MudWatt

GUIDE TO DISCOVERING MUD POWER!

Use this guide to learn how to use your new Mudwatt!

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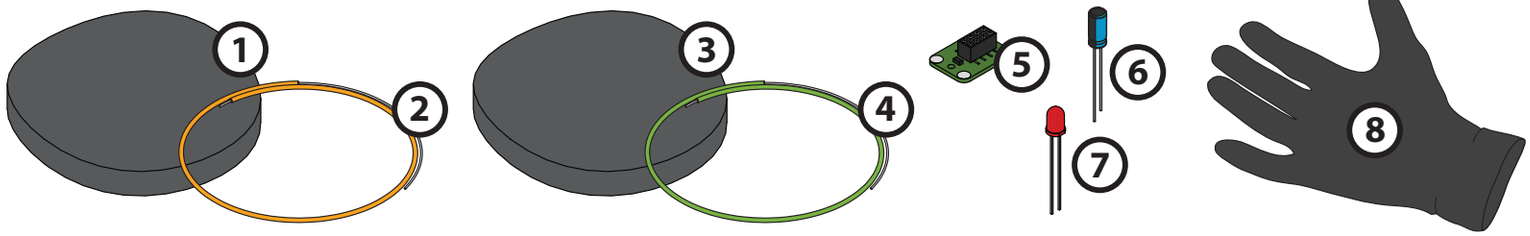
What's In Your MudWatt?

Let's make sure you have everything you need:

Mudwatt Core Kit



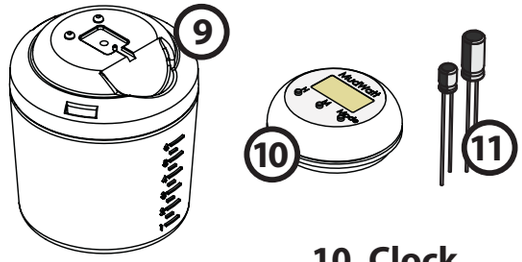
1. Cathode Felt
2. Cathode Wire

3. Anode Felt
4. Anode Wire

5. Blinker Board
6. Capacitor 7. LED

8. Nitrile Gloves

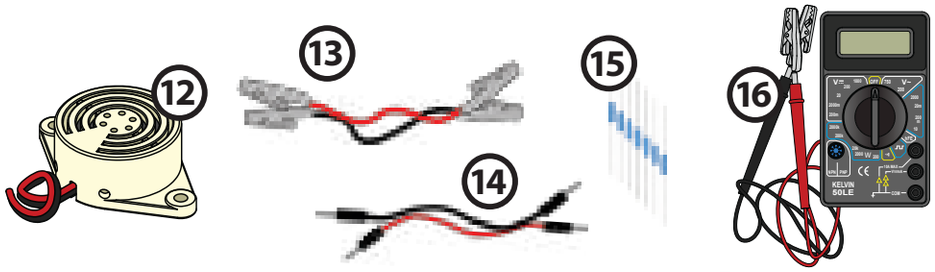
Mudwatt Classic Kit



9. Vessel

10. Clock
11. Capacitors

Mudwatt DeepDig / Science Fair Pack



12. Buzzer

13. Jumper Wires
14. Alligator Wires

15. Resistors
16. Multimeter

Warning: *The Anode and Cathode are made of conductive fibers, which can cause electrical short circuits. To prevent any damage, keep the conductive fibers away from other electronic devices.*

Like Electric Bacteria? Check out the "Shewy, the Electric Microbe" comic book and plush toy on our website: **www.mudwatt.com**

How Does MudWatt Work?

The answer lies within the dirt!

"Shewy", a microbe

Although we cannot see them with the naked eye, with bodies one-tenth the thickness of a human hair, **micro-organisms** or **"microbes"** live throughout virtually all dirt and sediment on the planet. Among these diverse communities of microbes are particular species that have the unique ability to **release electrons** outside their own bodies.

The MudWatt utilizes this remarkable ability by providing mud-based microbes with two conductive graphite discs, called the **anode** and **cathode**. The anode is placed within the mud where the electron-generating microbes can grow, while the cathode is placed on top exposing it to oxygen in the air (see diagram on next page).

Shewanella (Shewy)

Known for their versatility, **Shewanella** species can be found almost everywhere on earth, from mountain dirt to ocean sediments. Due to their unique ability to expel electrons to compounds outside their bodies, Shewanella can metabolize a variety of substances and link together through conductive appendages, transferring electrons to their neighbors. They can even metabolize toxic compounds containing radioactive Uranium!

Geobacter (Geo)

Geobacter species have the ability to respire iron compounds and use them in a way similar to the way humans respire oxygen. In fact, they prefer to live in environments where there is no oxygen, such as deep underground or within ocean sediments. Like Shewanella, due to their ability to expel electrons, they can metabolize many environmental pollutants, including petroleum and Uranium, and have been used to help clean up pollution.

Fig 1: MudWatt

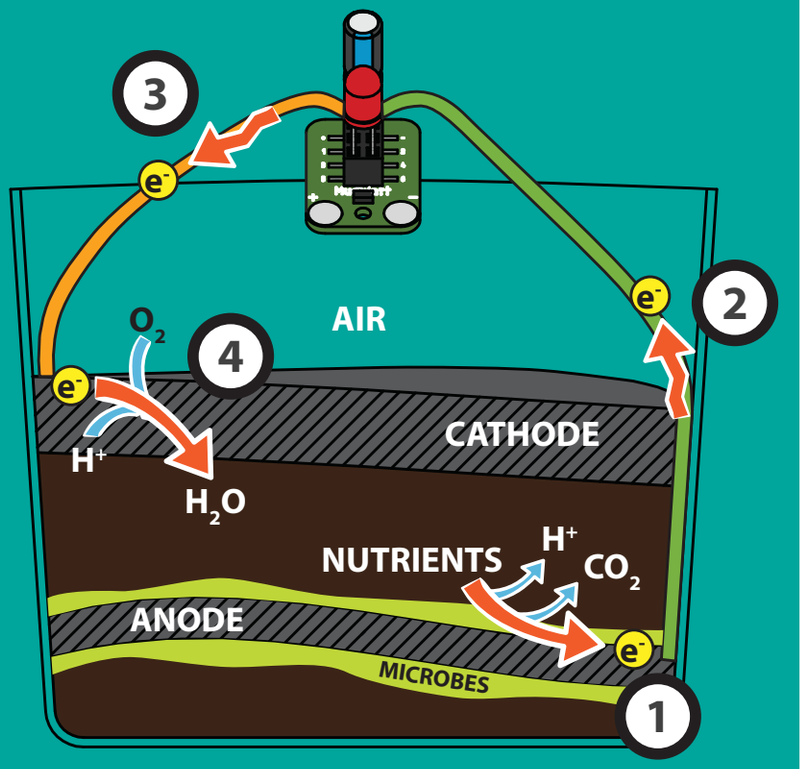


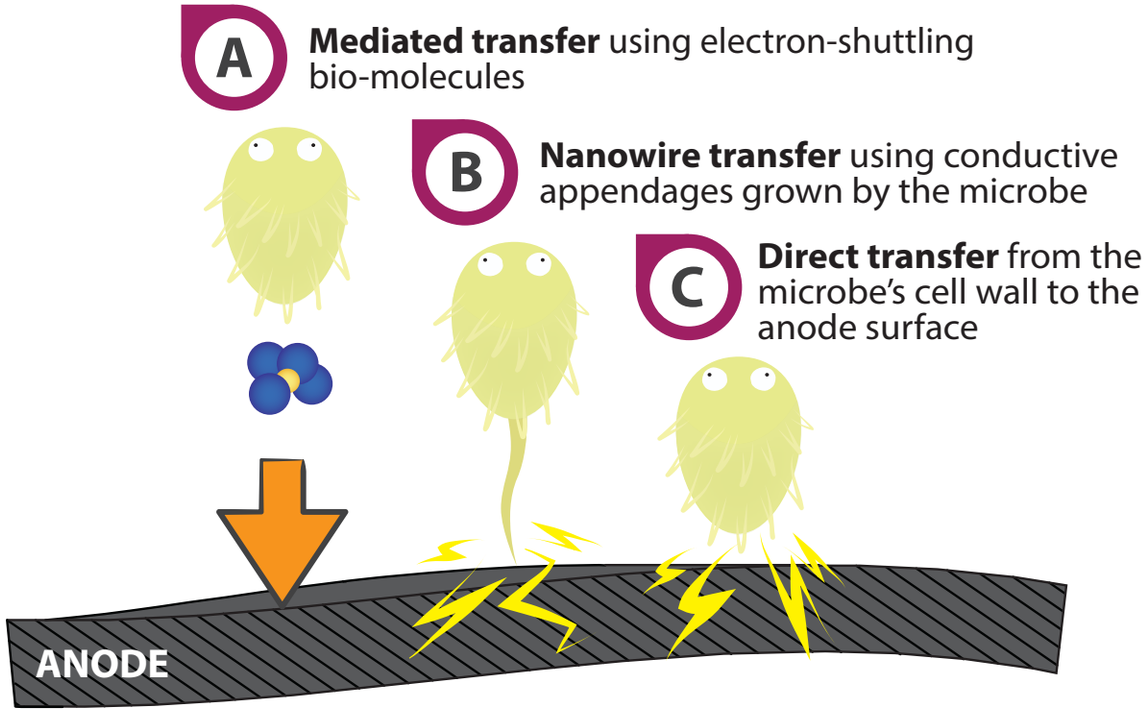
Figure 1 shows the **flow of electrons** through a MudWatt:

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 the three different ways microbes donate their spare electrons onto the anode.



Real World Applications:

The MudWatt is based on **microbial fuel cell technology**, which converts chemical energy stored in sugars and nutrients (like those found in soil, or the food you eat) into electricity. Microbes are the engines that drive this process.

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 emerge as theis technology is developed further.

Clean Energy at the Ocean Floor

Underwater sensors are used for monitoring the environment and equipment such as pipelines and cables. However, once these sensors are deployed, it's extremely difficult and expensive to change their **batteries**. Luckily, microbial fuel cells 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. Microbial fuel cells 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 produce **energy** and provide **electricity** to homes. The MudWatt is an example of how waste can be turned into energy. You can even tear up the MudWatt's packaging, put it in your MudWatt, and watch it decompose into electricity instead of getting thrown in the trash!

The Art of Experimentation: Part 1

With the MudWatt, you can **design your own experiments** and take control of your own learning. Listed below are the things you should think about when designing your experiment. This framework, called the **"Scientific Method"** , is used by engineers and scientists all over the world to design investigations and 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 only be answered by experimentation.

Independent Variables
What things will be changed in this experiment?
(ex: soil type, temperature, etc.)

Dependent Variables
What variable will be measured in this experiment?
(ex: power, lifetime, etc.)

Hypothesis
What do you think will happen based on what you already know about this subject?

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.

Helpful experiment templates and worksheets are available on our website: **www.mudwatt.com**

The Art of Experimentation: Part 2

Once you've prepared your investigation and built your MudWatts, you can begin to collect and anaylze your data.

Analyzing Data

Data Collection

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

Data Display

Find the best way to display the data for others to easily understand it. Options include graphs (line, bar, circle, scatter) or time series of sketches.

Analysis

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

Conclusion

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

Did anthing 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 have arisen as a result of running this experiment.

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 power data!

Available on the App Store

Get it on Google play

Sample MudWatt Experiments

We encourage you to get creative and come up with your own experiments to run with the MudWatt. To help spark your creativity, here are a few great experiments to get you started:

Beginner Level Experiments

Does the type of soil impact how much power is produced from the MudWatt?

Soil type can vary by source, texture, color, smell, etc. Note: You can use the MudWatt Soil Standard (aka the "DirtBag") available at www.mudwatt.com as a control in you experiment.

What food items from the fridge would increase power generation in a MudWatt?

With any special ingredient, you'll want to add just a modest amount, and mix it well into the soil. We recommend using 1 part special ingredient for every 5 parts of soil.

Does the temperature of soil impact how much power is produced?

We recommend testing the temperature and power at many points as you put your MudWatts in baths of cold or warm water.

How is power impacted by connecting multiple MudWatts together?

You can connect MudWatts in series or in parallel. This will impact the total voltage and current output of the system.

Advance Level Experiments

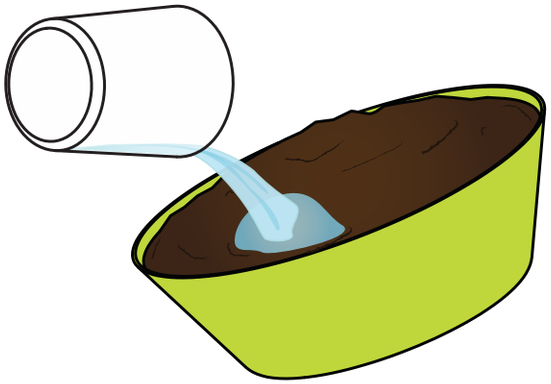
How do the variables listed above impact a MudWatt's voltage and current?

Note: You'll need the multimeter that comes in the DeepDig Kit to measure voltage and current. The voltage value can tell you a lot about the chemistry in your MudWatt, whereas the current can tell you a lot about how healthy your microbes are.

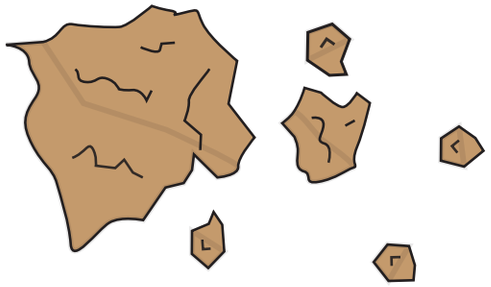
For more ideas and details about experiments you can perform with your MudWatt, visit our website at: **www.mudwatt.com**

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.

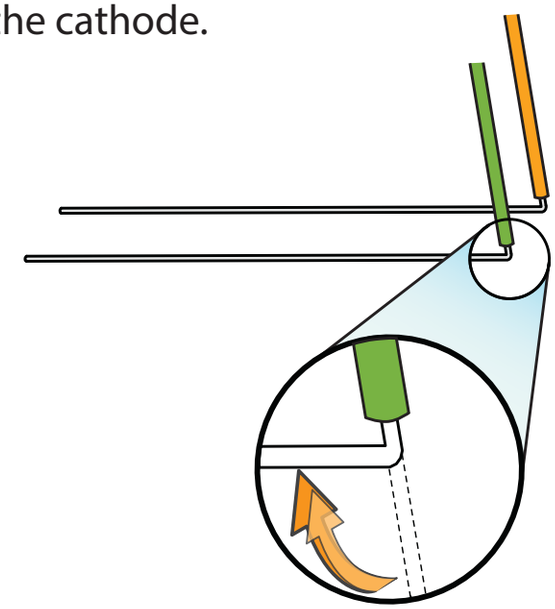


1. Put on your gloves and find 3-4 handfuls of soil or swamp goo – the smellier the better! Try to avoid using soils that have little white balls, because those will created unwanted air pockets in the soil. The consistency of your mud is ***very important*** and should be completely saturated but not too soupy. If your mud is too dry, add a little water. If it is too wet, pour a little out.

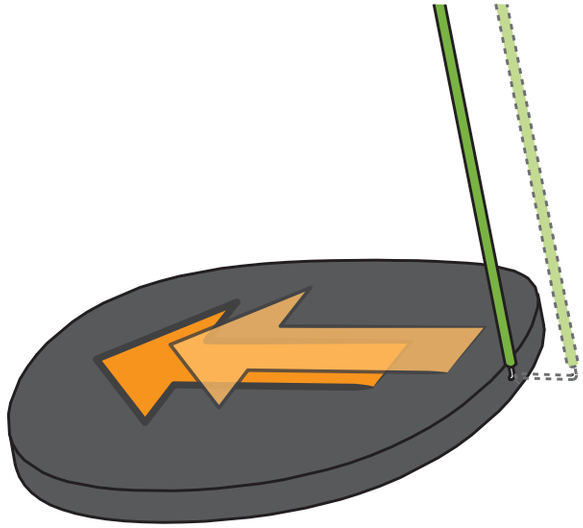


Note: To give your MudWatt some extra nutrients, we recommend tearing up the MudWatt packaging into 1cm^2 bits and mixing it in your soil!

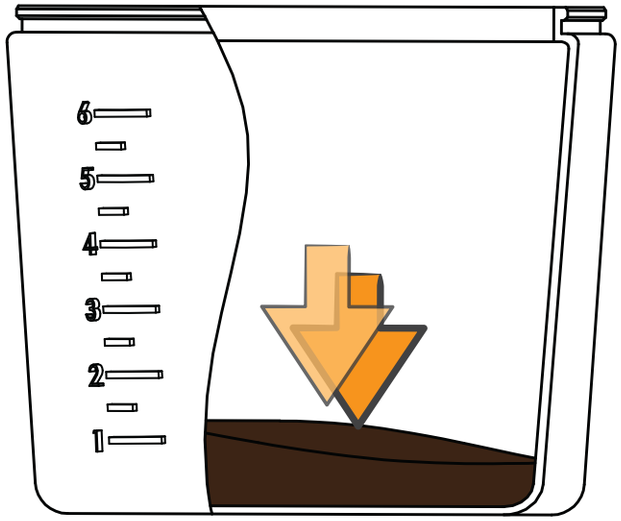
2. Bend both wires 90° where the plastic sheath ends. Straighten out the bare end of the wire. The green wire will be used to make the anode, and the orange wire will be used to make the cathode.



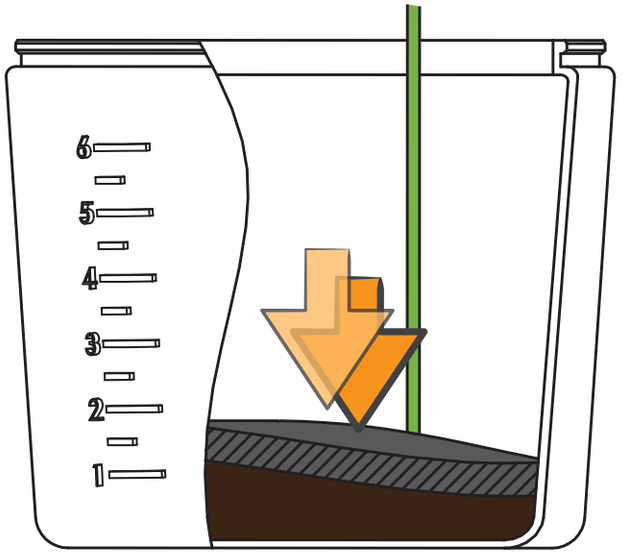
3. Insert the bare end of the anode (green) wire into the side of the thin felt disc while wearing the gloves provided. Try to keep the wire from exiting the felt. Repeat this step with the cathode (orange) wire and the thick felt disc.



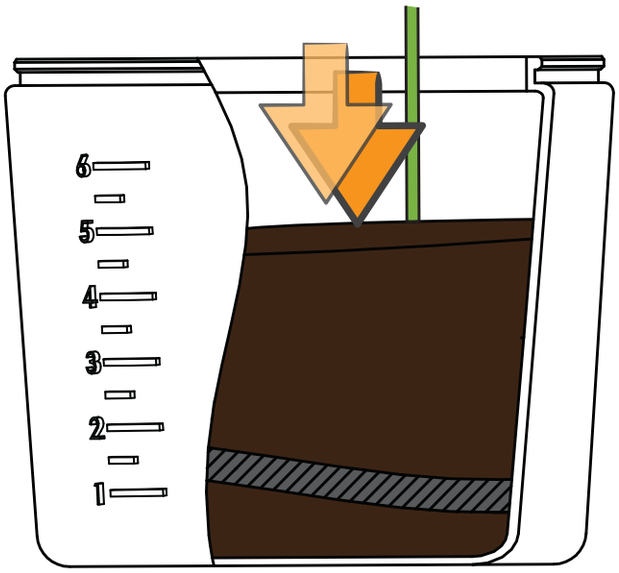
4. Pack a layer of mud into the bottom of your container, at least 1cm deep. Pat down the soil so that you have a smooth layer.



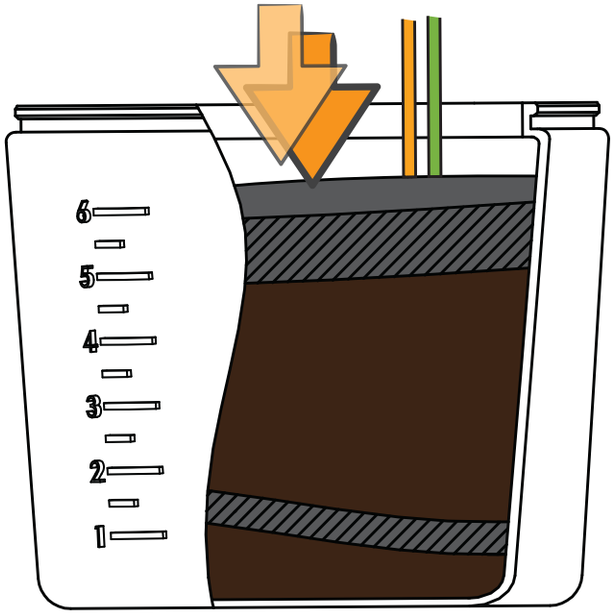
5. Place the anode (green) you constructed in Step 3 on top of the mud, pressing it down firmly to squeeze out air bubbles.



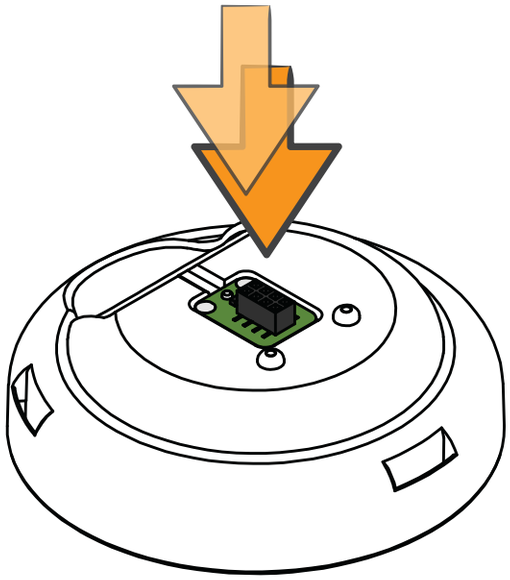
6. Fill your container with more mud, at least 5cm deep, pressing down firmly to squeeze out air bubbles. Let your mud rest for a few minutes and drain any excess liquid.



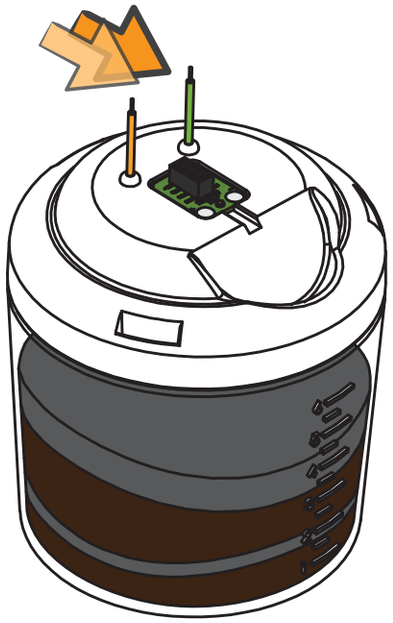
7. Place the cathode (orange) gently on top of the mud. Do not cover the cathode with mud.



8. If your kit came with the MudWatt Vessel, then remove your gloves and attach the Hacker Board into the indentation on the lid. If not, then please skip to the next page.



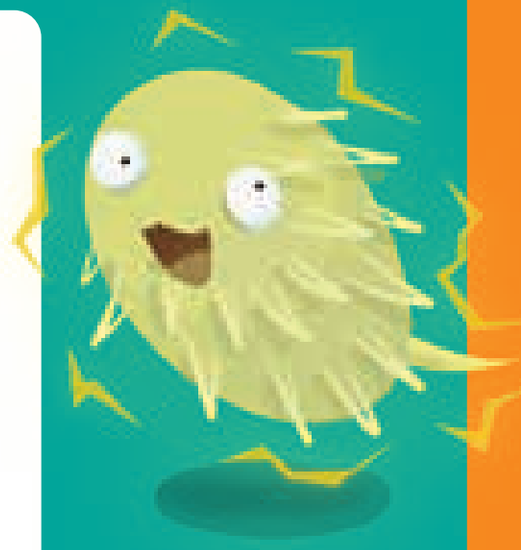
9. Pass the electrode wires through the lid. Facing the semicircular indentation, the cathode (orange) should be on the left and the anode (green) on the right. Now press the lid down onto the jar to snap it into place.



Congratulations!

You are now ready to harness the **power of the microbes** in your dirt! With an open container, evaporation will occur. You'll need to ensure the soil remains saturated. If you see your soil drying up, add more water. You can also cover your container with a lid or plastic wrap to minimize evaporation.

Now let's see what your microbial fuel cell can do!

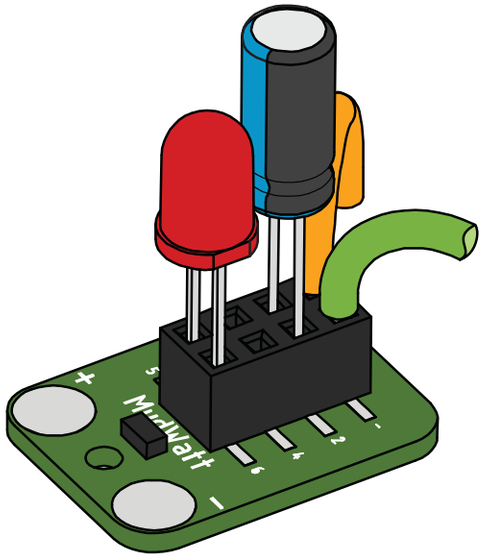


Mode 1: Blinker

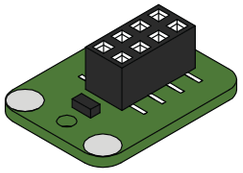
Blinker Setup

1. Bend and connect the cathode wire (orange) to '+' and anode wire (green) to '-' on the Hacker Board.
2. Connect the long end of the blue (10µF) capacitor to pin 1 and its short end to pin 2. You may need to bend the wires so that they fit snuggly.
3. Connect the LED 's long end to pin 5 and its short end to pin 6.

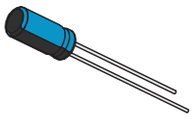
That's it! You should start seeing the LED blink after a few days, once your MudWatt has developed a healthy community of microbes!



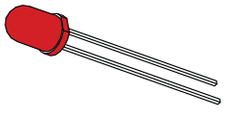
What do these components do?



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



Capacitor: The Capacitor is a little energy storage component. It is able to build up energy as power 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

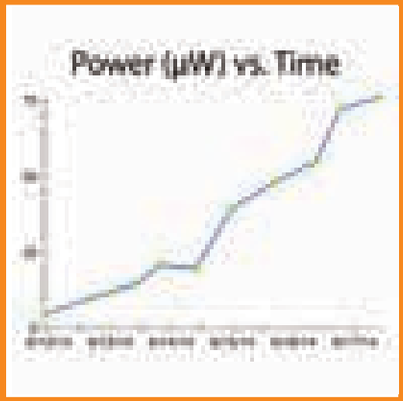
Get it on Google play

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 blinker is blinking, open the MudWatt Explorer App and select **Measure** from the main menu. Line up the blinker 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 Measure - ments

Record several measurements by using the **Record** button on the Measurement screen, and go to the **Analyze**section of the app to see how your MudWatt functions over time!

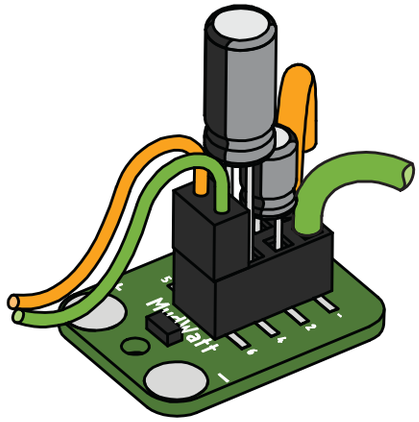
Step 3: Discover a Hidden World

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

Mode 2: Clock/Thermometer (Classic, DeepDig, and Science Fair Packs)

Switch to this mode once your MudWatt's power has stabilized.

Setup *(Order of steps is important!)*



1. Disconnect the Blinker's capacitor and LED.
2. Connect the **small black** (0.47µF) capacitor's long end to pin 1 and its short end to pin 2. You may need to bend the wires so that they fit snuggly.
3. Connect the **large black** (47µF) capacitor's long end to pin 3 and its short end to pin 4. You may need to bend the wires so that they fit snuggly.
4. 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

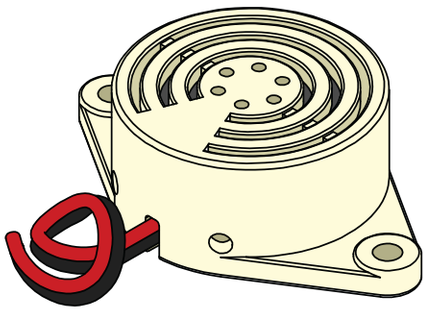
Peel off the backing from the rear of the clock to expose its adhesive sticker. Press the clock firmly into the pocket on the lid for 10 seconds.

You're done!

You've now got yourself a dirt-powered clock and thermometer. The clock's electronics are being energized by trillions of electrons donated every second by your MudWatt's microbes. To learn more, visit **www.mudwatt.com**

Mode 3: Buzzer (DeepDig and Science Fair Packs)

The setup for the Buzzer is similar to the setup for the LED, except instead of the LED, you connect the Buzzer using the alligator clips and jumper wires that come with the DeepDig Kit. Plug one jumper wire into pin 5 and another in pin 6. Then use an alligator clip to connect the buzzer's red wire to the jumper wire in pin 5. Then use the other alligator clip to connect the buzzer's black wire to the jumper wire in pin 6.



Discovering Max Power: Part 1

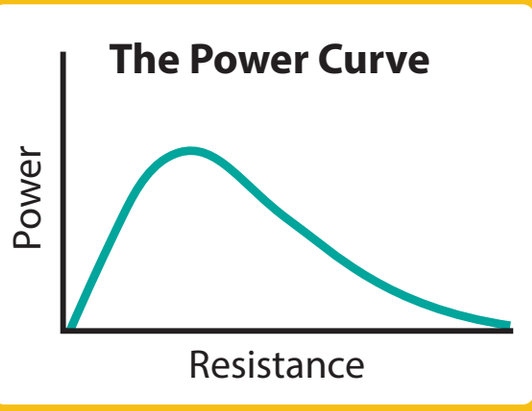
To find your MudWatt's **max power output**, you'll need to perform a technique called a **"Sweep",** outlined on the next page. With your Sweep data, calculate power for each resistor using Ohm's law (shown to the right). Plot your **Power vs. Resistance** as shown on the right to find your MudWatt's 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 (Watts)
V = Voltage (Volts)
R = Resistance (Ohms)



Important Terms

Voltage

Voltage is the measure of the electron "pressure" that drives the flow of electrons through the 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 is not flowing, there is still pressure in the hose. The amount of pressure in the hose is analogous to level of voltage in an electrical circuit.

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.

Resistance

Every electrical circuit has a certain amount of resistance (measured in Ohms) to the flow of current through it. Resistance in a wire or other conductive material creates friction, which produces heat. If you send to much current through a wire, then the friction causes so much heat that fires can start! Resistors are components that restrict the flow of electricity in a controlled way.

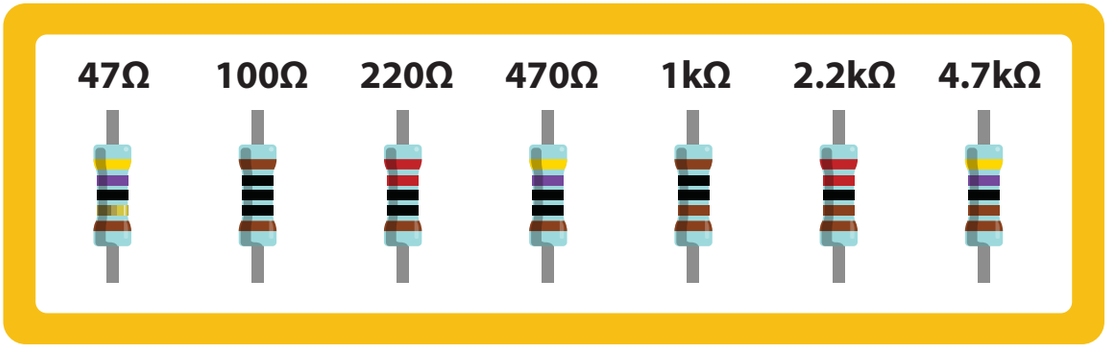
Power, Glorious Power!

This is the term used the most when talking about energy production. Power is the amount of energy consumed or generated per unit 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

Resistor Color Chart

Resistors can be so small that you can't print numbers visible to the naked eye on them. Instead, resistors use a series of color bands to label their resistance value. You can match the colors of your resistors below to identify their resistance value. (Ω = Ohms, k = x1000)



Performing a Sweep

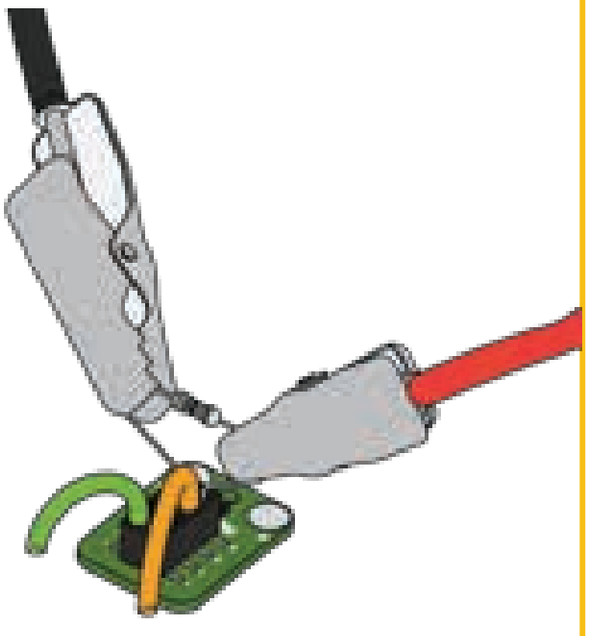
1. Remove all components from the Hacker Board, except the anode wire (green). Plug the cathode wire (orange) into Pin 3.

2. Switch the multimeter setting to "2000 m," and plug the red probe (+) into the "VΩmA" 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 does not matter). Identify and record its value using the color chart shown above.

4. After 15 minutes, check the voltage by clipping the multimeter's red probe (+) to the resistor's wire in Pin 5, and the multimeter's **black** probe (-) to the resistor's wire in Pin 6 as shown below. Record the measured voltage.

5. Repeat Steps 4 and 5 for all resistors provided, noting the measured voltage as it corresponds to 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!

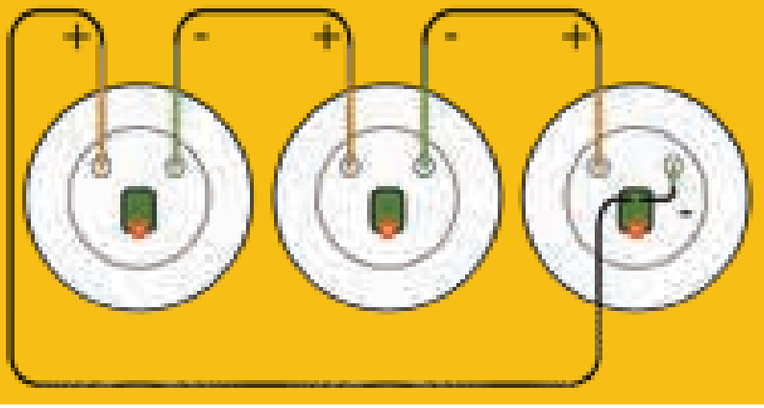


Connecting Multiple Mudwatts

What happens when you connect multiple MudWatts together? **More Power!** But, depending on how you connect them, you will either get more voltage or more current. We encourage you to experiment with connecting multiple mudwatts together and seeing the effects for yourself!

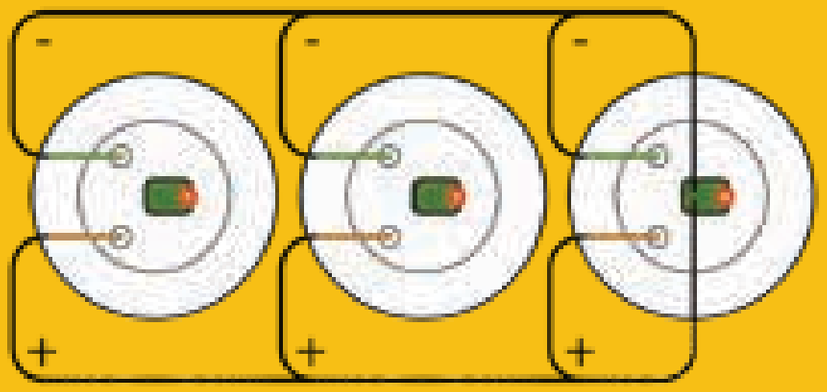
Connecting MudWatts in Series

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 could use alligator clips and jumper wire (which are included in DeepDig Kits) to put some MudWatts in series and others in parallel and measure the circuit's overall voltage and current values to see if they are what you would expect.

Apart from measuring the voltage and current of your multi-MudWatt circuit, try to measure the impact on the power as measured by the blinking LED and the MudWatt Explorer App. Does higher voltage or higher current increase the blink rate of the LED, or the buzz rate of the buzzer?

Troubleshooting

MudWatt power is low...

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:

- Make sure the cathode is not submerged in water. If it is, pour out excess water and pat the cathode down with a paper towel. This is the most common cause for low power.
- Make sure the soil is saturated, but not soupy. If you see it drying up, add some more water.
- Make sure there are no large air bubbles within the soil. If you see some, try to get rid of them with a stick or other utensil.
- Make sure the LED and capacitor are well connected to the Hacker board. Sometimes they can become loose.
- Make sure you have at least 3 cm of soil between the Anode and Cathode. The more soil you have between, the greater your voltage will be. You can check the MudWatt's voltage by unplugging the MudWatt from the Hacker board and connecting the leads of the multimeter to the titanium wires of the MudWatt. If it is over 0.35V, then you can infer that something is amiss with the Hacker board.
- Sometimes warming the MudWatt up to body temperature (about 37 °C/99 °F) is enough to kick start the microbes and establish a good microbial community

Clock/Thermometer is blinking...

The clock/thermometer blinks when it detects low power. Try unplugging all the components, and then plugging them back in slowly. Plug them in using the sequential order specified in the instructions and wait 1-2 minutes between each component. This will help build up charge before you plug in the clock/thermometer. If the clock/thermometer still blinks, that means your MudWatt is just producing low power at the moment.

These steps usually get MudWatts going on the right track. If you still experience issues, please drop us a line at **info@mudwatt.com**!

DOWNLOAD THE MUDWATT EXPLORER APP!

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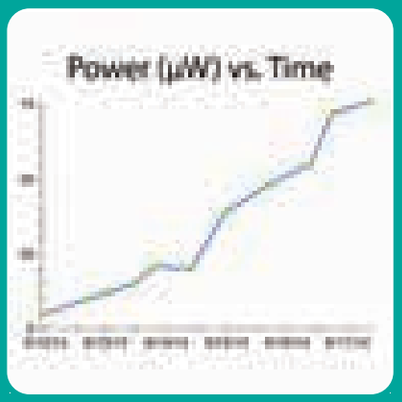
Measure your MudWatt's power!
Unlock chapters of a fun comic!
Record and share your power data!



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