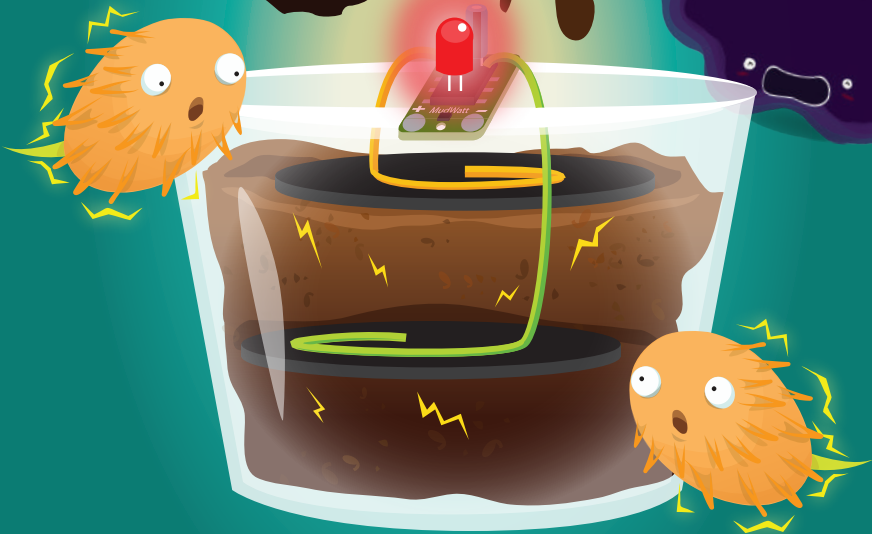




# MudWatt

GUIDE TO DISCOVERING MUD POWER!

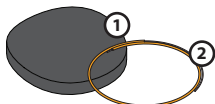


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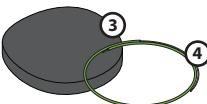
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# What's In Your MudWatt?

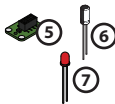
## Core Kit



1. Cathode Felt  
2. Cathode Wire



3. Anode Felt  
4. Anode Wire



5. Blinker Board  
6. Capacitor 7. LED



8. Nitrile Gloves

## Classic Kit

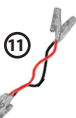


9. Vessel

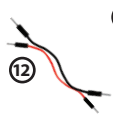


10. Clock & Adhesive

## Science Fair Pack



11. Alligator Wires



12. Jumper Wires



13. Resistors  
14. Multimeter

Warning: The Anode and Cathode are made of conductive graphite fibers, which can cause electrical short circuits. To prevent any damage, keep the conductive fibers away from other electronics and wear the included gloves during construction.

## Like Electric Bacteria?

Check out the “The Electric Microbe” comic book and plush toy at [www.magicalmicrobes.com](http://www.magicalmicrobes.com)



## How Does MudWatt Work?

The answer lies within the soil!



"Geo",  
a microbe

Meet Geo the Geobacter. Geo is a microbe, one of BILLIONS of types of tiny creatures who happen to be smaller than one-tenth the thickness of a single human hair. And, even though we can't see Geo or Geo's microbe friends, they live in almost all soils and sediments, all over the planet. Among these diverse microbes are certain species, including Geobacter, that hold the unique power to release electrons outside their bodies.

The MudWatt gives microbes like Geo a cozy home by providing them with two conductive (electron-moving) graphite discs (think pencil-lead pucks!) called the anode and cathode. The anode is placed deep in the mud where electron-generating microbes grow, while the cathode is placed on top, exposed to air (see diagram on next page).



### Shewanella (Shewy)

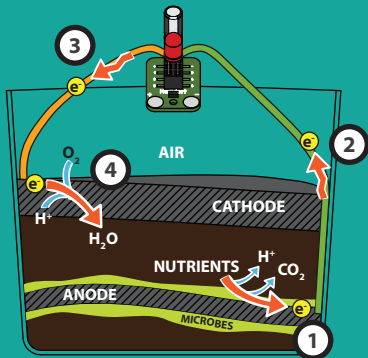
Shewanella species, affectionately called Shewies, can be found almost everywhere on earth, from mountain to sea. Shewies release electrons outside their bodies and transfer these electrons to their neighbors by linking together with their conductive appendages, called nanowires. Talk about a strong community! Shewies can even eat up toxins and compounds containing radioactive uranium, which makes Shewies great at helping clean up contaminated soils.

### Geobacter (Geo)

Geobacter species, or Geos, have the ability to breathe iron compounds, similar to the way we humans breathe oxygen. In fact, Geos prefer to live where there is no oxygen, in places like deep underground or deep in ocean sediments. Like Shewies, they can munch up pollutants, including petroleum, and have been used to help clean up the environment, getting rid of electrons along the way.



## Fig 1: MudWatt



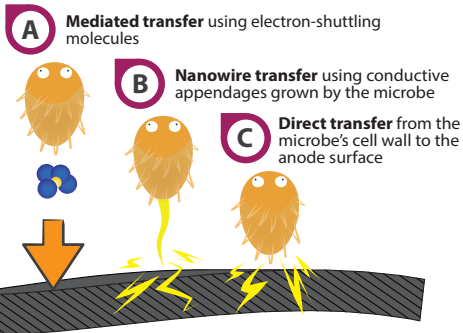
**Figure 1** shows the **flow of electrons** through a MudWatt:

- 1 As the microbes around the anode munch up the nutrients in the mud, they **deposit electrons** onto the **anode** in one of three ways, as illustrated in **Figure 2** below.
- 2 These electrons travel through the wire to the **Blinker Board**, where they power the electronics.
- 3 The electrons then travel back down through the wire to the **cathode**.
- 4 At the cathode, electrons interact with oxygen and protons to form **water**.

This cycle happens over and over, trillions of times every second. This continuous flow of electrons is what we call **"electricity"** which can power small electronics.

## Fig 2: Electron Transfer Modes

**Figure 2** on the right shows three different ways microbes kindly give their spare electrons to the anode.



## Real-world Applications:

The MudWatt is based on **microbial fuel cell technology**. Microbial fuel cells (MFCs) are nifty devices that convert chemical energy into electricity. When microbes eat up the sugars and nutrients in the soil around them, they release the chemical energy stored in these foods as waste electrons outside their tiny bodies.

Microbial fuel cells are a new and exciting technology currently being researched in high-tech labs around the world. And some real world applications have already started to take shape. Below are two examples, but more applications are sure to come.

### Clean Energy at the Ocean Floor



Underwater sensors are used for monitoring the environment, infrastructure, and equipment, such as pipelines and cables. However, once these sensors are deployed, changing their **batteries** is tricky and expensive. Luckily, MFCs can provide clean, **renewable energy** at the sea floor, using ocean sediment itself as the fuel! As sea animals die and sink to the ocean floor, they become a renewable source of nutrients for microbes in the sediment. MFCs can harness these microbes to produce continuous power for the sensors!

### Waste-to-Energy



Treating **wastewater** is very expensive and takes a lot of energy. In fact, about 3% of the U.S. energy budget is used to treat wastewater. However, wastewater contains about five times more energy than what is needed to treat it! Instead of consuming energy, wastewater treatment plants could use MFCs to produce **energy** and provide **electricity** to homes.

The MudWatt shows how MFCs can turn waste into energy. Just tear up the MudWatt's packaging, put it in your MudWatt, and watch the cardboard turn into electricity!

## The Art of Experimentation: Part 1

Listed below are things to think about as you **design your MudWatt experiment** extraordinaire! This framework, called the **“Scientific Method,”** is used by engineers and scientists all over the world to design investigations that further our understanding of the world around us:

### Scientific Method

#### Purpose

What do you want to learn about or find the answer to? What do you already know about this subject?

#### Testable Question

Pose your idea in the form of a question that can be answered by experimentation.

#### Independent Variables

What things will be changed in this experiment? These are the independent variables. (ex: soil type, temperature, etc.)

#### Dependent Variables

What things will be measured in this experiment? These are the dependent variables. (ex: power, lifetime, etc.)

#### Hypothesis

What do you think will happen?

#### Materials

List all the materials and supplies you will need to conduct this investigation.

#### Procedure

Write out each step in enough detail that someone else could do the same experiment from your directions.

## The Art of Experimentation: Part 2

Once you've prepared your experiment and built your MudWatt(s), you can begin to collect and analyze your data.

### Analyzing Data

#### Data Collection

Record what happens, especially to your dependent variables. (Remember to include units, times of measurements, sketches, any unexpected observations, etc.)

#### Data Display

Find the best way to display your data so that others can easily understand it. Options include graphs (line, bar, circle, scatter) or a time-series of sketches.

#### Analysis

Examine the data and describe any patterns, trends, and changes you see.

#### Conclusion

Were you able to answer your testable question from the results of this experiment? What did you find out? Did you get the results you expected? Why or why not?

Did anything go wrong along the way? Identify anything you would do differently if you were to do the experiment again.

Identify any new ideas or new questions that came up.

If you are measuring power in your experiment, you can use the **MudWatt Explorer App** with a smart phone or tablet! The app makes it easy to record power and analyze your data!





## Sample MudWatt Experiments

We encourage you to get creative and come up with your own experiments to run with the MudWatt. Here are a few to get you started:

### Beginner-Level Experiments

#### Does soil type impact how much power the MudWatt produces?

Soil type varies by source, with differences in texture, color, smell, etc. Note: You can use the MudWatt Soil Standard, aka the "DirtBag," available at [www.magicalmicrobes.com](http://www.magicalmicrobes.com), as a control.

#### Which human foods increase power generation?

With any special ingredient, you'll want to mix just a little into the soil. We recommend using 1 part special ingredient to 5 parts soil.

#### Does soil temperature impact how much power the MudWatt produces?

Give your MudWatt a bath! We recommend testing the temperature and power at many points as you set your MudWatt in cold or warm water up to the soil line.

#### How is power impacted by connecting multiple MudWatts together?

You can connect MudWatts in series or parallel. The total voltage and current will change with your configuration and as you connect more MudWatts.

### Advance-Level Experiments

#### How do the variables listed above impact a MudWatt's voltage and current?

**Note:** For this experiment, you'll need a multimeter, like the one that comes in the Science Fair Pack, to measure voltage and current. The voltage can tell you a lot about the chemistry in your MudWatt, whereas the current can tell you about how healthy your microbes are.

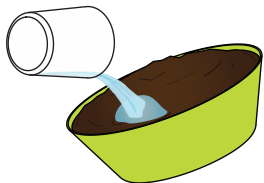


For more ideas and details about experiments, visit our website at:  
[www.magicalmicrobes.com](http://www.magicalmicrobes.com)

## Let's Build Your MudWatt!

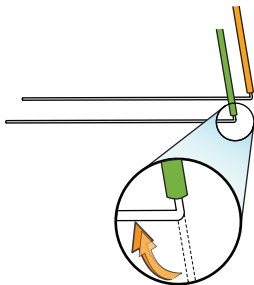
**Note for MudWatt Core users:** Before you start building, you'll need to find a container for your MudWatt. You can use any container that is wide enough to fit the electrodes and at least 5 cm tall.

**1. Put on your gloves and find 3-4 handfuls of soil** or swamp goo – **the darker and smellier the better!** Turn your soil into mud (if it isn't already). The consistency of your mud is **very important**. It should be completely saturated but not too soupy. Try to avoid using soils that have little white balls, as those will create unwanted air pockets.

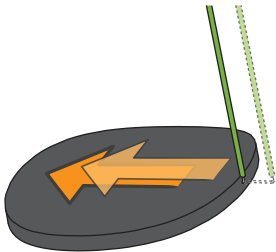


**Note:** To give your MudWatt some extra nutrients, we recommend cutting up the MudWatt packaging into dime-size bits and mixing it into your soil!

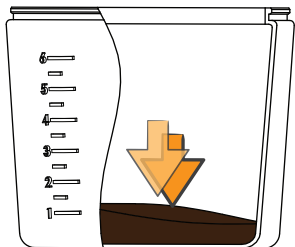
**2. Bend both wires 90°** where the plastic sheath ends. Straighten the bare ends of the wires.



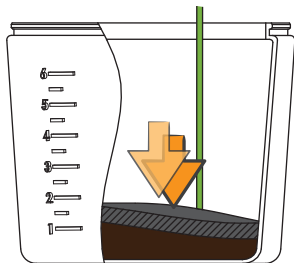
**3. Insert the bare end of the green (anode) wire into the side of the thin felt disc** while **wearing the gloves** provided. Try to keep the wire from poking out the felt. Repeat with the orange (cathode) wire and the thick felt disc.



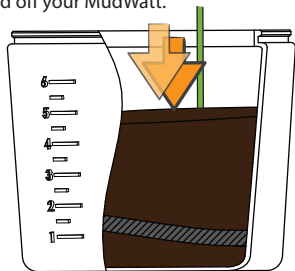
**4. Pack a layer of mud** at least 1 cm deep into the bottom of your container. Give your mud a friendly squish so that it forms a smooth layer.



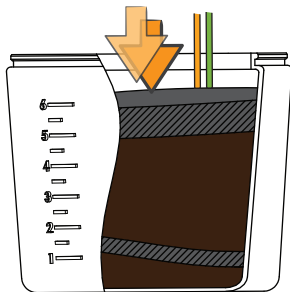
**5. Place the anode** (green) you constructed in Step 3 on top of the mud, pressing down firmly to squeeze out air bubbles. Make sure the anode is saturated with liquid, adding extra water if needed.



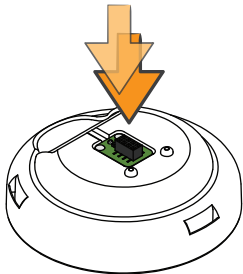
**6. Fill your container with more mud**, at least 5cm deep, pressing down firmly to squeeze out air bubbles. Give your mud and yourself a rest for a few minutes. Then, drain any excess liquid off your MudWatt.



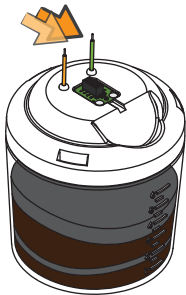
**7. Place the cathode** (orange) gently on top of the mud, making sure the top of the cathode is exposed to air.



8. If your kit came with one (or three!) Vessel(s), remove your gloves and attach the Hacker Board(s) into the indentation on the lid. Otherwise, skip ahead to the next page.



9. Pass the electrode wires through the lid. With the semicircular indentation in front, the cathode (orange) should be on the left and the anode (green) on the right. Snap the lid into place.



## Congratulations!

You are now ready to harness the **power of the microbes** living in your mud! You'll need to make sure your mud remains saturated. If you see your mud drying up, add a little water. If you have a Core Kit, you can cover your container with a lid or plastic wrap to minimize evaporation.

Now, let's see what your Mudwatt can do!

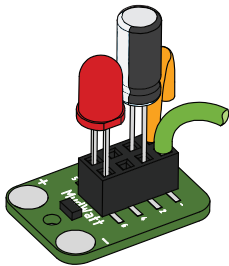


## Mode 1: Blinker

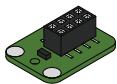
### Blinker Setup

1. Bend and connect the cathode wire (orange) to '+' and the anode wire (green) to '-' on the Hacker Board.
2. Connect the long end of the **black** (10 $\mu$ F) capacitor to Pin 1 and the short end to Pin 2. You may need to bend the wires so they fit snugly.
3. Connect the **LED**'s long end to Pin 5 and its short end to Pin 6.

**That's it!** The LED should begin to blink after just a few days, once your MudWatt has developed a healthy community of microbes!



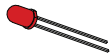
### What do these components do?



**Hacker Board:** The Hacker Board takes the low voltage and low current coming from the MudWatt and converts them into short bursts of higher voltage and higher current.



**Capacitor:** The Capacitor is a small energy storage component. It's able to build up energy as it comes in from the MudWatt and then discharge that energy in a quick burst to blink the LED.



**LED:** The Light Emitting Diode (LED) takes the electrons being discharged by the capacitor and converts those electrons' energy into light energy.



Download the **MudWatt Explorer App** before continuing!



Available on the  
**App Store**



Get it on  
**Google play**

## Measuring Power!

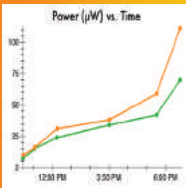


Did you find the **MudWatt Explorer App** on the **App Store** or **Google Play**? You'll be using it to measure, record, and analyze your MudWatt data in the few next steps!



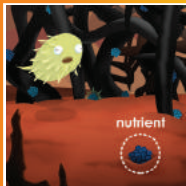
### Step 1: Ready, Aim...Measure!

Once your MudWatt's LED is blinking, open the MudWatt Explorer App and select **Measure** from the main menu. Line up the LED in the target on your screen, and the App will automatically measure your power and your population of electric bacteria!



### Step 2: Record & Analyze Multiple Measurements

Record several measurements by using the **Record** button on the Measurement screen. Go to the **Analyze** section of the app to see how your MudWatt's power changes over time!



### Step 3: Discover a Hidden World

Use your power readings to unlock chapters of a comic following Shewy, the Electric Microbe. **Discover** the magic of microbes as Shewy explores this complex, muddy world.

## Mode 2: Clock (Classic Kits and Science Fair Packs)

Switch to this mode once your MudWatt's power is above 20 microWatts

### Setup (Order of steps is important!)

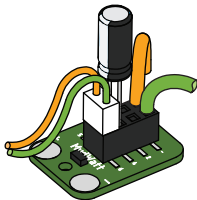
1. Disconnect the LED.
2. Disconnect the **black** (10 $\mu$ F) capacitor and reconnect its long end to Pin 3 and its short end to Pin 4.
3. Lastly, connect the clock wires so that the **orange** wire goes to Pin 5 and the **green** wire goes to Pin 6.

### Attaching the Clock

Peel off one side of the adhesive strip and stick it to the back of the clock. Peel off the other side, and press the clock firmly into the indentation on the lid for 5 seconds.

### You're done!

You've now got yourself a dirt-powered clock. Your clock is being energized by trillions of electrons donated every second by your MudWatt's microbes. Learn more at [www.magicalmicrobes.com](http://www.magicalmicrobes.com)



### Like Electric Bacteria?

Check out the "The Electric Microbe" comic book and plush toy at [www.magicalmicrobes.com](http://www.magicalmicrobes.com)



## Discovering Max Power: Part 1 (for Science Fair Packs)

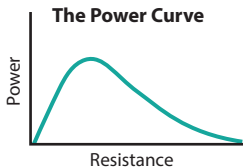
To find your MudWatt's **max power output**, you'll need to perform a "**Sweep**," detailed on the next page. With your Sweep data, you'll calculate power under different resistances using Ohm's law, shown to the right. Plot your **Power vs. Resistance** to find your MudWatt's max power!

Note: A MudWatt's max power will change over time as your microbe community develops, so track your MudWatt's growth by performing Sweeps throughout its lifetime.

Use Ohm's Law to calculate the power:

$$P = \frac{V^2}{R}$$

P = Power in Watts  
V = Voltage in Volts  
R = Resistance in Ohms



### Important Terms

#### Voltage

Voltage is the measure of the electron "pressure" that drives the flow of electrons through a circuit. Another way to think of voltage is to think about water in a hose with a nozzle on the end. Even when the water isn't flowing, there's still pressure in the hose. The amount of pressure in the hose is like the level of voltage in an electrical circuit. Voltage is measured in Volts--shocking!

#### Current

The rate at which electrons are flowing through the wires is called the electrical current. In the water hose analogy, current is like the flow rate of the water in the hose. Current is measured in amperes.

#### Resistance

Every electrical circuit has resistance to the flow of current through it. Resistance in a wire or other conductive material creates friction, which produces heat. And, if you send too much current through a wire, the friction can cause so much heat that fires start! Resistors are components that restrict the flow of electricity in a controlled way (to prevent fires and protect electronics). Resistance is measured in a unit, called Ohms.

#### Power, Glorious Power!

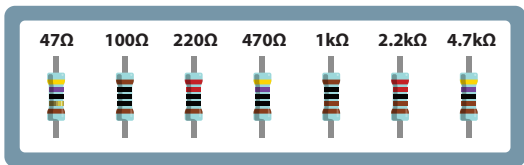
When we talk about energy production, we're talkin' about power! Power is the amount of energy consumed or generated over a given period of time. The standard unit of power is the Watt, which corresponds to the amount of energy, measured in units called Joules, being transferred per second.



## Discovering Max Power: Part 2 (for Science Fair Packs)

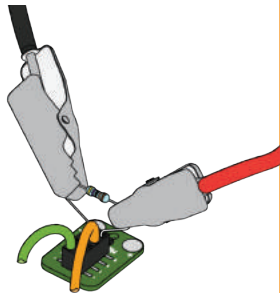
### Resistor Color Chart

Some resistors are so small that you can't label them with numbers. Instead, these resistors are labeled with a series of color bands that represent resistance value. Match the colors of your resistors to those below to identify your resistors' resistance. ( $\Omega$  = Ohms,  $k$  =  $\times 1000$ )



### Performing a Sweep

1. Remove all components from the Hacker Board, except the anode wire (green). Plug the cathode wire (orange) into Pin 3.
2. Switch the multimeter setting to "2000 m." Plug the red probe (+) into the "V $\Omega$ mA" port and the black probe (-) into the "COM" port. Attach the alligator clips to the tips of the probes.
3. Plug a resistor into Pin 5 and Pin 6 (orientation doesn't matter). Identify and record its value using the color chart shown above.
4. After 15 minutes, check the voltage by clipping the alligator cable attached to the multimeter's red probe (+) to the resistor's wire in Pin 5 and the alligator cable attached to the multimeter's black probe (-) to the resistor's wire in Pin 6 as shown to the right. Record the measured voltage.
5. Repeat Steps 4 and 5 for all resistors provided, noting the measured voltage for each resistor. Follow the instructions on the previous page to calculate the power and plot your data. Don't forget to turn off the multimeter when you're done!

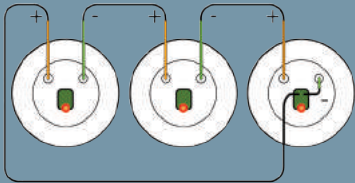


## Connecting Multiple MudWatts

What happens when you connect multiple MudWatts together? **More Power!** But, depending on how you connect them, you'll get either more voltage or more current. Experiment with connecting multiple MudWatts to see the effects for yourself!

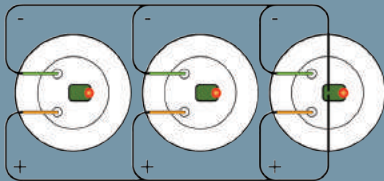
### Connecting MudWatts in Series

In circuits, when components are connected in **series**, it means that the (-) end of one component is connected to the (+) end of another. In this configuration, an electron has to go through all the components in order to complete the circuit. When MudWatts (or standard batteries) are connected in series, their voltage is added, but their current stays the same.



### Connecting MudWatts in Parallel

In circuits, when components are connected in **parallel**, it means that the (+) end of one component is connected to the (+) end of another and the same is true for the (-) ends. When MudWatts (or standard batteries) are connected in parallel, their current is added, but their voltage stays the same.



We encourage you to experiment with different configurations to see the effect. For example, you can use alligator clips and jumper wires, included in Science Fair Packs, to put some MudWatts in series and others in parallel and measure the circuit's overall voltage and current values to see if they're what you'd expect.

In addition to measuring the voltage and current of your multi-MudWatt circuit, measure the power using the MudWatt Explorer App. Does higher voltage or higher current increase the blink rate of the LED?

## Troubleshooting

Typically it takes about 3-7 days to ramp up. You will need a voltage of at least 0.35V in order to activate the Hacker Board circuit that makes the LED blink. Here are a few common steps that can help you get your MudWatt operating like a fine-tuned machine:

**Soil choice:** The darker and smellier, the better. To ensure you have enough nutrients for the microbes, tear up some dime-size pieces of the MudWatt packaging and mix them into your soil near the anode. Don't use "garden soils" with little white balls in them. These are good for plants, but not MudWatts.

The cathode needs to breathe, so make sure it is not submerged in water

Make sure the soil is completely saturated. It is best if there is a 2-3mm layer of water resting above the soil

Make sure the LED and capacitor are well connected to the Hacker Board, and that they're placed in the correct orientation.

Make sure there's at least 3cm of wet soil between the cathode and anode.

Make sure there are no air bubbles within the soil. If you see some, try squeezing them out by compressing the soil.

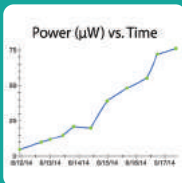
**Temperature:** Warming up your MudWatt to body temperature (37 C / 99 F) can kickstart your microbe community

These steps usually get MudWatts going, but if you still experience issues, please drop us a line at [info@magicalmicrobes.com](mailto:info@magicalmicrobes.com) or (617) 858-0728.

DOWNLOAD THE MUDWATT EXPLORER APP!



**Measure** your MudWatt's power!  
**Unlock** chapters of a fun comic!  
**Record** and share your power data!



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