Name: _____ Date: _____

Watt-Hours and Bike Lanes

Reading level 13 · 1749 words

On 31 December 1895, a patent was granted to Ogden Bolton Jr. of Canton, Ohio, for an "Electrical Bicycle." Its drawings show a battery hung from the frame. They show a motor built into the wheel, spinning around a hollow axle. The text says the motor is wound to take a heavy current at a low voltage, for instance one hundred amperes at ten volts. Multiply those and you get 1,000 watts going in. United States law now defines a low-speed electric bicycle as one with a motor of less than 750 watts. That figure rates a motor's output, so the match is rough. Still, Bolton's example sits well above today's line. Whether such a machine counts as a bicycle is a question about definitions, and definitions turn out to be most of the story.

Bolton's was one of several patents of the 1890s. In 1897 Hosea Libbey of Boston patented an electric bicycle with a double motor that drove the rear wheel through cranks and rods. A century later, the design that changed everyday riding was less about power than about listening. Yamaha began developing a power-assist bicycle in April 1988. In August 1990 it began asking Japan's transport ministry and police to treat the machine as a bicycle, so that riders would need no license. It announced its first system on 27 July 1993 and sold it at first in three prefectures. The motor no longer ran on its own. It gave help in line with the force on the pedals. By October 1997 Yamaha had built 250,000 of the power units.

How much energy does the help cost? A watt-hour is one watt used for one hour, or 3,600 joules. Take a rider and bicycle with a combined mass of about 100 kilograms. At 20 miles an hour they carry roughly 4,000 joules of motion energy, a little over one watt-hour. That comes from the formula half the mass times the speed squared. Yet a citizen-science project from a Berkeley climate group metered 30 electric bicycles over 3,457 miles. It measured 1.36 kilowatt-hours for every 100 miles at the charger, or 13.6 watt-hours a mile. The same project lists new electric cars at 24 to 72 kilowatt-hours for every 100 miles. Against the most and least frugal of those cars, the 30 bicycles used about 18 to 53 times less energy for each mile. Cars carry more people, and volunteers are no random sample.

Each mile costs about a dozen times the energy stored in the bicycle's own motion. Much of the rest goes into air drag, which grows with the square of speed, into everything else that resists the wheels, and into losses in the charger, battery and motor. This also explains why regenerative braking is rare on bicycles. It runs the motor backward as a generator, to slow the bicycle and slightly recharge the battery. Stopping from 20 miles an hour can return at most about one watt-hour, and no motor recovers all of it. It also needs a direct-drive hub motor and cannot be combined with a freewheel. As of 2024, one summary notes, the amount regenerated is usually too low to be worthwhile.

The battery behind this arithmetic has a history of near misses. In the 1970s Stanley Whittingham built a cell with a cathode that could house lithium ions and an anode of metallic lithium. It had just over two volts of potential. But metallic lithium is reactive, and the cell was too explosive to be useful. In 1980 John Goodenough showed that a cobalt oxide cathode could give as much as four volts. In 1985 Akira Yoshino swapped the reactive lithium for petroleum coke. That made the first commercially viable lithium-ion cell, light, durable and able to be charged hundreds of times. Its ions flow back and forth between the electrodes, rather than in reactions that break the electrodes down. It reached the market in 1991.

A cell is only the start. Packs for these bicycles usually use cylindrical cells of two sizes, 18650 and 21700. The numbers are the width and height in millimeters, so an 18650 is 18 wide and 65 tall. Cells are wired in series to raise the voltage and in parallel to raise the current and capacity. A 10S2P pack has two strings of ten cells, twenty in all, and each cell is nominally 3.7 volts, so ten in series come to about 37. Bosch's 2021 battery guide lists frame batteries of 400, 500 and 625 watt-hours. At the project's average, 500 watt-hours would last about 37 miles. Yet Bosch says one charge can take a rider anywhere from 14 to 90 miles, depending on the rider, hills, wind, temperature and weight.

Why can a battery fail? A cell is meant to stay inside a safe range. For charging that is usually 0 to 45 degrees Celsius, and for discharging 0 to 60. Overcharge it, drain it too far or overheat it, and it can fail badly. The worst failure is thermal runaway. It feeds itself, making heat that ignites the flammable liquid inside, and the pressure can throw out hot gas and flame. The fire can set off the next cell. Nearly all of a pack's power goes to the motor, and heating rises with current, so riding fast or uphill warms the cells. A battery management system can disconnect the pack. It cannot stop a defect built into a cell. A thin plastic separator keeps the two electrodes apart, and a damaged separator, like a folded electrode, is one such defect.

Standards try to find weak packs before riders do. UL 2849 tests the drive system, battery and charger together. One test drops a 535-gram steel ball onto the battery case from a height of 51 inches. Others splash the case, hold the system in 88% humidity, test its insulation again afterward and flex its wiring 500 times. Nine abnormal-operation tests include overcharging by 10%. During them, the bicycle must not give off flames or molten metal. While a fully drained battery charges, it may draw no more than 110% of its rated current. New York City now requires outside certification of electric bicycles, scooters and their batteries. The safety commission's plain advice is to use the charger that came with the bicycle and never charge it while you sleep.

The numbers need care. The Consumer Product Safety Commission's April 2026 report knew of 310 deaths on electric bicycles from 2017 through 2024, and warns that late reports will raise the count. The same report puts 2017 through 2022 at 122, up from 104 in the commission's 2023 report. Of the 310, 170 were collisions with motor vehicles, 61 were control issues such as hitting a fixed object, 19 involved pedestrians, and 19 were linked to

battery fires. Seven of those fire deaths involved homemade packs or repair shops. A separate count of all micromobility products, from 2019 through 2023, found 227 battery incidents with 39 deaths and 181 injuries. Fire caused 195 of the incidents and all 39 deaths. The counts cover different products, years and definitions, and both are incomplete, so they cannot be added together. In June 2026 the agency proposed requiring UL 2849. Its staff observed that certified products show a decreased likelihood of fire risk.

Stopping obeys the same square. If the tires' grip sets the limit, braking distance is the speed squared, divided by twice the grip times gravity, and weight cancels out: a heavier bicycle presses harder on the road, so its tires hold harder too. So an electric bicycle needs more room mostly because it goes faster, plus the distance covered while the rider reacts. In a study in Gothenburg, Sweden, six regular riders on 250-watt e-bikes braked at roughly 20 kilometers an hour. When something unexpected happened, their stops averaged 2.4 meters per second squared with both brakes and under 1.6 with one. These are averages over many stops, not the most a bicycle can do. A hard front-brake stop can throw a rider over the handlebar. Because these bicycles carry a heavy battery and motor, researchers suggest mounting them lower and further back.

An electric scooter changes the geometry. The rider stands upright on a deck, over wheels often 8 to 11 inches across. Italian engineers note that bicycle wheels are larger and add a steadying effect. Yet in their braking tests, three riders on one scooter and one bicycle showed no significant difference. In the safety commission's 2024 study, only 18% of injured scooter riders were wearing a helmet. CDC's 2018 Austin study found fewer than one in a hundred. The commission's April 2026 report counted 206 scooter deaths from 2017 through 2024, with 140 involving motor vehicles and 15 fires. Half of the injured riders CDC interviewed in Austin said a pothole or crack may have contributed.

So what is a bicycle? United States law defines a low-speed electric bicycle as one with working pedals and a motor of less than 750 watts. Its top speed on the motor alone must be under 20 miles an hour, for a 170-pound rider. A model law from the group PeopleForBikes sets three classes under the same 750-watt ceiling, with the Class 3 top at 28. The group counted 36 states using it in 2021 and 43 in 2024, and it says the laws still differ by state. In January 2026 New Jersey passed a law that, the group says, counts only Class 1 as a low-speed electric bicycle. New York City's chart lists Class 3 at 25 miles an hour, and since 24 October 2025 the city has limited every electric bicycle to 15. The European Union draws its line at 25 kilometers an hour and 250 watts.

The fairest way to state the argument is as a question of kind or degree. The Interior Department's Order 3376, signed in August 2019, aimed to widen recreation for people with limits of age, illness or fitness. It directed agencies to allow electric bicycles where bicycles are allowed. When the Park Service wrote its 2020 rule, some commenters warned that electric bicycles could carry riders farther into remote areas, and fast along winding trails with

limited sight lines. The Service replied that research suggests certain classes have impacts like bicycles, but that research is still being developed. Each park superintendent decides. Both sides reason from incomplete data, and how fast is too fast on a shared path is a number each place must still choose.

Questions

1. Why does the book compare Bolton's 1,000 watts with 750?

A. Bolton's example sits above today's 750-watt line, though the match is rough
B. Bolton's patent was refused
C. The motor was too weak to climb hills

2. Why is regenerative braking rare on bicycles?

A. It is illegal in most states
B. The stopping energy is small, and the motor must be a direct-drive hub
C. Batteries cannot be recharged

3. In this book, what does "thermal runaway" mean?

A. A bicycle that rolls away from heat
B. A rule about hot weather
C. A self-feeding overheating reaction in a battery cell

4. Why does the book say the two safety counts cannot be added together?

A. They cover different products, years and definitions, and both are incomplete
B. One of them is wrong
C. They were counted by the same person

5. According to the braking formula in this book, what mostly makes a faster e-bike take longer to stop?

A. The color of the frame
B. Its heavier battery, since weight lengthens the stop
C. The higher speed, because distance grows with the square of the speed

6. Which statement fits what the Park Service said about e-bike impacts?

A. Research is complete and e-bikes are banned
B. Research suggests some classes have similar impacts to bicycles, but research is still being developed
C. E-bikes damage trails more than motorcycles

Words to know

watt: power unit
joule: energy unit
regenerative: energy-recovering

thermal: about heat
separator: electrode divider

Answer key: Watt-Hours and Bike Lanes

1. A. Bolton's example sits above today's 750-watt line, though the match is rough
2. B. The stopping energy is small, and the motor must be a direct-drive hub
3. C. A self-feeding overheating reaction in a battery cell
4. A. They cover different products, years and definitions, and both are incomplete
5. C. The higher speed, because distance grows with the square of the speed
6. B. Research suggests some classes have similar impacts to bicycles, but research is still being developed