2017 R&D Project Report

Electric Bikes: Survey and Energy Efficiency Analysis

Executive Summary

Efficiency Vermont, in partnership with Burlington Electric Department, set out to understand the electric bicycle (e-bike) market in Vermont, and to evaluate e-bikes as an energy efficiency measure. Over ninety e-bike owners from across the state completed a survey. Efficiency Vermont's analysis of the results is presented here. The survey indicated that the great majority of e-bike owners were extremely satisfied with their investments. Ownership is increasing rapidly in Vermont, especially around urban areas. E-bikes displace meaningful amounts of driving miles, and are much more efficient than electric or conventional cars. However, e-bikes consume very little electricity relative to their upfront costs, so utility incentives to promote certain relatively more efficient e-bike models would be impractical. The large battery chargers that are paired with e-bikes may waste more energy than the bikes themselves use. These battery chargers for e-bikes and other large equipment may present a good opportunity for energy efficiency programs.

Background

E-Bikes are gaining in popularity as the technology improves and prices fall. Efficiency Vermont wished to evaluate the e-bike market in the state, the way e-bikes are used, and the potential for energy efficiency measures related to e-bikes.

Research Plan

In partnership with local bike organizations and retailers, Efficiency Vermont will gain increased knowledge on new owners' electric bike selection decision and satisfaction with the bike after using for several months. This effort will help Efficiency Vermont to (1) understand existing electric bicycles in Vermont, (2) evaluate energy efficiency of various bicycles, and (3) develop a framework to characterize and evaluate the various electric bike equipment available in the state.

Approach

An online survey was distributed over the summer of 2017 with help from local organizations. The survey was designed to gather information from E-bike owners in Vermont. Efficiency Vermont analyzed the survey results to glean insight into e-bikes as an efficiency measure. The results of the survey analysis are included in this report.

Contents

Background

E-Bikes are growing increasingly popular worldwide. Sales in China have been robust for years, with over 200 million e-bikes on the road as of 2016.[1] The market is expanding rapidly in Europe, with over 1.6 million units sold in 2016[2].Worldwide annual sales are in the tens of millions, though in the U.S., sales were only in the hundreds of thousands as of 2016[3]. U.S. sales increased rapidly in 2017.[4]

Vermont organizations are actively promoting e-bikes as a way to reduce automobile use. At least two organizations: VBike[5] and Local Motion[6], have established e-bike lending programs to allow locals to try out an e-bike for a few days. Burlington Electric Department is offering a rebate to customers purchasing e-bikes.[7]

Legal Status of E-bikes

E-Bike Classes

E-Bikes are often placed into three classes,[8] summarized below:

i. Class 1 electric bicycle: Assists pedaling up to a maximum speed of 20mph, at which speed assistance stops. Will not provide electric power without pedaling.
ii. Class 2 electric bicycle: A bicycle with working pedals, capable of propelling itself without pedaling to a maximum speed of 20mph. Motor does not operate above 20mph. May also have an assist mode.
iii. Class 3 electric bicycle: Similar to Class 2, but limited to 28mph, and must have a speedometer.

Legality in Vermont[9]

Vermont law appears to consider a *Motor-Assisted Bicycle* to be essentially a Class 1 or Class 2 e-bike, as long as the motor output is under 1000 watts. Class 3 E-Bikes are considered *Motor-Driven Cycles,* and are treated as mopeds.

Vermont law treats a *Motor-Assisted Bicycle* just like a conventional bicycle, except that it prohibits use of these e-bikes on roads by persons under 16 years old.

E-bikes with a selectable "off-road mode" which allows for speeds over 20mph would probably not qualify as *Motor-Assisted Bicycles* under Vermont law.

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1 www.bike-eu.com/home/nieuws/2016/4/china-bans-e-bike-use-in-major-cities-10126136
2 www.navigantresearch.com/research/electric-bicycles
3 cyclingindustry.news/u-s-electric-bike-market-up-at-least-50-says-market-analysts-ecycleelectric/
4 www.bike-eu.com/sales-trends/nieuws/2017/9/usa-e-bike-market-doubles-in-units-and-value-10131284
5 www.vbikesolutions.org/take-it-home.html
6 www.localmotion.org/marigold
7 www.burlingtonelectric.com/ebike
8 peopleforbikes.org
9 See Appendix: Vermont Legal Language

E-Bike Types

E-Bikes are built for particular uses. To provide an apples-to-apples comparison system, E-bikes in this report are classified according to the types below.

Bike Type Definitions:

www.radpowerbikes.com

Cargo Bikes: Bikes with an extended wheelbase and larger-than-standard racks for carrying cargo.

www.sondors.com

Fat Tire Bikes: Bikes with larger-than-standard tires, advertised as "Fat" bikes.

www.juicedbikes.com

Mountain Bikes: Bikes with suspension, sold without standard cargo racks.

www.Electrabike.com

Standard Bikes: "Commuter" bikes. Bikes without suspension, without fat tires, and with a standard wheel base. Most come with a rear rack.

dillengerelectricbikes.com

Modified Bikes: Retrofit kits may be installed on almost any type of bicycle to convert it into an e-bike.

E-Bike Market

Efficiency Vermont set out to evaluate what role, if any, it should play in the e-bike market in Vermont. A study of the market was completed to gather the necessary background information.

Survey Design and Promotion

A survey of current and prospective e-bike owners was developed to assess the present applications of the technology in Vermont. The survey questions gathered information on reasons for purchase, e-bike usage for different types of trips, and owner satisfaction. The survey results are detailed below.

Efficiency Vermont and Burlington Electric Department would like to extend heartfelt thanks to all of the survey respondents as well as organizations who assisted in promoting the survey, including:

- Drive Electric Vermont
- Local Motion
- Old Spokes Home
- VBike Solutions
- VECAN: Vermont Energy & Climate Action Network

Survey Participation

Table 1

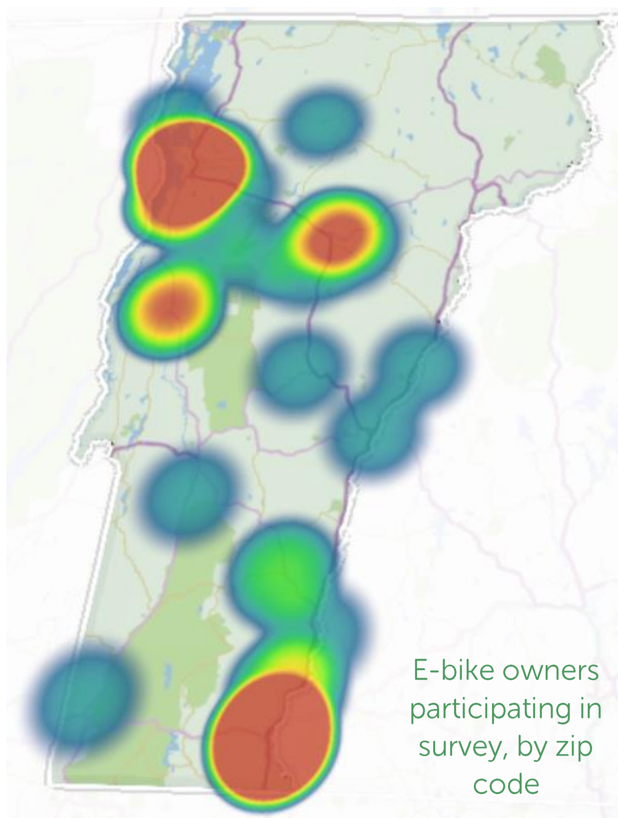
County and Town	Total Responses
Addison	**6**
Middlebury	4
New Haven	1
Starksboro	1
Bennington	**1**
Shaftsbury	1
Chittenden	**43**
Burlington	20
Colchester	2
Essex Junction	2
Richmond	1
Shelburne	6
South Burlington	10
Winooski	2
Grand Isle	**1**
South Hero	1
Lamoille	**1**
Johnson	1
Orange	**1**
North Thetford	1
Rutland	**1**
Wallingford	1
Washington	**8**
Barre	1
East Montpelier	1
Montpelier	4
Northfield	1
Waitsfield	1
Windham	**27**
Brattleboro	23
Putney	3
Westminster	1
Windsor	**4**
Bethel	1
Chester	2
White River Junction	1
Grand Total	**93**

[10]

Table 2

Total Survey Starts	Non-E-Bike Owners Providing Useful Data	E-Bike Owners Providing Useful Data
161	34	94

Figure 1



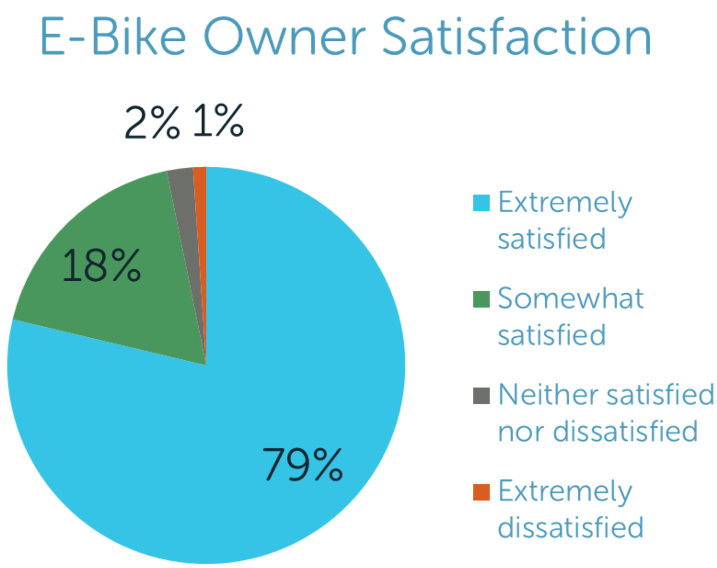
E-bike owner responses came from across the state, but urban zip codes in Chittenden and Windham counties were most heavily represented.

[10] Ninety Four e-bike owners provided useful responses to the survey. One of these did not provide a zip code.

General E-Bike Results

E-Bike Owner Satisfaction

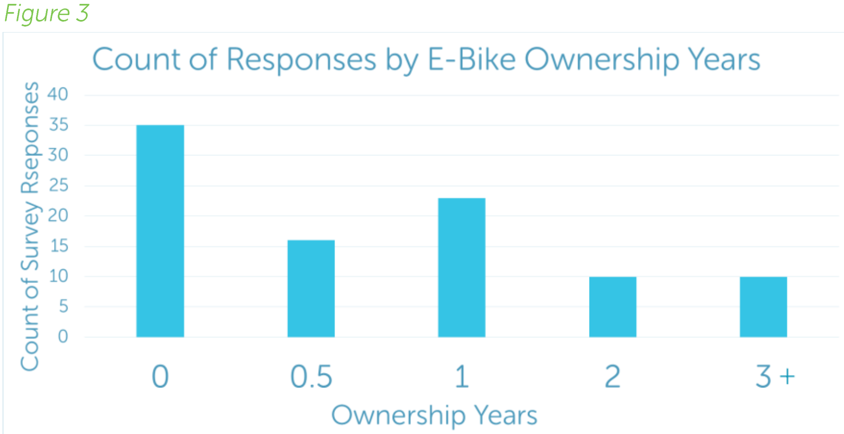
Figure 2



Owners reported overall high levels of satisfaction with their E-Bikes.

Duration of Ownership

Figure 3



Most respondents had purchased their e-bike within the last two years. Those who had recently acquired an e-bike might have been more likely to receive a survey link from their bike shop. Newer owners may have been more eager to share their thoughts. However, data seems to indicate that Vermonters are buying more e-bikes.

No trends emerged from time of ownership. Duration of ownership did not correlate with satisfaction or annual miles ridden.

Common E-Bike Models

Respondents reported a wide variety of E-Bike models. Of the E-bikes reported, 36 were kits added to traditional bicycles, and 58 were designed as E-bikes. Over 35 unique models were reported.

Table 1

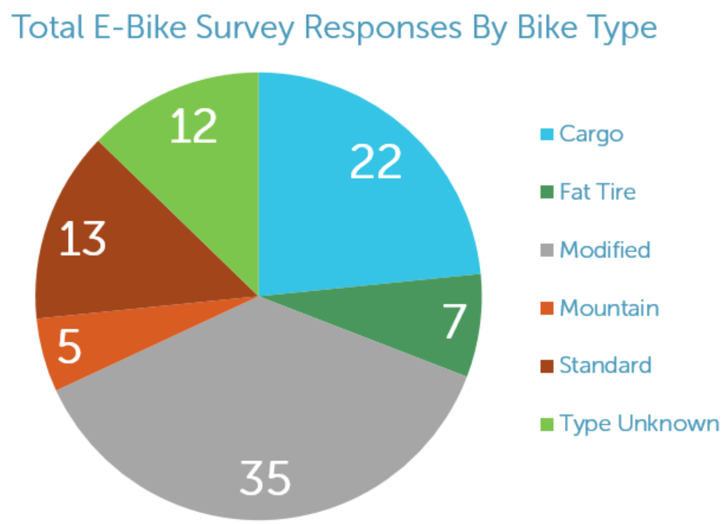
Brand	Model	Type	Quantity Reported in Survey	List Price	Estimated Incremental Cost
Bafang	BBSHD	Retrofit Kit	3	$1,066	$1,066
Clean Republic	Hill topper	Retrofit Kit	10	$799	$799
Dillenger	Bafang	Retrofit Kit	3	$962	$962
Dillenger	Samsung	Retrofit Kit	2	$629	$629
Electra	Townie	Standard	2	$2,599	$2,100
Evelo	Aurora	Standard	2	$2,499	$2,149
Juiced	Cross current	Mountain	2	$1,095	$895
Rad Power	Radwagon	Cargo	8	$1,599	$600
Rad Power	Rover	Fat Tire	2	$1,499	$1,299
Sondors	Original	Fat Tire	3	$499	$299
Yuba	Boda Boda	Cargo	2	$2,999	$1,500
Yuba	Mundo	Cargo	5	$3,799	$1,800
Yuba	Spicy Curry	Cargo	1	$4,499	$2,300

Table 1 provides basic information on the most commonly reported E-bike models. The Incremental cost of an electric kit is an estimate based on the difference between the MSRP of the E-bike and the MSRP of a roughly comparable model without an electric kit. For retrofit kits, full cost of a typical kit is used. The average incremental cost of an electric bike was $1,261. Median incremental cost was $1,066. The Sondors Original was significantly less expensive than all other options, with an incremental cost of about $300.

E-Bike Types

Each model reported in the survey was categorized according to the bike types above. Modified conventional bikes were the most common. Mountain bikes and fat tire bikes were not heavily represented.

Figure 4



Reasons Cited for E-Bike Purchase

Respondents were asked to explain their reasons for getting an e-bike. Many cited more than one reason. Reasons were quantified based on interpretation of open-ended qualitative responses. Reasons for the original purchase did not always match reported actual usage.

Figure 5

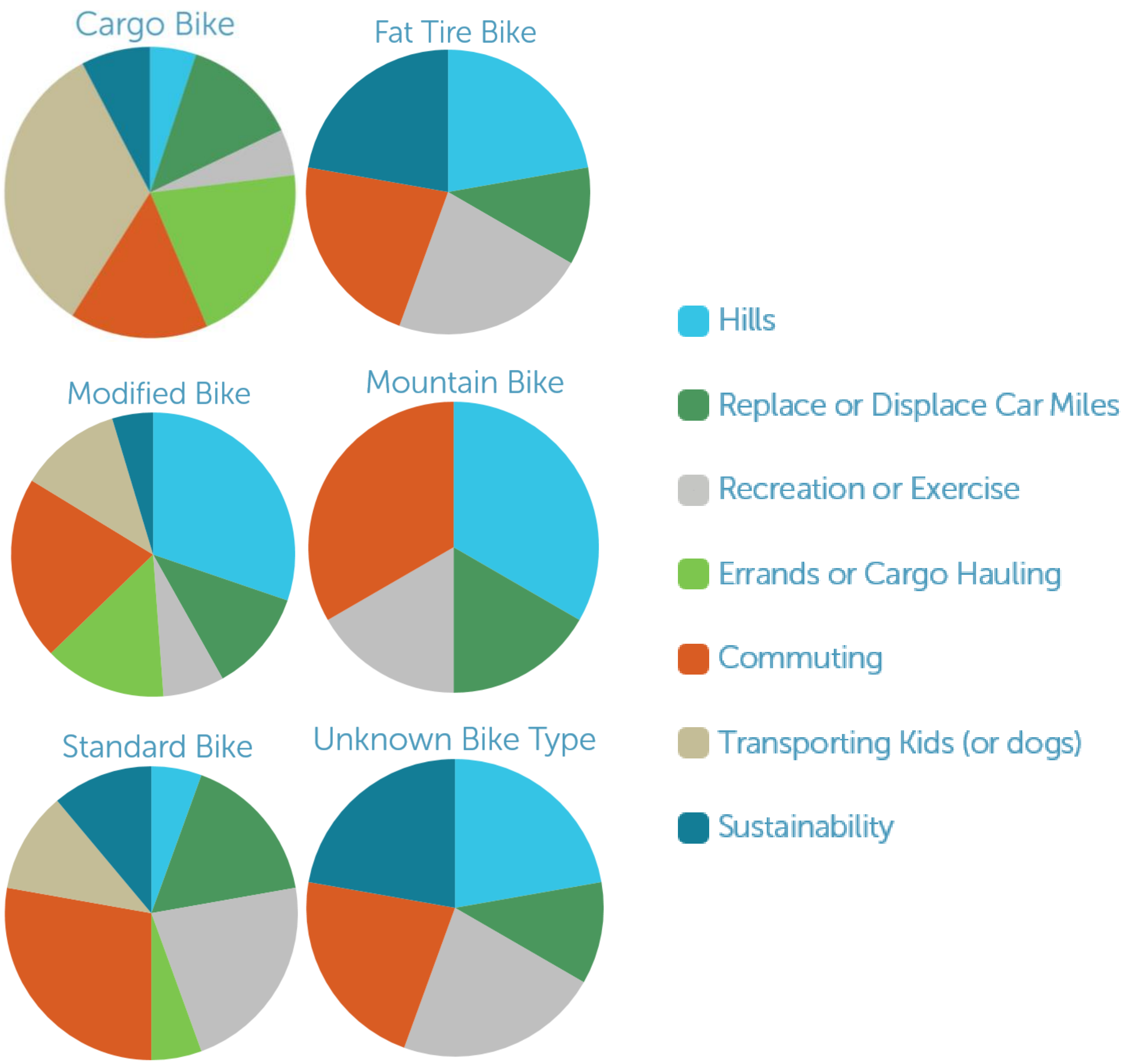
"To make hills easier. I am 77 years old."

"Make the hills in Brattleboro easier when loaded down with groceries and pulling my son on a trail-a-bike."

"To ensure I could use my bike as a commuter transportation method rather than just a hobby for exercise biking."

Reasons Cited for Purchase of E-Bike, by E-Bike Type

Figure 6

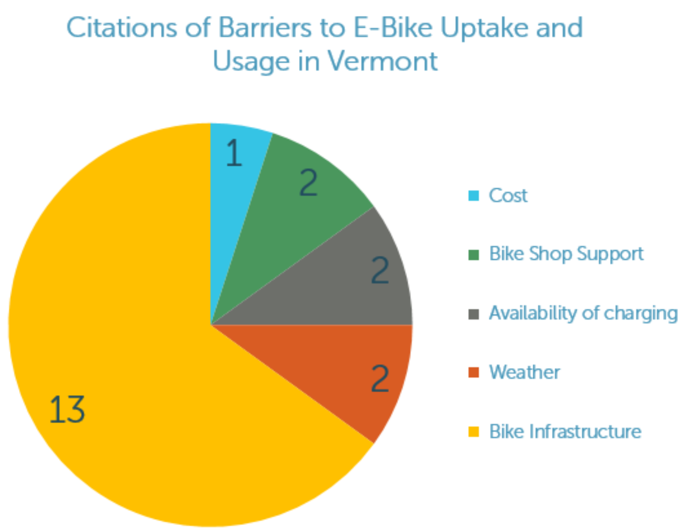


Cargo e-bikes fill a unique niche: they allow cyclists to transport children or heavy items that would be difficult to load onto a conventional bicycle. The electric motor helps to overcome the weight of the cargo and the heavier frame. This type of e-bike may represent a unique transportation option.

Perceived Barriers to E-Bike use

Many respondents chose to use open-ended fields to report on barriers to E-bike usage in Vermont. By far the most commonly cited obstacle was a lack of bike infrastructure in the form of road shoulders, bike lanes, and bike paths. Two respondents wished for access to public charging stations. Two others cited problems with maintenance support from local bike shops.

Figure 7



"As with other bikes, some roads just not safe enough. Narrow, hill, visibility problems, pavement edge drop off."

"We need bike shops to make clear what make/models they support."

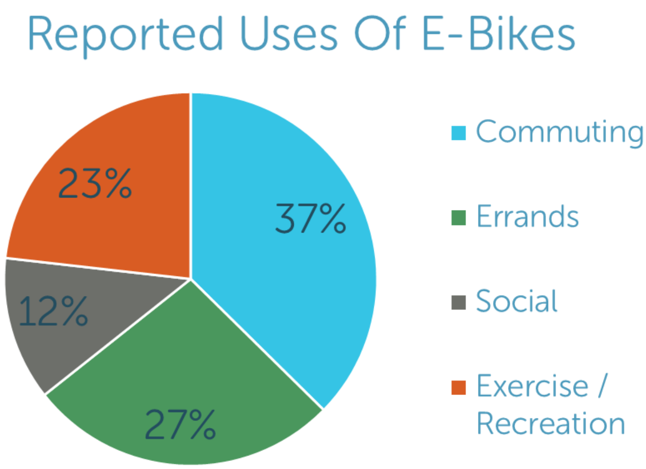
"Wish there were bike paths connecting to other towns and places to charge them."

Only two respondents cited lack of charging infrastructure as a problem. Most respondents likely found the range of their e-bike to be sufficient to recharge only at home. Adverse selection may be at work: many of those for whom charging would be inconvenient may not have opted to purchase an e-bike.

Uses of E-Bikes

Participants were asked to break down their e-bike usage into four categories. Several respondents mentioned that they would have liked to see a category for transporting children.

Figure 8

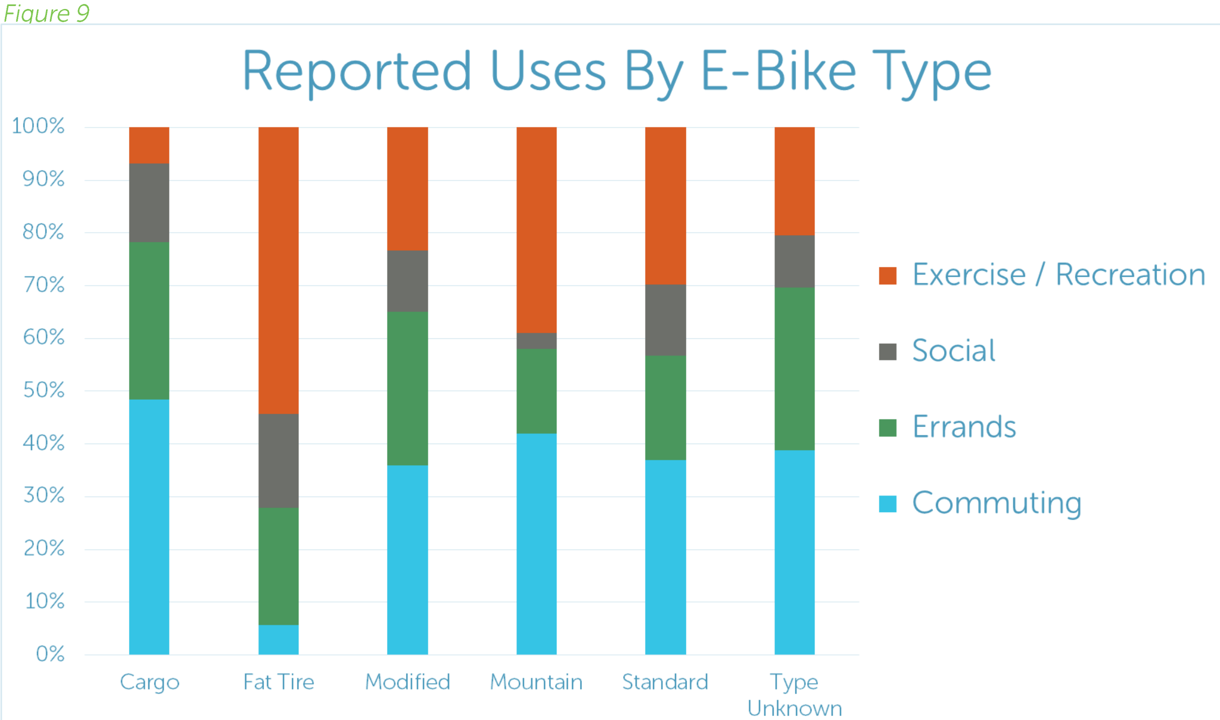


These categories were intended to capture actual e-bike use, while the write-in response earlier captured the reasons that the respondent chose to purchase the e-bike. There is some overlap.

The 'Exercise or Recreation' category is important for energy use and displaced driving mileage calculations. Miles in this category should not be included when calculating automobile miles displaced.

Recreational use of e-bikes may be a drawback from an energy conservation standpoint. For example, an e-bike used exclusively for recreation with some amount of pedal assist would use more energy than a conventional bicycle. While users may see health benefits from exercise, recreational miles are a slight negative for energy saving programs.

Figure 9



Type of use varied by type of e-bike.

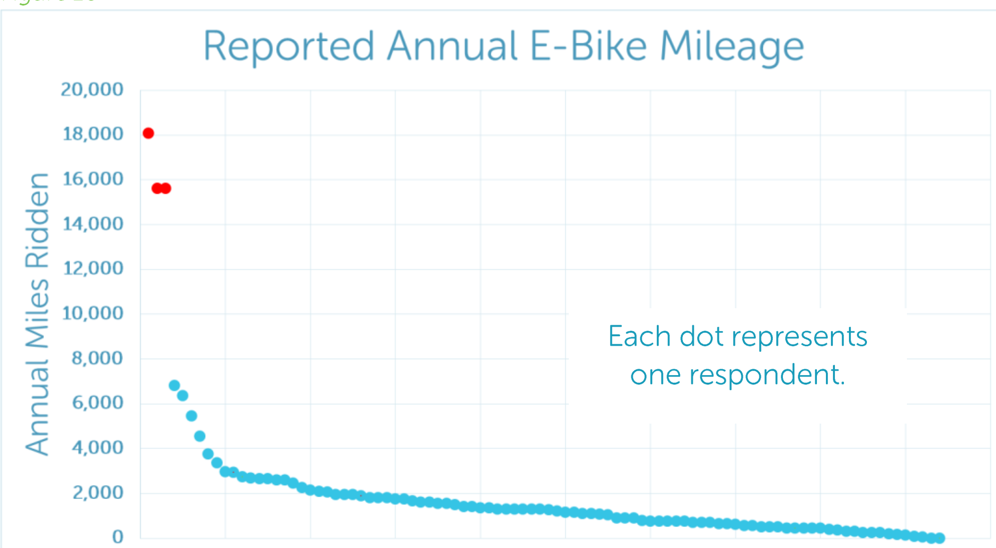
E-Bike Mileage

Reported mileage was an open-ended quantitative question. This left it up to respondent interpretation. The wording of this question (#18) may have confused some respondents. All four seasons had a field for respondents to enter a mileage number. An example:

Question 18: [11] *"Typically, how many miles do you ride your E-bike in a one week period during the following times of the year? (If you have had your E-bike for less than a year, please list the number of miles you plan to ride.)*

- Summer (June-August) - # of Miles Traveled on an Average Week"

Figure 10



Correction for outliers

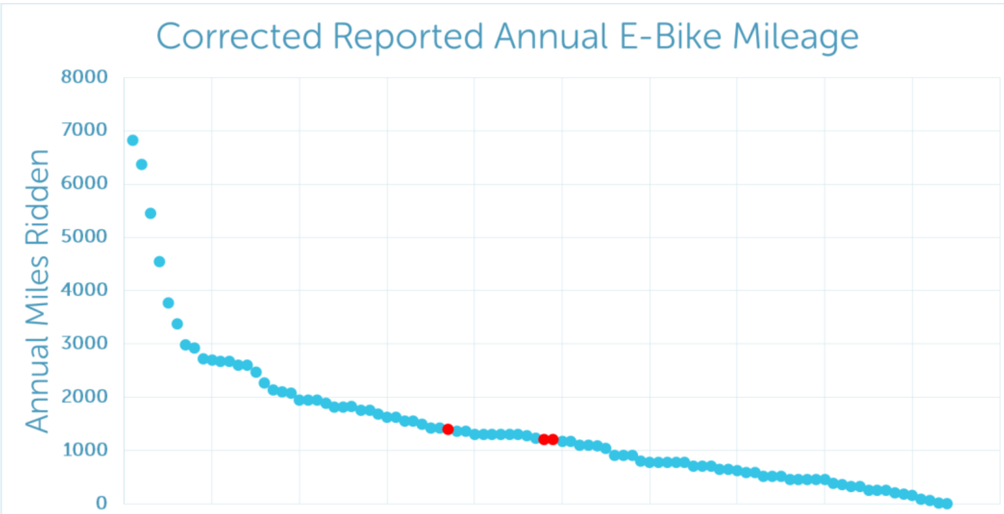
Based on the distribution of the responses in Figure 10, outliers probably misread the question. Respondents may have missed the key phrase, *"in a one week period"* in question 18. To travel 15,000 miles on a bicycle in a year, a cyclist would have to average over 40 miles every day. These high mileages are greater than the average mileage for a car in the United States (13,500 miles per year).[12] An e-bike rider at an average speed of 12 to 15 mph would need to be on the bike for more than 2.5 hours every single day of the year to achieve this mileage.

Red dots represent likely mis-reading of the mileage question. To correct for this, the outliers were divided by 13: the number of weeks in one season. This put them in the middle of the pack.

[11] See Appendix: Complete Survey

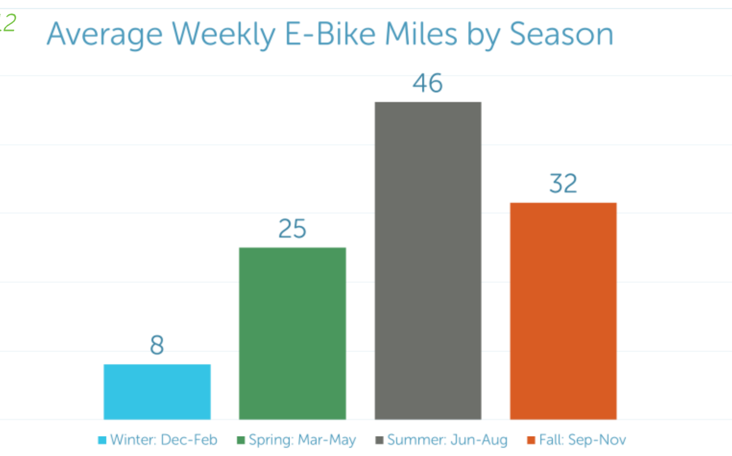
[12] U.S. Department of Transportation Federal Highway Administration https://www.fhwa.dot.gov/resources/pubstats/

Figure 11



After correction for outliers, the median annual self-reported e-bike mileage was 1,218 miles, and the mean was 1,440 miles.

Figure 12



E-Bike Mileage varied predictably by season in Vermont.

Displaced Driving Miles

Participants provided an estimate of the amount of non-recreational miles that they would have driven without an e-bike. These non-recreational miles will be referred to as *essential* miles.

If a respondent indicated that they exclusively used the bike for recreation, then their e-bike displaced zero driving miles. For essential use, respondents were asked to select one of four levels of driving displacement.

Survey Question 22: *"You mentioned that you sometimes use your E-bike to commute and run errands. Prior to owning an E-bike would you typically have been driving to those places instead?"*

Table 2

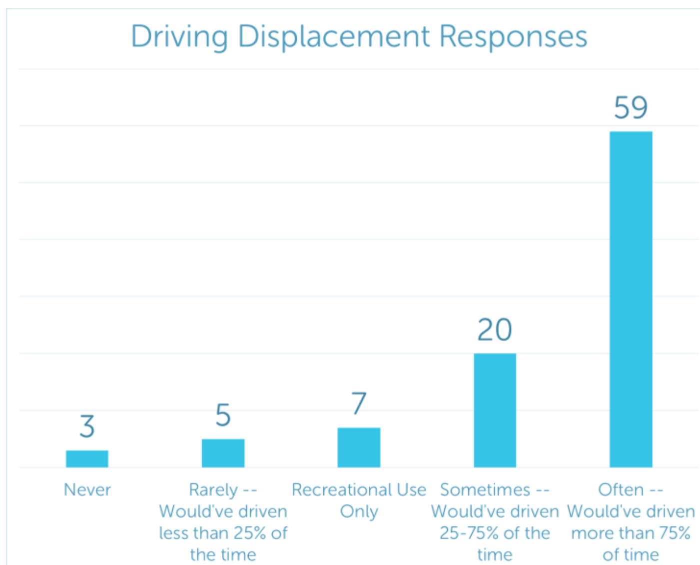
Response Choice: Level of Driving Displacement	Percentage Driving Displacement Assumption
Often -- Would've driven more than 75% of time	87.5%
Sometimes -- Would've driven 25-75% of the time	50%
Rarely -- Would've driven less than 25% of the time	12.5%
Never	0%

To estimate miles displaced, a percentage displacement was selected in the middle of each possible response range. This percentage was then applied to the total essential miles of each respondent to determine driving miles displaced. The average e-bike traveled 1,157 miles for essential purposes.

Though the question wording did not mention miles traveled in the social engagements category[13], these miles are assumed to be displaced at the same rate as commuting and errands. The question was presented to all respondents who claimed any essential miles.

On average, e-bikes displaced 760 driving miles. The median displaced mileage was 568.

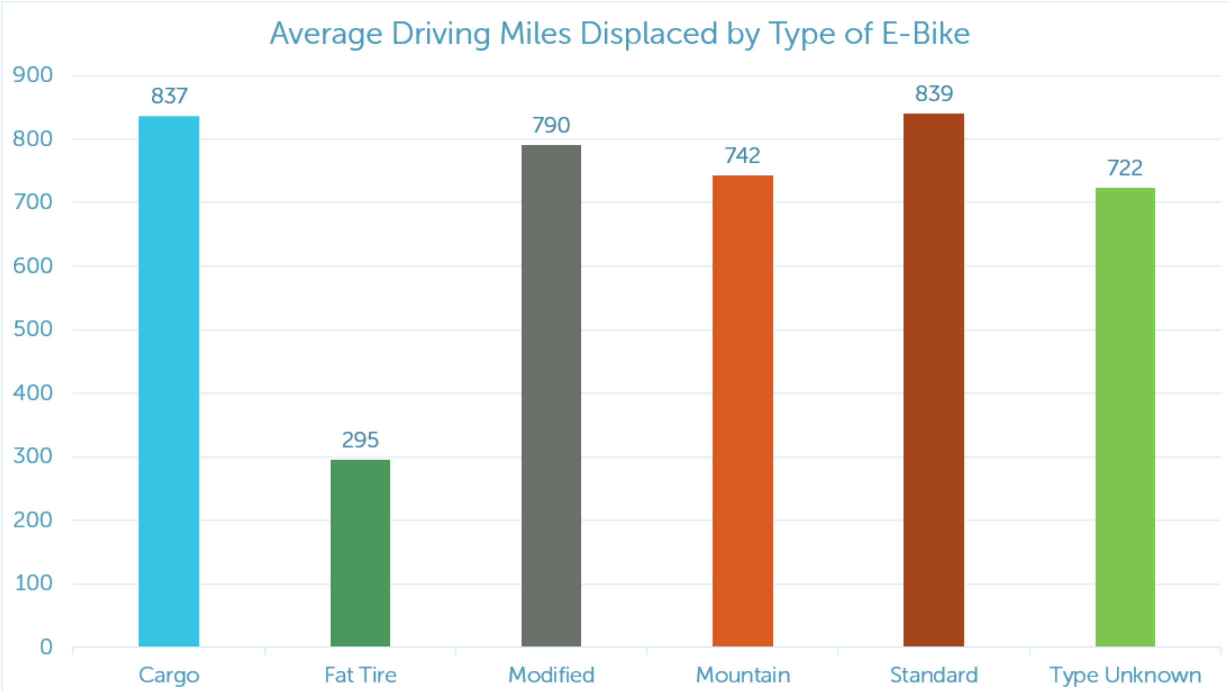
Figure 13



Before correcting for the three outlying mileage responses as shown in Figure 11, the average e-bike displaced 940 driving miles, and the median e-bike displaced 580. An early snapshot of survey results appeared to indicate even higher mileage displacement. Unfortunately the early snapshot included all three uncorrected outliers, which were averaged into a smaller pool of respondents.

[13]See Appendix: Complete Survey Text, Question 22

Figure 14



"Our E-bike, combined with a subscription to Carshare VT, has allowed our family to forego the expense of owning a primary motor vehicle. While we did a lot of conventional biking previously, the E-bike allows us to carry grocery loads and kids, and increases our range and speed."

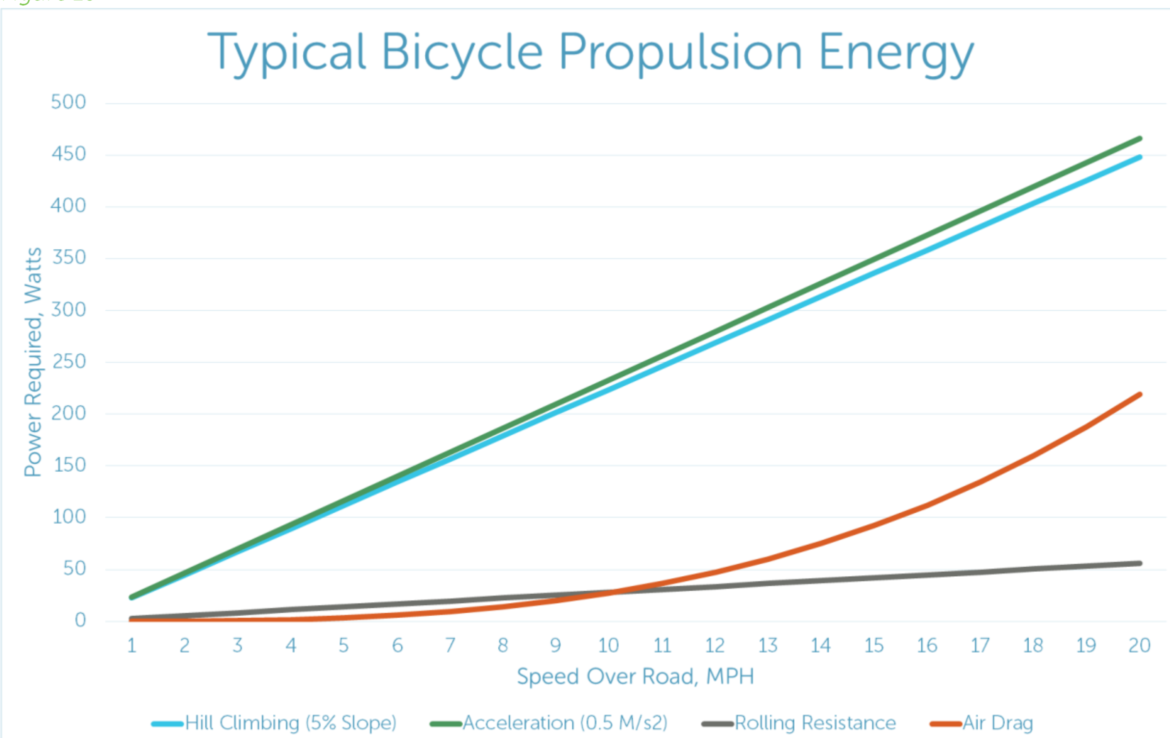
Fat tire bikes displaced fewer driving miles due to lower levels of both overall and essential mileage.

Efficiency Program Considerations

Bicycle Energy Efficiency

Figure 15 shows the energy required to overcome sources of resistance to propel a typical e-bike. These energy requirements were calculated assuming a 60lb bicycle and 165lb rider on typical e-bike tires.[14] Hill climbing and acceleration are intermittent, while air drag and rolling resistance are present at all times that the bicycle is in motion.

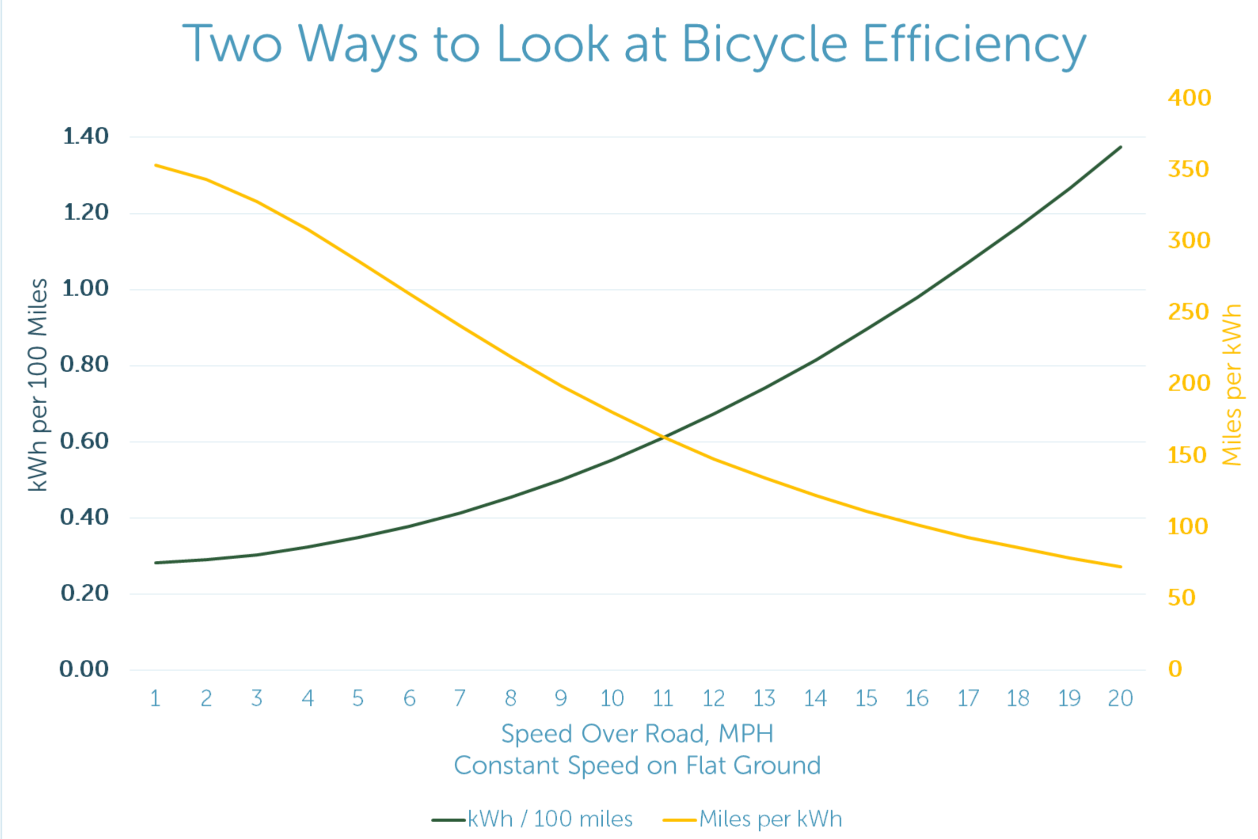
Figure 15



An e-bike motor on the theoretical bicycle would need to supply around 275W watts to maintain 20mph cruising speeds. A typical e-bike motor size is 350W, which should provide enough power to accelerate to 20mph on flat ground and maintain moderate speed on hills.

[14] See Appendix: Bicycle Energy Calculations

Figure 16



Efficiency drops rapidly with speed. Wind resistance is the most important factor. If an e-bike's assistance is limited to 20MPH, and the rider always accelerates to this speed when possible, the e-bike might have an overall flat-ground cruising efficiency of about 70 miles per kWh, or about 1.4 kWh per 100 miles. At 10 MPH, cruising efficiency nearly triples to 181 miles per kWh, or 0.5 kWh per mile.

Intermittent hill climbing and acceleration will reduce overall efficiency in real-world scenarios. Some energy exerted for acceleration and hill climbing will be recovered while decelerating or rolling downhill, though much will be dissipated as heat while braking.

Energy Efficiency of E-Bikes

E-Bikes vary in their capabilities. Rider behavior ultimately determines efficiency. There is no single energy efficiency metric that can be easily used to compare e-bike models in a meaningful way.

Manufacturers often post minimum and maximum ranges. Using battery capacity and range, these ranges can yield estimates of energy efficiency. On average, the minimum range indicated a minimum efficiency of 1.9 kWh per 100 miles. The average maximum efficiency was 0.94 kWh per 100 miles.

Table 3

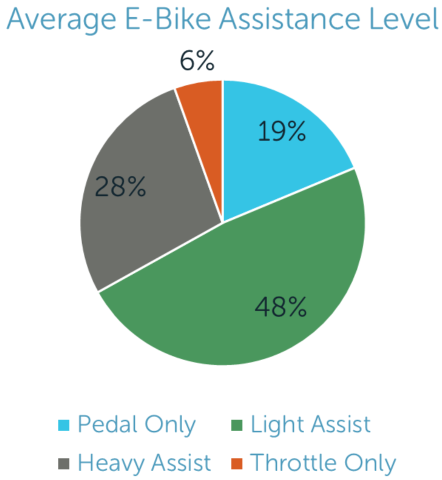
Brand	Model	Type	Advertised Minimum Range (Miles)	Minimum Efficiency (kWh / 100 Miles)	Advertised Maximum Range (Miles)	Maximum Efficiency (kWh / 100 Miles)
Bafang	BBSHD	Retrofit Kit				
Clean Republic	Hill topper	Retrofit Kit				
Dillenger	Bafang	Retrofit Kit	27	1.7	50	0.9
Dillenger	Samsung	Retrofit Kit	40	1.2	60	0.8
Electra	Townie	Standard	20	2.0	100	0.4
Evelo	Aurora	Standard	20	1.8	40	0.9
Juiced	Cross current	Mountain	19	2.0	37	1.0
Rad Power	Radwagon	Cargo	20	2.8	40	1.4
Rad Power	Rover	Fat Tire	20	2.8	40	1.4
Sondors	Original	Fat Tire	20	1.6	50	0.6
Yuba	Boda Boda	Cargo			50	1.1
Yuba	Mundo	Cargo			50	1.1
Yuba	Spicy Curry	Cargo	30	1.3	60	0.7
Average/Median			24	1.90	52	0.94

In reality the maximum range of an e-bike is effectively unlimited, since the rider can supply 100% of power after the battery runs out. The advertised maximum range probably assumes a low level of assistance.

These efficiency estimates line up well with the bicycle efficiencies from Figure 16, once some amount of hill climbing and acceleration is added.

To account for some manufacturer optimism, maximum efficiency was assumed to be 1 kWh per 100 miles, and minimum efficiency was assumed to be 2 kWh per 100 miles. These averages were used to calculate total energy use for all e-bike types. A breakdown in efficiency by bike type was not possible due to limited available data.

Assistance Levels



Participants were asked to indicate the percentage of time that they spent at each of four assistance levels.

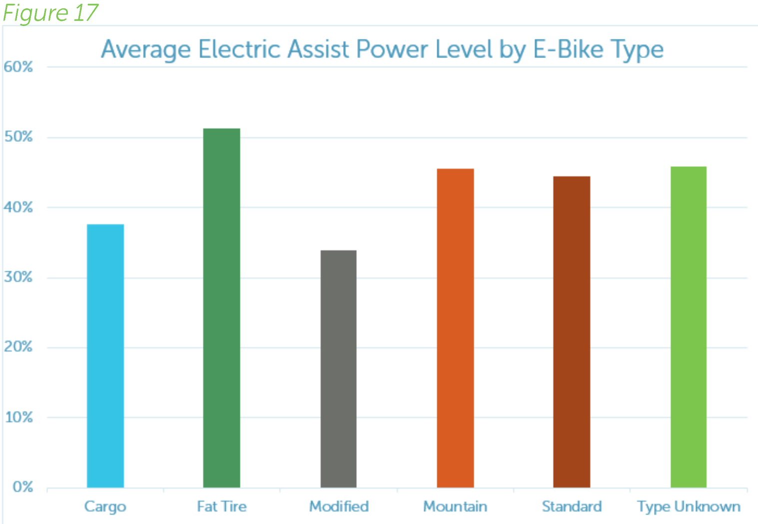
Using assumed electric power percentages, and the respondents' reported time in each assistance level, an average level of assistance power is calculated for each respondent.

Based on survey responses, the motor provided about 40% of average e-bike propulsion energy, while the rider provided the remaining 60%. Motor assistance varied slightly by E-bike type, but assistance levels did not vary dramatically. Fat tire bike riders generally used a higher level of assistance. Modified bike riders generally used slightly lower levels of assistance.

Table 4

Assist Level From Survey	Assumed Share of Motive Power from Electric Drive	Assumed kWh / 100 Miles
No Motor Assist – Pedaling Only	0%	0
Light Assist	33%	1
High Assist	66%	1.5
Throttle Only – No pedaling	100%	2

Figure 17



Fat Tire bikes may require more assistance to overcome high tire rolling resistance and resistance to acceleration due to heavy wheels. Modified bikes may not assist as smoothly, or may only have a throttle and no assist function. In this way assistances may have been less convenient. Modified bikes in this survey may also have been built by bicycle enthusiasts who were already accustomed to largely human-powered riding. Cargo bikes generally had higher-wattage motors. Lower levels of assistance could have provided more wattage on some cargo bikes.

Motor efficiency metrics for e-bike DC motors are not readily available. Motor efficiency is unlikely to vary substantially: a less-efficient motor requires a larger battery to provide the desired range and power. E-bike manufacturers face cost tradeoffs between more efficient motors and larger batteries.

Since field testing of energy efficiency was beyond the scope of this project, level of assistance was the best proxy available for relative efficiency in this report.

Energy Consumed By E-Bikes

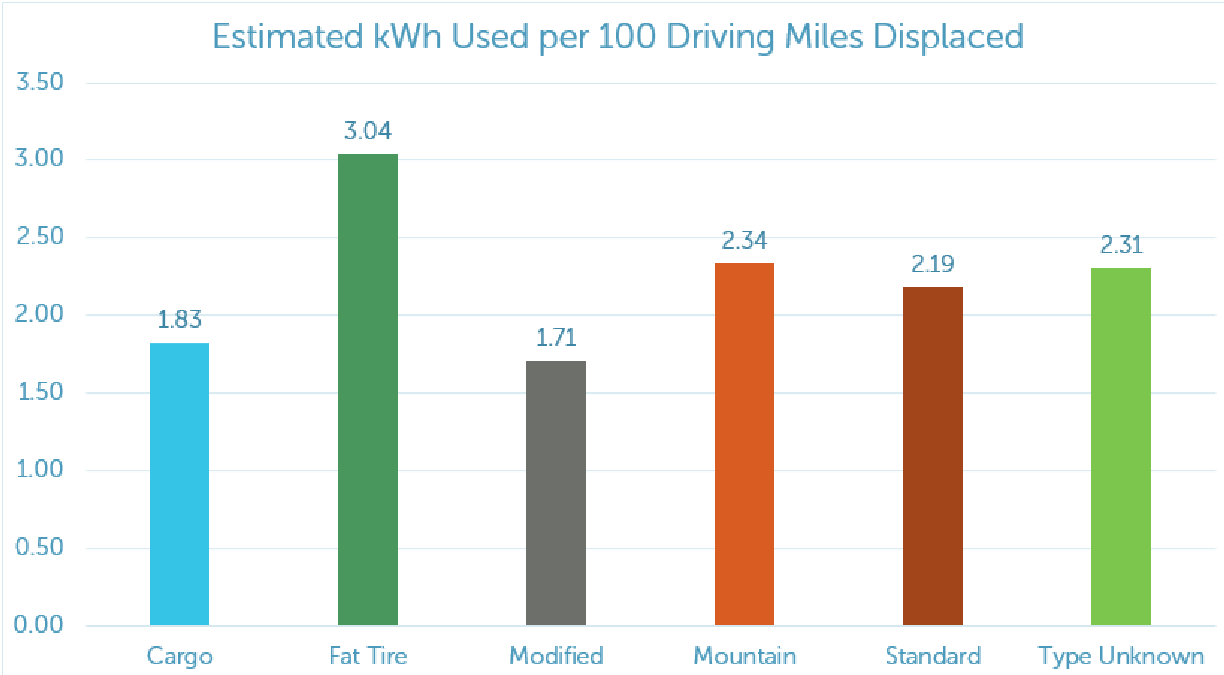
When the efficiency assumptions from Table 4 are applied to reported assist levels, e-bikes averaged 1.02 kWh per 100 miles. Relative efficiencies varied according to reported assistance levels. Overall, the average e-bike motor from the survey would consume 14.9 kWh per year.

Since each bicycle class has unique characteristics, a universal comparison of e-bike efficiency is very difficult to achieve. A retrofit kit on a lightweight racing bike would probably propel a rider many more miles per kilowatt-hour than a 60-pound electric cargo bike could. However, the added utility of the cargo bike makes a direct efficiency comparison akin to comparing the efficiency of a motorcycle to a minivan. A motorcycle can move very efficiently, but a minivan can do a lot of things that the motorcycle cannot.

Energy Consumed per Mile Displaced

When considering e-bikes as an energy-saving measure, simple efficiency per mile is not necessarily a good way to compare e-bikes to automobiles. Not all e-bike miles replace auto miles, but e-bikes are using energy for every mile traveled with electric assistance. When an e-bike is using energy for mileage that does not displace auto miles, this is energy that would not otherwise have been consumed. A useful metric may be to divide the total energy use of the e-bike by the total car miles displaced, as shown in Figure 18.

Figure 18



On average, e-bikes consumed 1.96 kWh per 100 driving miles displaced.

Rider Behavior

Rider behavior will have a dramatic effect on efficiency. If a rider often choses low or no assistance, efficiency will be high. If a rider never pedals and always uses a throttle, then efficiency will be much lower, but still much better than the efficiency of an automobile.

Weight

Bicycle weight matters. Acceleration and hill-climbing are greatly impacted by bicycle weight, and these are times when an e-bike motor is likely to be engaged. With motors and batteries, e-bikes are bound to be heavier than comparable conventional bikes. However, weight also varies with utility. Cargo bikes are heavy because they are strengthened for extra cargo capacity. The survey did not ask about the weight of cargo being carried.

Fat Tires

Fat tires have a negative impact on efficiency. The weight of heavier wheels has a double negative effect on acceleration, since wheels must be accelerated rotationally. Higher rolling resistance of fat tires will require more power input at all times. However, fat tires may provide a sense of security for year-round biking, allowing for more winter use. The survey results indicate that fat bikes may displace fewer driving miles than other types.

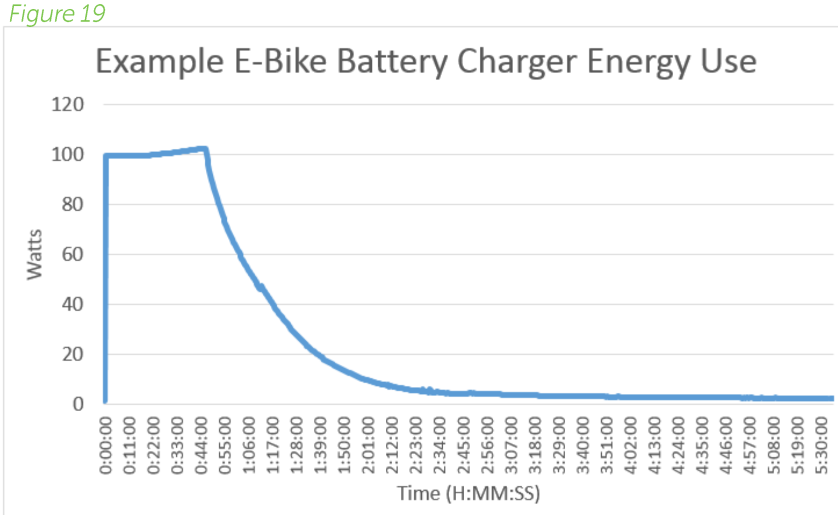
Modified Bikes with Retrofit Kits

Some retrofit kits such as the Hill Topper operate by throttle only. Without the convenience of an automatic assist, it is possible that power from these kits is used only intermittently for acceleration and hill climbing. E-bikes with assistance may tend to use the motor more often for maintaining speed.

Battery Charger Efficiency

An existing e-bike battery charger at the Efficiency Vermont office was metered for power use. Figure 19 represents a single charge cycle with a partially discharged battery.

Figure 19



The charger used an average of 1.7 Watts when plugged in with no battery. It used an average of 2.4 Watts when connected to a fully-charged battery. These nonproductive energy uses are known as 'vampire' loads.

If an e-bike battery were left on this charger at all times when the bike was not in use, the charger itself might consume 22 kWh per year. This vampire load exceeds the energy that an average e-bike from the survey might consume for propulsion. If charge cycle inefficiency is accounted for, the charger's consumption will be even higher.[15]Chargers of this type can be expected to achieve 80%-85% charge efficiency.

E-bike battery chargers may actually be wasting more energy than e-bikes are putting to use.

Energy Star certified Electric Vehicle Supply Equipment for full sized electric vehicles can use as little as 2 watts to maintain a charged battery, and 1.9 watts when no battery is connected[16]. These vampire loads are comparable to the loads from the tested e-bike charger. Relative to total energy delivered and total equipment costs, these loads are very small for an electric car. The same vampire load becomes much more significant relative to an e-bike's energy use and equipment cost.

The Department Of Energy's analysis of battery chargers on the market in 2016 found that 'best in market' battery chargers were nearly four times as efficient as baseline battery chargers. A baseline battery charger in the e-bike class could consume up to 120 kWh per year, on top of the energy consumed by the associated e-bike. The 'best in market' charger would only consume 33 kWh per year.[17]

As of 2017 there are no nationwide standards for battery charger efficiency.

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[15] See Appendix: Battery Metering Calculations
[16] https://www.energystar.gov/productfinder/product/certified-evse/results
[17]See Appendix: Battery Chargers on the Market

New federal battery charger efficiency standards will be in effect for all chargers manufactured after June 13, 2018. These standards would require a charger for a typical e-bike battery of 500 Watt-hours to waste no more than 41.3 kWh per year.[18]

Electrical Energy Efficiency Measures

Battery Chargers

Though e-bike propulsion efficiency is subject to many variables, battery charger efficiency is relatively straightforward. Even under upcoming federal efficiency standards, an e-bike battery charger may waste more energy than the e-bike uses for propulsion.

	Average E-Bike Energy Used for Propulsion (Based on Survey)	D.O.E. Compliant Battery Charger for 500 W-h Battery	Average E-Bike Plus D.O.E. Compliant Battery Charger
kWh total (1,440 miles)	14.7	+ 41.3	= 56.0
kWh / 100 mi	1.0	+ 2.9	= 3.9
kWh / 100 driving miles displaced (760 miles average)	2.0	+ 5.4	= 7.4

An average e-bike paired with a D.O.E. compliant charger might consume 7.4 kWh per 100 driving miles displaced.

The Department of Energy will publish battery charger test results in its compliance certification database once the new rule takes effect[19]. As of November 2017, Energy Star has removed its battery charger program, but an updated version may arrive in 2018.

E-bike battery chargers may consume more energy than the bikes themselves, and may have much more quantifiable energy efficiency metrics. An incremental cost increase of a few dollars may be able yield savings of 10kWh per year or more.[20]

Challenges for a Battery Charger Efficiency Program

Battery chargers are generally sold paired with e-bike batteries and may account for only 1% to 2% of total e-bike cost. Financial incentives of a few dollars at the time of purchase are unlikely to have much impact on a consumer's decision about a $1,500 e-bike.

E-bike retailers might become interested in providing incentivized after-market battery chargers as an additional revenue source. However, correct battery and charger pairing is crucial for battery life and performance.

[18] See Appendix: Battery Charger Classification
[19] https://www.regulations.doe.gov/certification-data
[20] See Appendix: Battery Chargers on the Market

Circumventing Battery Charger Inefficiency

The most cost-effective way to minimize charger vampire loads may be to switch off the charger when not in use. A simple countdown timer product like the Belkin Conserve Socket [21] could be an effective way to eliminate vampire load losses. The user would press a start button to start the charger. After six hours, the timer would shut the charger off.

This example timer product costs about $15, and could save 10 to 20 kWh per e-bike, per year. If battery chargers continue to present a relatively large electrical savings opportunity for e-bikes, an energy efficiency program could consider partnering with e-bike retailers to offer a rebate on countdown timers to e-bike owners, or offer discounted timers at the time of e-bike purchase.

Displacing Electric Vehicle Miles as an Efficiency Measure

Electric automobiles (EVs) on the market in 2017 can achieve efficiencies of about 25 kWh per 100 miles[22]. An ebike alone could displace over 90% of the energy used by an electric vehicle on a per mile basis. Depending on charging assumptions, an ebike could displace 130-175 kwh that would have been used by the EV. An electric bike can be a societally cost effective measure in offsetting electric vehicle miles using the current State of Vermont net present value screening tool and certain assumptions on cost, charger efficiency, and maintenance. More work needs to be done to determine how electric bikes fit into the Efficiency Vermont portfolio.

Behavioral Energy Savings

E-bike users can save energy and increase range by operating at low motor assistance levels and by avoiding high speeds under power. However, savings from these behavioral changes will be in the single digits of kilowatt-hours. Unless e-bike use becomes much more widespread, a program to encourage behavioral energy savings would not be cost-effective.

[21] http://www.belkin.com/us/p/P-F7C009/

[22] http://www.fueleconomy.gov/

Conclusions

E-bikes in the survey did displace driving miles, and were significantly more efficient than the most efficient electric cars on the market. E-bikes are difficult to compare directly across different types so if any programs advance in the future they may want to engage in further study of which e-bikes types and/or models to incentivize.

E-Bike Classes

Class 3 e-bikes cannot legally be used on roads in Vermont[23], and therefore cannot legally displace driving miles. Class 3 e-bikes would be poor candidates an efficiency program targeting driving mileage displacement.

E-Bike Types

Fat tire bikes are inherently less efficient than bikes with conventional tires, and are oriented toward recreational off-road use. They may displace fewer driving miles than other e-bikes, at lower efficiencies.

Electric drive systems have the ability to make a heavy, slow bicycle feel weightless and fast. This could make cargo bikes an attractive new option for users who need to carry groceries or children. Fat bikes will feel similarly weightless, but without the practical benefits of cargo bikes.

Relative Efficiency of E-Bikes

E-bikes consume very little energy relative to purchase price. An electrical energy efficiency program to incentivize some e-bikes over others would be unable to cost-effectively influence consumer choice of e-bikes.

Battery Chargers

Battery chargers are likely to use as much energy as e-bikes. Public and retailer education about charger efficiency and vampire loads may help to reduce wasted energy. A generalized vampire-load reduction program may be able to apply to e-bikes and other larger battery-powered equipment, like lawnmowers. Large battery-powered equipment is becoming more common as battery prices fall. Further research will be required to incorporate battery chargers into an efficiency program.

[23]See Appendix: Vermont Legal Language

Appendices

Bicycle Energy Calculations

Assumptions:

Rider mass: 75 kg

M: Bicycle mass 27 kg

Mw: Wheel Mass: 2 kg

A: Acceleration: 0.5 M/s^2

S: Slope: 5%

G: Gravity: 9.8M/s^2

Ad: Air Density: 1.225 kg/m^3

Cd: Drag Coefficient * Cross-sectional area: 0.5

RR: Rolling Resistance Coefficient: 0.005

V: Speed over road (variable) M/s

Calculations:

Speed is in meters per second

Drive train efficiency is considered to be 100%

Air Drag:

$0.5*(Ad)*(V^3)*(Cd)$ = Power Watts

Rolling Resistance:

(V)*(M)*(G)*(RR) = Power Watts

Climbing

(V)*(M)*(G)*(S) = Power Watts

Acceleration:

(V)*(M+Mw)*(A) = Power Watts

Common E-Bike Powertrains

Brand	Model	Type	Battery Volts	Battery Watt-Hours	Motor Watts
Bafang	BBSHD	Retrofit Kit	48	504	1000
Clean Republic	Hill topper	Retrofit Kit	36	Varies	350
Dillenger	Bafang	Retrofit Kit	36	468	350
Dillenger	Samsung	Retrofit Kit	36	468	250
Electra	Townie	Standard	36	396	250
Evelo	Aurora	Standard	36	360	250
Juiced	Cross current	Mountain	48	374	350
Rad Power	Radwagon	Cargo	48	557	750
Rad Power	Rover	Fat Tire	48	557	750
Sondors	Original	Fat Tire	36	317	350
Yuba	Boda Boda	Cargo	48	557	350
Yuba	Mundo	Cargo	48	557	750
Yuba	Spicy Curry	Cargo	36	396	250
Average/Median			36	459	462

Vermont Legal Language

From Vermont Act 158:

* * * Motor-Assisted Bicycles * * *

Sec. 56. 23 V.S.A. § 4 is amended to read:

§ 4. DEFINITIONS

Except as may be otherwise provided herein, and unless the context otherwise requires in statutes relating to motor vehicles and enforcement of the law regulating vehicles, as provided in this title and 20 V.S.A. part 5, the following definitions shall apply:

* * *

(45)(A) "Motor-driven cycle" means any vehicle equipped with two or three wheels, a power source providing up to a maximum of two brake horsepower and having a maximum piston or rotor displacement of 50 cubic centimeters if a combustion engine is used, which will propel the vehicle, unassisted, at a speed not to exceed 30 miles per hour on a level road surface, and which is equipped with a power drive system that functions directly or automatically only, not requiring clutching or shifting by the operator after the drive system is engaged. As motor vehicles, motor-driven cycles shall be subject to the purchase and use tax imposed under 32 V.S.A. chapter 219 rather than to a general sales tax. An Neither an electric personal assistive mobility device nor a motor-assisted bicycle is not a motor-driven cycle.

(B)(i) "Motor-assisted bicycle" means any bicycle or tricycle with fully operable pedals and equipped with a motor that:

(I) has a power output of not more than 1,000 watts or 1.3 horsepower; and

(II) in itself is capable of producing a top speed of no more than 20 miles per hour on a paved level surface when ridden by an operator who weighs 170 pounds.
(ii) Motor-assisted bicycles shall be regulated in accordance with section 1136 of this title.
* * *
Sec. 57. 23 V.S.A. § 1136(d) is added to read:
(d)(1) Except as provided in this subsection, motor-assisted bicycles shall be governed as bicycles under Vermont law, and operators of motor-assisted bicycles shall be subject to all of the rights and duties applicable to bicyclists under Vermont law. Motor-assisted bicycles and their operators shall be exempt from motor vehicle registration and inspection and operator's license requirements. A person shall not operate a motor-assisted bicycle on a sidewalk in Vermont. No. 158 Page 77 of 104 2016
(2) A person under 16 years of age shall not operate a motor-assisted bicycle on a highway in Vermont.
(3) Nothing in this subsection shall interfere with the right of municipalities to regulate the operation and use of motor-assisted bicycles pursuant to 24 V.S.A. § 2291(1) and (4), as long as the regulations do not conflict with this subsection.

Model E-Bike legislation

http://peopleforbikes.org/our-work/e-bikes/policies-and-laws/

Battery Charger Efficiency

Battery Chargers on the Market

6450-01-P
DEPARTMENT OF ENERGY
10 CFR Part 430
[Docket Number EERE–2008–BT–STD–0005]
RIN: 1904-AB57
Energy Conservation Program: Energy Conservation Standards for Battery Chargers

Table IV-9 Product Class 6 (Medium-Energy, High-Voltage) Engineering Analysis Results

	EL 0	EL 1	EL 2	EL 3
EL Description	Baseline	Intermediate	Best in Market	Max Tech
24-Hour Energy (Wh)	891.6	786.1	652.00	466.20
Maintenance Mode Power (W)	10.6	6.0	0.50	0.0
No-Battery Mode Power (W)	10.0	5.8	0.30	0.0
Off-Mode Power (W)	0.0	0.0	0.0	0.0
Unit Energy Consumption (kWh/yr)	120.60	81.72	33.53	8.15
Incremental MSP [$]	$18.48	$21.71	$26.81	$127.00

Battery Charger Classification

6450-01-P
DEPARTMENT OF ENERGY
10 CFR Part 430
[Docket Number EERE–2008–BT–STD–0005]
RIN: 1904-AB57
Energy Conservation Program: Energy Conservation Standards for Battery Chargers

Electronic Code of Federal Regulations

Title 10 → Chapter II → Subchapter D → Part 430 → Subpart C → §430.32

Product class	Product class description	Rated battery energy (Ebatt**)	Special characteristic or battery voltage	Maximum UEC (kWh/yr) (as a function of Ebatt**)
1	Low-Energy	≤5 Wh	Inductive Connection*	3.04
2	Low-Energy, Low-Voltage	<100 Wh	<4 V	0.1440 * E_{batt} + 2.95
3	Low-Energy, Medium-Voltage		4-10 V	For E_{batt} <10 Wh, 1.42 kWh/y E_{batt} ≥10 Wh, 0.0255 * E_{batt} + 1.16
4	Low-Energy, High-Voltage		>10 V	0.11 * E_{batt} + 3.18
5	Medium-Energy, Low-Voltage	100-3000 Wh	<20 V	0.0257 * E_{batt} + .815
6	Medium-Energy, High-Voltage		≥20 V	0.0778 * E_{batt} + 2.4
7	High-Energy	>3000 Wh		0.0502 * E_{batt} + 4.53

*Inductive connection and designed for use in a wet environment (*e.g.* electric toothbrushes).

**E_{batt} = Rated battery energy as determined in 10 CFR part 429.39(a).

Battery Charger Test Conditions

Appendix Y to Subpart B of Part 430—Uniform Test Method for Measuring the Energy Consumption of Battery Chargers

Table 5.3—Battery Charger Usage Profiles **Product class**				**Hours per day *****			**Charges(n)**	**Threshold charge time ***
No.	**Description**	**Rated battery energy (Ebatt) ****	**Special characteristic or battery voltage**	**Active + maintenance (ta&m)**	**Standby (tsb)**	**Off (toff)**	**Number per day**	**Hours**
1	Low-Energy	≤5 Wh	Inductive Connection ****	20.66	0.10	0.00	0.15	137.73
2	Low-Energy, Low-Voltage	<100 Wh	<4 V	7.82	5.29	0.00	0.54	14.48
3	Low-Energy, Medium-Voltage	<100 Wh	4-10 V	6.42	0.30	0.00	0.10	64.20
4	Low-Energy, High-Voltage	<100 Wh	>10 V	16.84	0.91	0.00	0.50	33.68
5	Medium-Energy, Low-Voltage	100-3000 Wh	<20 V	6.52	1.16	0.00	0.11	59.27
6	Medium-Energy, High-Voltage	100-3000 Wh	≥20 V	17.15	6.85	0.00	0.34	50.44
7	High-Energy	>3000 Wh		8.14	7.30	0.00	0.32	25.44

Most e-bike batteries would fall into Product Class 6: "Medium-Energy, High-Voltage." Many e-bikes come with several battery size options

Battery Metering

Equipment

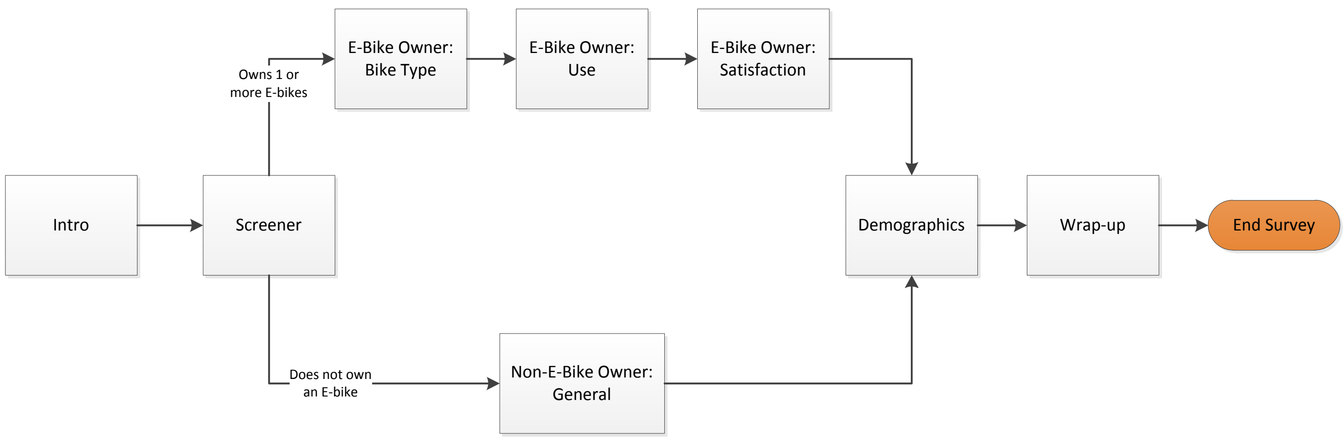
Metering was done with an Onset HOBO UX120-018 plug load logger. The charger model was CP100L1002. The battery being charged was a BiXPower BX3632H-809 36V 300Wh Li-ion battery.

Calculations

Reference	Value		Source
M	1440	Average E-bike miles	Survey
ee	1.02	e-bike kWh per 100 miles	Calculated from Survey Data
E	14.7	e-Bike kWh energy consumption	(M / 100) * ee
Mt	15	Miles per round trip	Assumed
T	96	Trips per year	M / Mt
Ht	6	Average hours per trip	Assumed time away from charger.
Hs	576	Hours away from charger	Ht * T
Ps	1.7	watts standby	Power meter
Pm	2.4	watts maintenance	Power meter
Pce	85%	Charge efficiency assumption	Assumed
	1.0	Standby kWh	Hs * Ps / 1000
	21	Maintenance kWh	(8760 - Hs) * Pm / 1000
	2.6	Charge cycle wasted kWh	(E / Pce) - E
	24.6	Sum of Wasted kWh	

Complete Survey Text

Efficiency Vermont E-Bike Survey -- 2017



SURVEY

I. Intro

Q1 Efficiency Vermont is seeking to better understand how Vermonters are using their electric bikes (a.k.a. E-bikes). Your feedback will be anonymous, so we encourage you to be as candid and accurate as possible in your responses. This survey will take approximately 5 minutes to complete and will be used to inform future energy efficiency programs. Thank you for your time and feedback.

II. Screener

Q2 How many, if any, electric bikes (E-bikes) do you personally own?

- ❍ None
- ❍ 1
- ❍ 2
- ❍ 3 or more

III. Non-E-Bike Owner: General

Q3 Do you plan on purchasing an E-bike within the next 12 months?

- ❍ Yes
- ❍ No
- ❍ Don't know

Display This Question:
If Do you plan on purchasing an E-bike within the next 12 months? Yes Is Selected

Q4 What is the main reason you want an E-bike?

IV. E-Bike Owner: Bike Type

Display This Question:
If How many, if any, electric bikes (E-bikes) do you personally own? 2 Is Selected
Or How many, if any, electric bikes (E-bikes) do you personally own? 3 or more Is Selected

Q9 For the following questions, please only consider the E-bike you use most frequently.

Q10 Which of the following best describes your E-bike?

- ❍ My bike was designed as an E-bike.
- ❍ My bike is a traditional bicycle that was modified using an E-bike kit.
- ❍ I am unsure.

Display This Question:
If Which of the following best describes your E-bike? My bike was designed as an E-bike. Is Selected
Or Which of the following best describes your E-bike? I am unsure. Is Selected

Q11 Please select the make/brand of your E-bike. (e.g. Trek)

❍ 8Fun	❍ Cube	❍ Evelo	❍ Green World Bike	❍ Moustache	❍ Sondors	❍ Yuba
❍ A2B	❍ Currie Tech	❍ Everly	❍ Haibike	❍ Nicolai	❍ Specialized	❍ Zehus
❍ Add-E	❍ Cutler Cycles	❍ EVO	❍ Hebb	❍ OHM	❍ SSR	❍ Zeitgeist
❍ Aerobic Cruiser	❍ Dahon	❍ eVox	❍ Hi-Power Cycles	❍ Optibike	❍ Stealth	❍ OTHER
❍ Ariel Rider	❍ Daymak	❍ eZip	❍ HP Velotechnik	❍ Organic Transit	❍ Stromer	❍ DON'T REMEMBER
❍ Electron	❍ Diamondback	❍ F4Q	❍ IES	❍ Outrider	❍ Sun	
❍ Benelli	❍ Dillenger	❍ Falco	❍ iGo	❍ Pegego	❍ Sun Seeker	

❍ Benno	❍ E-BikeKit	❍ Falcon	❍ IZIP	❍ Polaris	❍ Super Pedestrain	
❍ BESV	❍ E-Glide	❍ Faraday	❍ Jetson	❍ Populo	❍ Surface	
❍ Big Cat	❍ E-Joe	❍ Felt Electric	❍ Juiced	❍ Prodeco	❍ Tern	
❍ Biktrix	❍ E-Lux	❍ Flight	❍ Kalkhoff	❍ Public	❍ Torker	
❍ Biomega	❍ Emazing	❍ FLX	❍ Kranked	❍ Rad Power	❍ Trek	
❍ BionX	❍ e-RAD	❍ FlyKly	❍ KTM	❍ Raleigh	❍ Urban Arrow	
❍ Biria	❍ Easy Motion	❍ Focus	❍ Lapierre	❍ Reveio	❍ Vanmoof	
❍ Binni	❍ eFlow	❍ Ford	❍ Leed	❍ Ridde	❍ Vela	
❍ Blix	❍ EG	❍ Freway	❍ Leisger	❍ Pubbee	❍ Vilano	
❍ BM	❍ Elby	❍ Gazelle	❍ Liberty	❍ Schwinn	❍ Vintage	
❍ Bodhi	❍ Electra	❍ GenZe	❍ Sport Technik	❍ Scott	❍ Virtue	
❍ Box Bike	❍ EBO	❍ Giant	❍ Magnum	❍ ShareRoller	❍ Volt	
❍ Brompton	❍ ElectroBike	❍ Go-Ped	❍ Mando	❍ Smart	❍ Volton	
❍ Bulls	❍ Energie Cycles	❍ Gocycle	❍ Marrs	❍ SmartMotion	❍ Watskea	
❍ Cannondale	❍ Enzo	❍ Golden Motor	❍ Moar	❍ Snelheid Cycles	❍ Worksman	
❍ Clean Republic	❍ Prodigy	❍ Grace	❍ Motiv	❍ Solex	❍ Xtracycle	

Display This Question:
If Which of the following best describes your E-bike? My bike was designed as an E-bike. Is Selected
Or Which of the following best describes your E-bike? I am unsure. Is Selected

Q12 Please write in the model of your E-bike. (e.g. Trek Powerfly)

Display This Question:
If Which of the following best describes your E-bike? My bike is a traditional bicycle that was modified using an E-bike kit. Is Selected

Q13 Please select the make/brand of your E-bike kit? (e.g. Dillenger)

Display This Question:
If Which of the following best describes your E-bike? My bike is a traditional bicycle that was modified using an E-bike kit. Is Selected

Q14 Please write in the model of your E-bike kit. (e.g. Dillenger Arc Street 250W)

Q15 When did you modify/buy your E-bike?

- ❍ Less than 6 months ago
- ❍ More than 6 months, but less than a year ago
- ❍ More than 1 year, but less than 2 years ago
- ❍ More than 2 years, but less than 3 years ago
- ❍ More than 3 years ago

Q16 What was the main reason you got an E-bike?

V. E-Bike Owner: Use

Display This Question:

If How many, if any, electric bikes (E-bikes) do you personally own? 2 Is Selected

Or How many, if any, electric bikes (E-bikes) do you personally own? 3 or more Is Selected

Q17 For the remainder of the survey, please consider all of the E-bikes you own.

Q18 Typically, how many miles do you ride your E-bike in a one week period during the following times of the year? (If you have had your E-bike for less than a year, please list the number of miles you plan to ride.)

	# of Miles Traveled on an Average Week
Winter (December-February)	
Spring (March-May)	
Summer (June-August)	
Fall (September-November)	

Q19 This next question focuses on the average amount of time you spend in different E-bike settings. "Assist" is defined as the level of power provided by your E-bike motor. Some E-bikes may have a different number of motor settings than what's listed below. If this is the case, please estimate to the best of your ability.

Q20 On an average E-bike ride, what percent of your time is spent in each of the following settings?(Note: Total must equal 100%.)

_______ No motor assist; pedaling only
_______ Light assist with motor while pedaling
_______ High assist with motor while pedaling
_______ Throttle only; no pedaling

Q21 Please indicate the percent of time you use your E-bike for the following activities.(Note: Total must equal 100%.)

_______ Commuting to/from work
_______ Errands
_______ Traveling to/from social engagements
_______ Exercise / Recreation

Display This Question:

If Please indicate the percent of time you use your E-bike for the following activities. (Note: Tota... Commuting to/from work Is Greater Than 0

Or Please indicate the percent of time you use your E-bike for the following activities. (Note: Tota... Errands Is Greater Than 0

Or Please indicate the percent of time you use your E-bike for the following activities. (Note: Tota... Traveling to/from social engagements Is Greater Than 0

Q22 You mentioned that you sometimes use your E-bike to commute and run errands. Prior to owning an E-bike would you typically have been driving to those places instead?

- Often -- Would've driven more than 75% of time
- Sometimes -- Would've driven 25-75% of the time
- Rarely -- Would've driven less than 25% of the time
- Never

VI. E-Bike Owner: Satisfaction

Q23 Overall, how satisfied are you with your E-bike?

- Extremely satisfied
- Somewhat satisfied
- Neither satisfied nor dissatisfied
- Somewhat dissatisfied
- Extremely dissatisfied

Q24 What, if any, other thoughts would you like to share about your E-bike?

VII. Demographics

Q5 What is your zip code?

VIII. Wrap-up

Q6 That wraps up our survey. Thank you so much for your participation!

Q7 If you'd like to be entered into our drawing for one of three $100 gift cards to your local bike shop, please enter your email address below. (Your email will be kept confidential, and will not distributed or used for promotional/marketing purposes.)

Q8 If you know a fellow E-biker that may interested in taking this survey, please share their email address below and we'll send them a link.