Single-Serve Coffee
A Partial Environmental Inventory

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Abstract: Waste produced by single-serve coffee packets have been discussed widely on Internet sites. This analysis seeks to contribute to that conversation by pointing out that the electricity used by coffee machines typically uses more fossil fuels than packaging or coffee. Most of the electricity use may be from when the machine is plugged in but not making coffee. Waste can be substantially reduced by unplugging the coffee machine when it is not being used.

1. Single-Serve Coffee Controversy

Single-serve coffee makers, also called pod filter machines, brew coffee by forcing heated water through a small container of ground coffee. More than 30% of US households are estimated to have this type of coffee maker.[2]

Comments on the environmental impacts of single-cup coffee systems have largely focused on the packaging.[3] There are a variety of types of capsules and packets, containing from 7 to 10 grams of coffee.[4,5] This packaging generally weighs about 4 grams,[6] so all together the coffee plus the packaging weighs about 11 to 14 grams.

The concern about the environmental impacts of single-cup coffee systems has generally focused on the amount of packaging, with mass or volume as the metric. The analysis below evaluates the fuels needed to provide electricity to the coffee maker to brew the coffee, and compares these quantities to the amount of packaging.

2. Minimum energy to heat water for coffee

The energy required to make coffee is, at a minimum, the energy needed to heat the water from room temperature. Coffee machines do not generally heat water completely to boiling; machines may heat water to 89°C, or as high as 100°C.[7] Heating water from room temperature, about 20°C, to 89-100°C, taking into account that the specific heat of water is 4.2 J/g°C, implies that heating 250 grams of water - about an 8 ounce cup - requires about 78±6 kJ of heat.

This same minimum energy requirement to heat water applies broadly: heating water using a stove, a microwave oven, an electric kettle, a household water heater, a solar stove or a wood fire all have the same minimum energy requirement, although different ways of heating water have different levels of efficiency.

In practice, more than the minimum amount of electricity is needed, because there will be some inefficiency in heating the water. Single serve coffee makers may use immersion heaters – a resistive element in water - as do electric kettles. Single serve coffee makers also typically have a pump to pressurize the water.

3. Total energy used to heat water for coffee

When electricity is used to heat water, the total energy use will include the direct electrical energy use, and any waste heat or other upstream energy use to make and deliver the electricity. The amount of fuel used to make electricity depends on how the electricity is made. In the US, typical electricity systems have power plants using coal, natural gas, nuclear, hydro, and some renewables. Coal-fired power plants have an average thermal efficiency of 33%,[8] electricity transmission losses are about 7%,[9] and the coal used in US power plants has an energy density of about 23 MJ/kg.[10] Multiplying this out, a minimum of 10.5 grams of coal is needed to heat the water using coal-sourced electricity.

In addition to the energy use to heat the water, electric coffee makers also use electricity for the entire time that they are plugged in. This "stand-by" energy use also is found in televisions, computers, and other office and household machines and appliances. Even when turned off but still plugged in, a single-serve coffee maker may use 9 watts in stand-by power.[11] If the single-serve coffee maker is used to make 10 cups of coffee per day, this stand-by power adds another 150 kJ of electric energy per cup, bringing the amount of coal per cup of coffee up to about 23 grams total. This standby power would be less per cup if the coffee maker were used to make more coffee. If the coffee maker were used to make less than 5 cups of coffee per day, most of the energy use would be the standby power. A 2009 survey by the Association of Home Appliance Manufacturers found that 16% of household single-serve coffee makers are used twice per day, 32% are used once per day, and 26% are used 2-3 times per week.[12] Office coffee machines may typically have a higher use rate. Measurements by the Swiss Agency of Efficiency Energy Use (SAFE) show that most of the electricity use by single-serve coffee makers is when the machine is in the "ready-to-use" mode.[13]

A similar calculation can be done for natural gas. The average efficiency of US natural gas power plants is 42%,[14] and natural gas has an energy density of 54 MJ/kg.[15] Accordingly, during the brewing of coffee a minimum of 3.5 grams of natural gas must be used, and the stand-by power adds an additional 7 grams of natural gas, for a total of about 10 grams of natural gas per cup of coffee.

For electricity sourced from nuclear, hydro, wind, or solar, the electrical energy use is the same, but the "mass of fuel" calculation is somewhat different: for nuclear the amount of fuel would be much less than the amounts of natural gas and coal calculated above because nuclear energy is much more mass-efficient than coal or natural gas. For hydropower, solar and wind, the mass could be calculated (for example mass of water evaporated, or mass of materials used to construct the

hydro, solar, or wind facility amortized per kWh of electricity, etc.) but these detailed calculations will not be detailed here.

The energy calculations above do not include the full inventory of growing, transporting, roasting, and grinding the coffee, nor the full inventory of producing electricity. However, the calculations do show that the mass fossil fuels used to make coffee can be comparable to or greater than the amount of packaging for single-serve systems, and greater than the amount of coffee.

Although there are many ways to make coffee, and many ways to heat water efficiently, an immediate opportunity to reduce waste is to turn off the coffee maker, and unplug it, when it is not in use.

Figure 1 summarizes the calculated results. The first bar shows the amount of coffee and amount of packaging in a typical single serve coffee packet or capsule. The second, and third bars shows the mass of fossil fuel used to make the electricity to brew the coffee, if the electricity is made from coal or natural gas, respectively. The last bar shows the (essentially zero) fossil fuel used if the electricity is made from nuclear, wind or solar power. The error bars indicate the potential range: the first error bar indicates the range of both coffee and packaging mass; the error bars on the second and third bars are dominated by the standby-power. Note that the stand-by power use is shown as larger than the energy used directly for brewing the coffee.

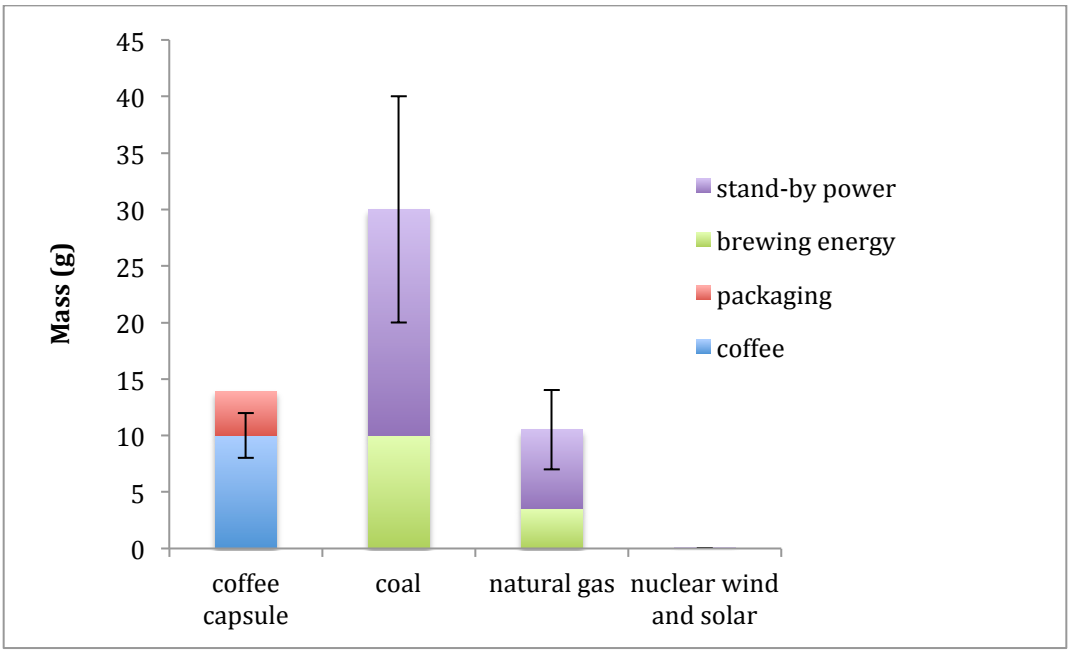

Figure 1. A comparison of the mass coffee (blue) and single-serve coffee packet (red), and the amount of coal or natural gas needed for the electricity to make the coffee. The figure shows that the mass of coal or natural gas used to make the electricity to brew the coffee (green) plus the stand-by power used by a plugged-in coffee machine (purple), can be close to or more than the mass of the coffee and the packet. Unplugging the coffee machine would substantially reduce the stand-by power use.

4. Opportunities for Improvement

One significant opportunity for reducing energy use is to reduce the energy used in "ready to use" and "off" mode. Having an automatic transition from "ready-to-use" to the "off" mode could save about 34% of the energy used by single-serve coffee machines.[16] The US EPA has indicated that a zero watt standby mode (the "off" mode) should be feasible for all types of coffee makers; this could be implemented by manufacturers without increasing costs.[17] Consumers can reduce the energy use of their coffee machines by completely unplugging them after use.

Some single serve coffee makers pre-heat water and keep it heated in standby mode. Other single-serve coffee makers use flow-through or continuous-flow water heating, which only heats water immediately before making a single cup of coffee. These are the most efficient water heaters for coffee on the market.[18]

There are a number of programs that rate coffee makers on energy use. In the European Union, non-commercial coffee makers are covered by energy efficiency regulations for standby and off-mode energy use. Euro-Top-Ten identifies the best products available in Europe based on energy use.[19] And the German Blue-Angel eco-label program covers pod and espresso machines, although as of October 2011 there were no products that had achieved the label standards.[20]

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[1] Please send comments or corrections to valerie.thomas@isye.gatech.edu

[2] Homeworld Business. Housewares Census 2011.

[3] Rancaño, V. Waste: The Dark Side of the New Coffee Craze. *Easy Bay Express*, August 21, 2013. http://www.eastbayexpress.com/oakland/waste-the-dark-side-of-the-new-coffee-craze/Content?oid=3687220

[4] Flavia Fresh Packs contain 7 grams of coffee.

[5] Keurig K-cups contain 8.5 to 10 grams of coffee. http://wiki.answers.com/Q/How_many_ounces_of_coffee_are_in_a_K_cup

[6] Single Serve Coffee Forums. http://www.singleservecoffeeforums.com/new-k-cups-brooklyn-bean-the-flood-gates-are-open-t9263-15.html

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[10] US Dept. of Energy, Energy Information Administration. What is the average heat content of U.S. coal? http://www.eia.gov/tools/faqs/faq.cfm?id=72&t=2

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[16] European Commission, *Preparatory Studies for Ecodesign Requirements of EuPs (III) Lot 25 Non-Tertiary Coffee Machines*, February 2011.
[17] US EPA. Energy Star Market and Industry Scoping Report. Coffee Makers. November 2011.
[18] US EPA. Energy Star Market and Industry Scoping Report. Coffee Makers. November 2011.
[19] For more information, see: www.topten.info
[20] For more information, see: www.blauer-engel.de/en/index.php