How much energy does it take to make a cup of coffee?

If there is one thing we have a particular obsession with at SolarMill, it's figuring out how much energy it takes to perform a task. This can be anything from making a cutting board to 3D printing a plastic toy. Our state-of-the-art facility is equipped with dozens of sensors that are constantly logging over 100 channels of data, such as volts, amps, watts, as well as environmental conditions like temperature and humidity. We are nerds for data and geeks about science. Today, we are going to take an in depth look at a common household task and consider the various ways to make a cup of coffee.

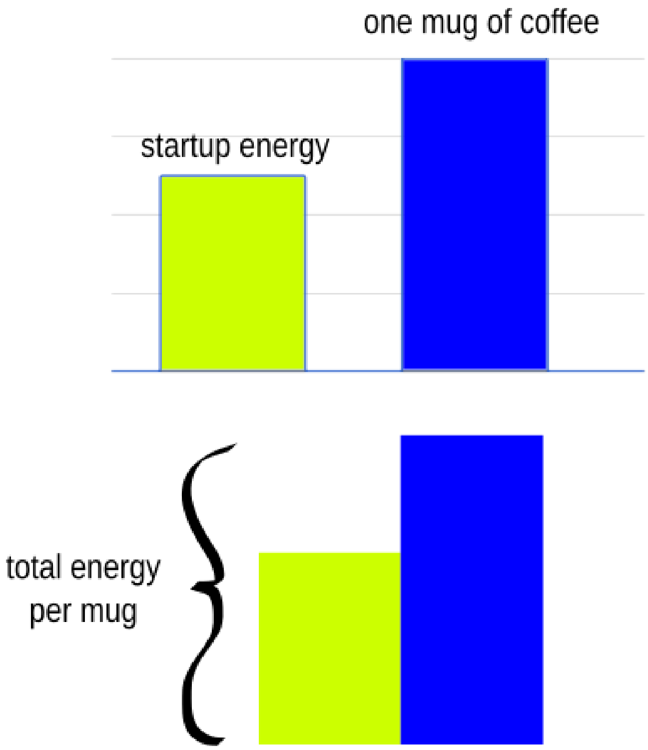
Experiment

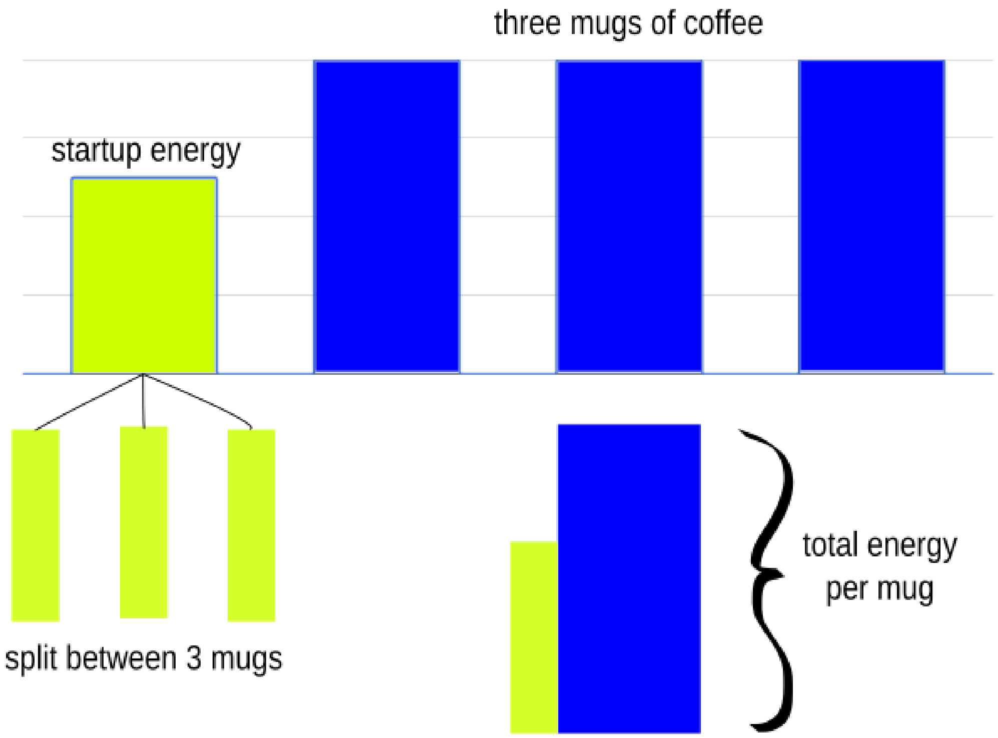
When it comes to producing anything there are always choices regarding how you can go about making it and the amount of energy that process will need, even with your morning brew. We decided to test what we thought might be the most common options available to the average (cup of) Joe. We looked at a standard drip coffee maker, a mini drip maker, a Keurig, an electric kettle, an espresso maker, and a microwave (not that common for coffee, I know, but we were really curious how it would compare). And of course there are plenty of other ways to heat a pot of coffee (eg. gas), but as a company which specializes in products made with solar-generated electricity, we kept it in our wheelhouse and produced all parts of this experiment and publication with rooftop solar.

Each of these machines was run through a number of trials to find their average energy consumption per ounce of water heated. For most, it was as simple as running the water through and checking the data collected (over and over and over again) but sometimes we would run into a variable we needed to make a bit more constant. For example, for most of the machines you just put in the water, run it, and turn it off, but for the microwave specifically, there isn't really a coffee setting, so we had to find a set temperature to heat the water to and the time setting that would (more or less) get it there every time. As it turns out, 1 minute 40 seconds fairly consistently got 8 ounces to around 172°F (the average temperature of water running through the drip maker) so that's what we went with for our microwave trials.

Some helpful background

We also decided we may need to get a range of scenarios for each method, because running a full pot of coffee will be at least slightly more efficient, per ounce, than just making a single mug. This is due to an idea called "amortization," typically used in a financial context for how an initial investment (here, the energy needed to get the heating element from room temperature to its peak) is spread over the time it's used. So if it takes 3 Watt-hours (Wh) to prep the heating element for any amount of water, it is better used, per ounce, spread over a full pot of coffee rather than just a single 8 oz mug.


one mug of coffee
startup energy
total energy
per mug

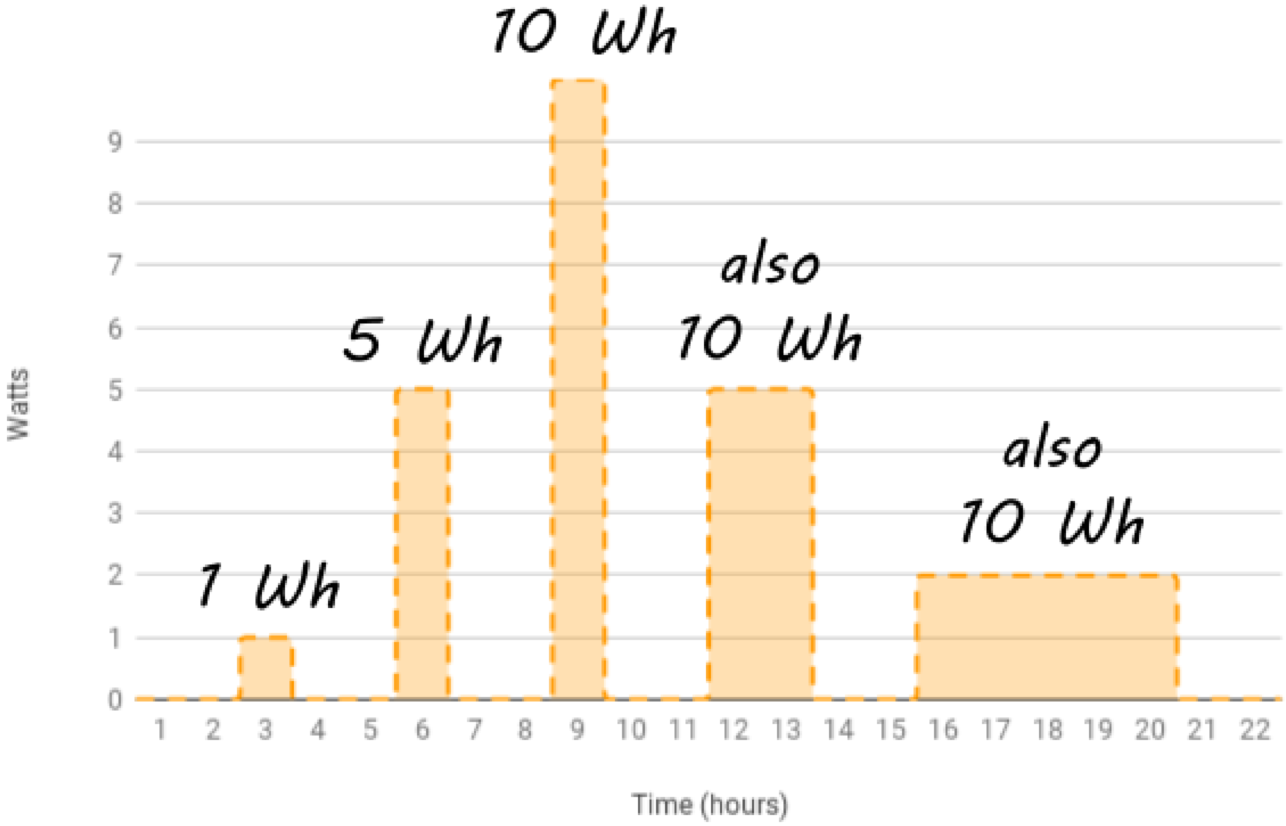

three mugs of coffee
startup energy
split between 3 mugs
total energy
per mug

Maybe think about this in terms of the energy it takes to start up your car before even going anywhere or the energy needed just to get out of bed in the morning.

For us here at SolarMill it's everything from warming up the 3D printer to all of the subsystems of the laser cutter, and it has a pretty big effect on how we plan our production.

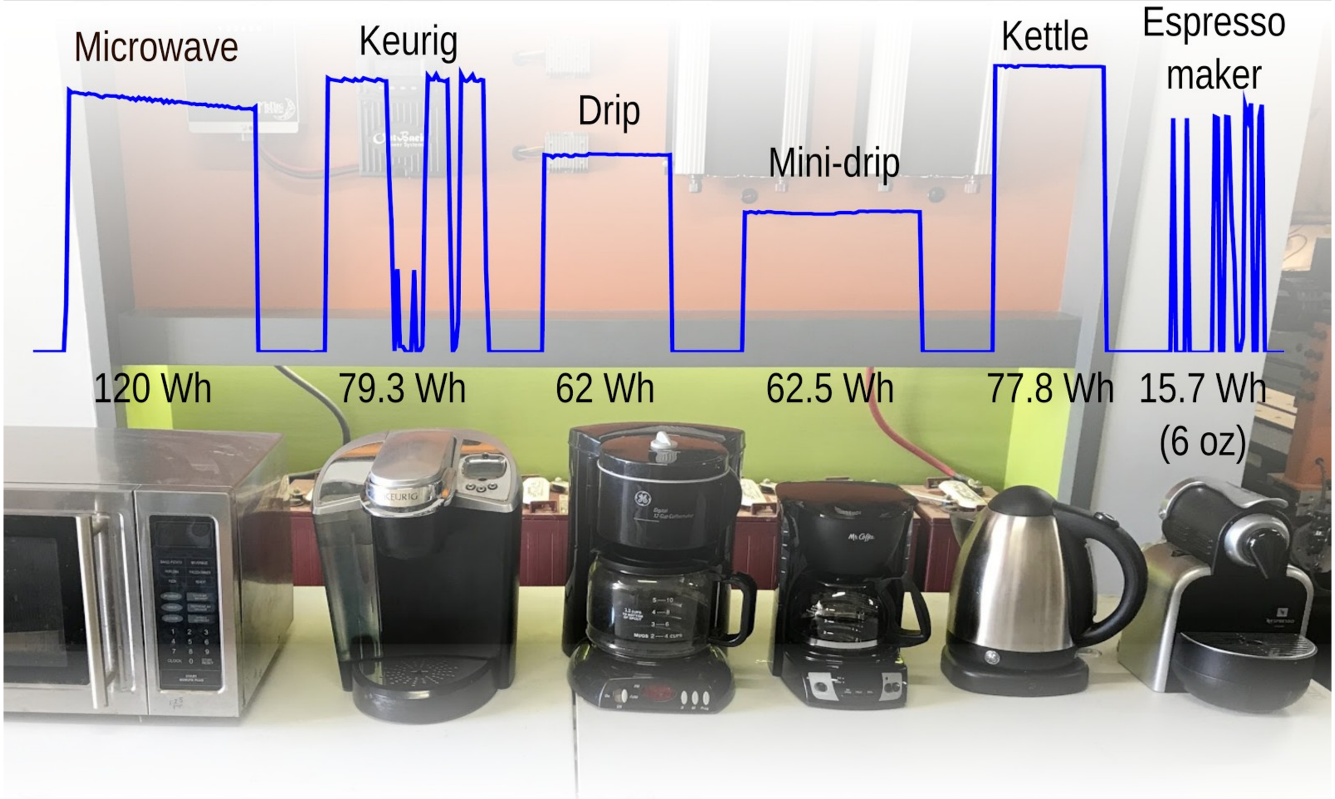
Another idea we should probably run over quickly before the fun part is the units we are using to measure this, specifically Watt-hours. Watt-hours are a measure of electrical energy equal to a power consumption of one watt for one hour. You should note, it isn't watts *per* hour but rather the integral (or area under the curve) of a graph with *watts* on one axis and *time* on the other (*Watts x hrs*).

Like this:



Results

Alright, now to the fun part. Here's what we found:



This graph shows the relative energy consumption of each of the devices to produce three servings of coffee, totaling 24 oz for all except for the espresso maker which made three two ounce shots. The area under each of those curves is the total energy consumed. Look at that huge chunk under the microwave curve!

FInal run (24 oz) (3 mugs)		
	Wh/3 servings	Wh/oz
Microwave	120	5
Keurig	79.3	3.30
Drip	62	2.58
Mini drip	62.5	2.60
Electric Kettle	77.8	3.24
Espresso (6 oz)	15.7	2.62

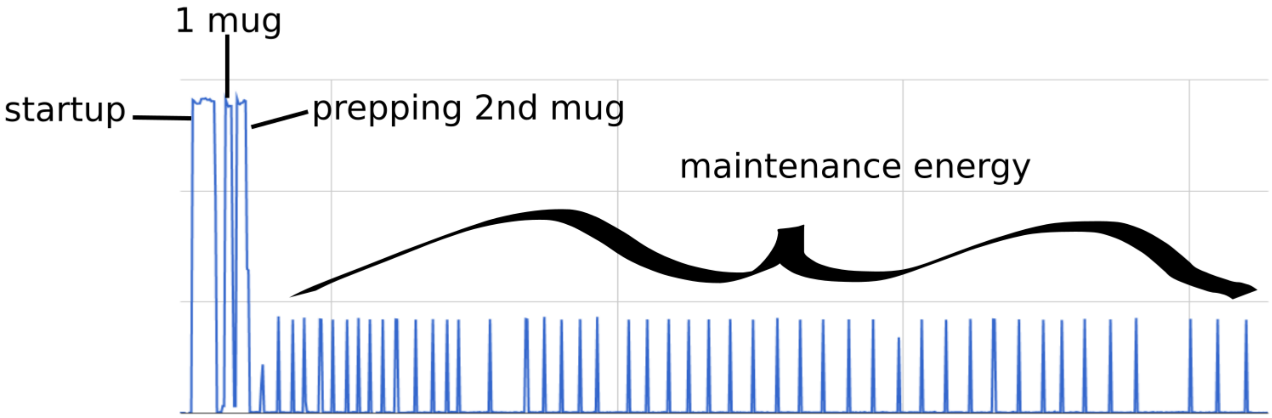
And hey, the drip maker wins for the most energy efficient way to make conventional coffee. If that factoid was all you were looking for, sorry about all the other awesome junk we packed into this article. You can go back to whatever political horror story was underneath this in your feed if you want. But you'll be missing out on some pretty fascinating data applications, just sayin'.

Reflections

Thinking back to startup energy, look at the Keurig on the above graph. That first big bump is the startup energy for as many cups as you can make with a full water tank, which, if you only use on one mug, is a whole lot of wasted energy.

What's more, the Keurig maintains a certain temperature in the reserve tank as long as it's on, so there is another whole factor of maintenance energy if you just make a mug before work and leave it on or have a Keurig sitting in a waiting room all day and only one or 2 people make a cup of coffee.

Check this out:



That's about 30 Wh of startup, 10 Wh for the first mug, 13 Wh prepping the second, and a whopping 31 Wh of maintenance energy keeping it warm. Including all the noise in between the spikes, that's a whole 90 Wh to make 8 ounces of coffee, worst case scenario, for the Keurig.

The point is, whatever you use, TURN IT OFF WHEN YOU'RE DONE!

And if we want to get even more technical about total embodied energy of a mug of coffee, we have to further consider both the energy needed to produce the coffee maker itself as well as the cup you drink it out of and how that energy is spread over the number of servings it is used for. The mug issue has been the topic of a good bit of debate, and a quick summary of it can be found here, but as for the coffee maker question, it's a little more complicated. While there isn't a whole lot of data available on the energy used to produce each device, we can safely assume the Keurig ranks pretty low in this category for a few reasons: those darn "k-cups" (which if you don't yet know the problems with them, even the new "recyclable" cups, get yourself educated), the machine's impossible to clean and repair, and they use a lot of complicated electrical and mechanical parts. We actually dissected our Keurig after the energy tests, just to see what was inside and found a pretty disturbing amount of mineral deposits and mold in the preheat reservoir and tubes. One of our neighbors even commented that his household replaces their Keurig every year because of how gross they can get. Now, back to the concept of amortization, if you're replacing your coffee maker yearly, the energy put into producing this complex machine is only spread over a year's worth of coffee and could add a considerable amount of embodied energy to each cup you make with it. Just some food (or drink?) for thought.

mold n'
minerals
yum yum

We at SolarMill use Watt hours because it's the best measurement for the energy we use on a day to day basis, but there are other units to measure energy as well, including one you might be a little more familiar with, calories.

Calories are typically used to show the amount of energy embodied in the food we eat. However, since science can be unnecessarily confusing at times, the "calories" we are used to seeing are actually kilocalories (1000 calories), but we'll just call them food Calories for the sake of this article.

Putting it into perspective, one food Calorie is equal to about 1.16 Watt hours, so your 500 Calorie sandwich you had for lunch the other day contains about 581.4 Wh of energy. Compare that to the amount that the drip maker took to make 24 oz of coffee: 62 Wh.

That's one hot chicken parm.

That means, theoretically, if the embodied energy of that sandwich were converted 100% efficiently into electricity, you could heat water for 9.4 mugs of coffee with it!
Huh, maybe we should switch to a sandwich powered energy grid.
Just kidding, solar is way cooler. And yeah, even cooler (not to mention at least a little more efficient) than sandwiches, but I guess you'll just have to read our next article, *Why a Solar-powered Energy Grid Is Most Definitely Better Than a Sandwich-powered Energy Grid* to find out more.

But back to coffee. That Calorie to Wh conversion we just talked about means that an 8 oz cup of coffee containing 5 Calories (steeped from the beans) has enough embodied energy to heat 3 oz of water to coffee brewing temp (ie. if you evaporated all the water, took the dried gunk at the bottom and burnt everything that would combust, you'd create the heat necessary to heat 3oz of water from room temperature to 77.8°C); meaning that three 8 oz mugs of coffee have the embodied energy in their caloric content alone (apart from any heat they may have) to brew a whole other mug of coffee!
Again, only in a theoretical environment in which energy can be converted and transported for different uses at 100% efficiency.

But why do I need to specify that? Well, theoretical physics is super fun and all, but nothing we encounter in our day to day lives ever works at 100% efficiency. For example, a calorie (and not the food kind, so 1/1000 of the food calorie) is the energy it takes to raise 1 gram of water by 1°C [calories =Tm].

I'll save you the math, but this means that, in a 100% efficient system, to raise 24 oz of water from room temp (21°C) to coffee temp (77.8°C) should take 46.1 Wh. However, in our actual tests with the drip coffee maker (the most efficient we tested) it takes closer to 62 Wh to heat 24 oz to coffee temp. That's 74% efficiency. Also, each of the devices heats to a different temperature, so their efficiency has to be calculated by the theoretical maximum for that machine alone.

At one point our data showed that the espresso maker was running at over 100% efficiency, leading to the conclusion we should probably just run our shop entirely off the excess energy generated by making espresso (which I guess we kind of already do?). Turns out, the machine only gets up to about 135°F, and we were erroneously calculating the efficiency from the average temperature for the drip maker (about 172°F), which is apples to oranges as far as brewing temp goes.

This might illustrate, to a point, why comparing efficiencies of different mechanisms can be so complicated and the data easily manipulated to shine a more favorable light on certain processes versus others (lookin' at you, fossil fuel lobby).

Energy consumption for 3 servings (24oz)			
Device	Theoretical (Wh)	Actual (Wh)	Efficiency
Microwave	47.5	120	40%
Drip	46.1	62	74%
Mini drip	40.6	62.5	65%
Keurig	40.6	79.3	51%
Espresso (6 oz)	7.3	15.7	46%
Electric kettle	47.5	77.8	61%

Another crucial point to consider is the espresso maker. Talk about apples to oranges. While even less efficient, compared to its own possibility, than the Keurig. The overall energy consumed to produce three servings is without a doubt the lowest. What if we want the minimum energy for the maximum caffeine content?

Well, black coffee has anywhere from 8-15 mg of caffeine per ounce while espresso has between 30-50 mg/oz. Take the average of each of those, multiply by the ounces in a serving (8 oz for coffee, 2 oz for espresso). And we get about 92 mg of caffeine for a serving of coffee and 80 mg for an espresso. So throwing this info back into our energy efficiencies gives us 4.45 mg caffeine/Wh for coffee and a whopping 15.3 mg caffeine/Wh for espresso! So while the espresso maker is one of the least efficient as far as heating water goes, it is leaps and bounds more efficient at getting that good ol' caffeine into your system.

Conclusion

While all of the data and facts about how to “most efficiently” brew a serving of coffee are fascinating and may or may not make you the most interesting guest at your next social gathering (or most annoying bloke at the cafe), there are two bigger points I hope you draw from this article. First is the difficulty in truly comparing one process to another, even with something as simple as making a cup of coffee. Depending on the variables and constraints introduced by each method or process as well as the specific difference by which you compare them, what you find and the decisions you make based on that can vary wildly. Second is that every little process requires energy, and there are energy-related choices in even the smallest of daily tasks which we make whether we know it or not. And no one can make those choices for us.

Oh, and if you haven’t noticed, this isn’t entirely about coffee.