customer, increasing the number of FCs needed

- Mix of delivery approaches—drone and BEV truck—can be considered to optimize efficiency

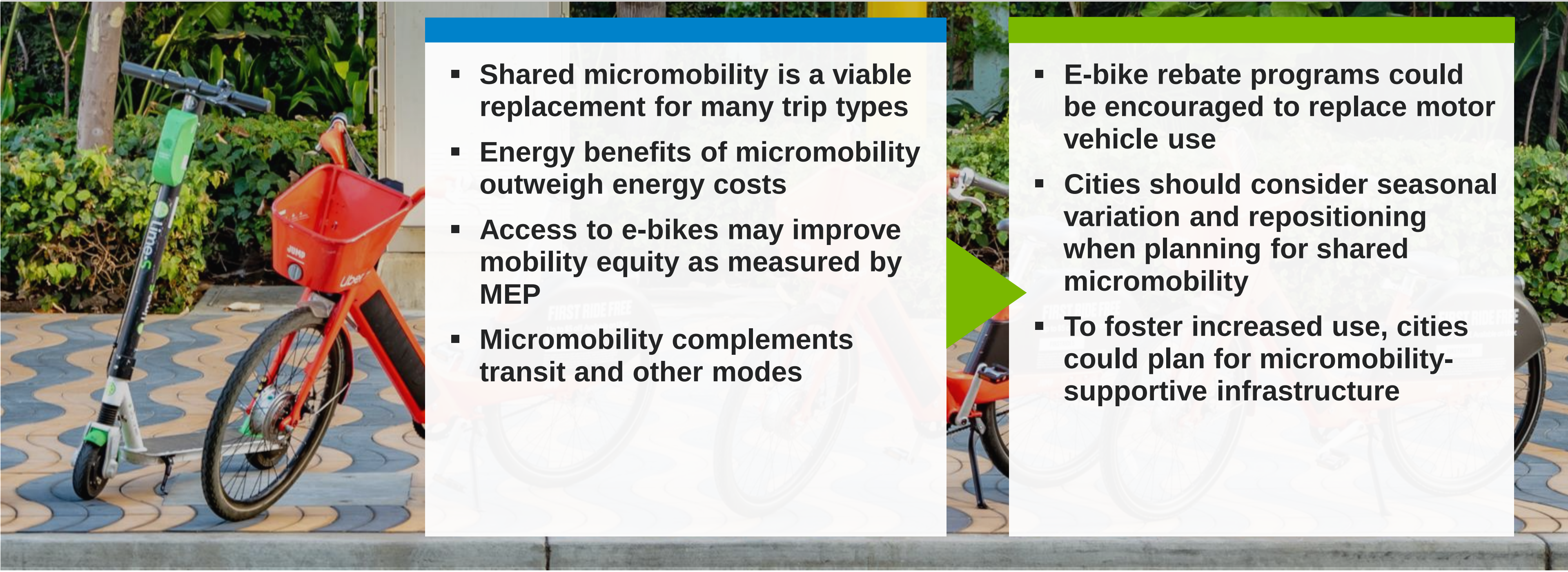
Per Customer Average Energy Comparison of Drone and Ground Vehicles



Per Customer Average VMT Comparison of Drone and Ground Vehicles



SUMMARY OF KEY INSIGHTS AND ACTIONS: MICROMOBILITY



- Shared micromobility is a viable replacement for many trip types
- Energy benefits of micromobility outweigh energy costs
- Access to e-bikes may improve mobility equity as measured by MEP
- Micromobility complements transit and other modes

- E-bike rebate programs could be encouraged to replace motor vehicle use
- Cities should consider seasonal variation and repositioning when planning for shared micromobility
- To foster increased use, cities could plan for micromobility-supportive infrastructure

SUMMARY OF KEY INSIGHTS AND ACTIONS: DRONES

- Drones can offer improved energy use and efficiencies over ground vehicles in local deliveries
- VTOL and rotary drones have significantly different attributes with weather and energy attributes over distances
- Larger VTOLs can enable improved rural solutions
- Right-sizing drones and optimizing with ground vehicles can reduce energy and improve weather mitigations

- Delivery providers can improve services, reduce delivery time, and reduce energy using drones
- Selecting the right drone for the delivery scenario can greatly improve the chance for success
- Actively working to reduce inhibitors can improve the acceptance and reduce issues with drone deliveries

CLOSING THOUGHTS

- These technologies continue to evolve
- Legacy practices could be complemented by emerging technologies
- New pathways could enable favorable energy and equity outcomes

- Agencies could work toward integrating new technologies
- Cities could benefit from agile approaches to meet changing practices

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Drones

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FREIGHT
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