**Feasibility and Design for Bush Microwave Ovens**

Detailed Response to the caught zomb from *poly*

As described at www.zombal.com

Report by *dragozzine*

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Zomb Statement:

A primary cause of harmful deforestation and loss of vegetation cover in poorer countries is the harvesting of plant parts for cooking fires. Imported fuels such as kerosene may be impracticable or unaffordable in remote regions. This zomb requires an analysis of how a manually-powered flywheel generator can run a simple but safe microwave cap, to cook food in a locally-supplied ceramic pot buried in the ground. The microwave cap and the flywheel generator components would be fabricated in an industrial country and supplied to the users. Users would perform a simple assembly of flywheels and fill the circular rim with water to supply inertial mass. More details in the attached file ZBL139X.pdf. (ZBL#139).

Response

**Abstract:** Millions of individuals in third world countries spend significant resources obtaining fuel, especially fuel need to heat and cook food. Often these resources are used inefficiently and/or unsustainably, leading to a myriad of negative consequences. These consequences can be mitigated or even eliminated with clever solutions as long as they are practical. In this response, I studying the basic physics and economics of a very clever idea: remove the need to gather fuel entirely by using a modified microwave oven for heat and for cooking food. While there are many benefits to this solution, there are also some difficulties. I recommend converting used microwaves into combined microwave/solar ovens with a electricity-producing bike/batteries to be shared among multiple families. See below for more details.

## Background

The most basic elements for survival are water, food, fuel, and shelter. In many areas of the third world, individuals focus their entire energies on these basic elements for survival.

Fuel can be an especially difficult problem. For reasons of health, sanitation, and flavor, food needs to be cooked and water boiled. Warming a home during the night may also be necessary for survival, also requiring significant amounts of fuel.

Despite the exponential technological progress of modern society, millions rely on ~10000-year old technology for producing energy: gathering wood to be burnt in a fire. There are cases where gathering fuel takes a significant portion of an individual's time. The need for fuel often drives environmentally unsustainable practices. And burning wood in an open fire is severely inefficient, besides the negative health effects of smoke and ash.

Using modern engineering methods to overcome these challenges is gaining ground. I recently became familiar with the BioLite Stove (http://www.biolitestove.com/). These chambers burn wood, but some of the heat is converted into electricity using thermoelectric technology. That electricity is used to power a fan, which allows for the wood to be burned much more efficiently, while providing a valuable, albeit minor, source of electricity for charging small electronic devices. The efficient burning process and fan system minimize the distribution of harmful smoke and ash. The goal of these devices is to increase the efficiency and value of biomass fuel, with many other positive benefits, and it is being actively pursued commercially (as sold to hikers) but mostly as a non-profit to benefit individuals in third-world countries who benefit significantly from improved fuel use.

Zombal member *poly* has taken this problem to its logical conclusion and solution: why use fuel at all? Microwave ovens can cook food, boil water, and provide heat (indirectly). They can provide the thermal energy needed for nearly all basic survival functions and would significantly reduce (and perhaps eliminate!) the need to use fire, which is generally less efficient. This very clever solution to the need of fuel in the third-world has significant potential and is worthy of further study. Here, I provide some initial thoughts based on basic physics principles in order to provide an initial motivation for this problem.

First, an introduction to the workings and physics of microwaves. In many ways, a microwave oven is a marvel of modern technology, an extremely useful manifestation of the fact that basic scientific research can yield valuable results for everyday life. In many ways, it's like magic: you put food in a box that's plugged into the wall, push a button, and after a very short period of time, the food is hot! Most people in first-world countries have used a microwave and surely they are found in several tens of millions of households. Despite it's clear utility, most microwave users may not understand the physics behind the devices, which I will introduce here as a preface to the discussion below.

A detailed explanation of the physics of microwave ovens can be found by searching online. An article at the level of physicists that I found useful is Vollmer 2004 “Physics of the Microwave Oven”
http://www.sfu.ca/phys/346/121/resources/physics_of_microwave_ovens.pdf

Microwaves are a form a light, the same electromagnetic waves that produce visible light, radio waves, X-rays, etc. The microwave region of the electromagnetic spectrum is quite broad. For this reason, it is clearest to avoid referring to microwave ovens as “microwaves”, although this colloquialism is so pervasive, I won't completely avoid it in this report. Their frequencies (wavelengths) are in the range from 300 MHz ($\lambda$ = 1 m) up to 300 GHz ($\lambda$ = 1 mm). Conventional microwave ovens uses 2.45 GHz frequencies (wavelength of 12.23 cm).

As understood in quantum mechanics, atoms and molecules can only emit and receive energy at very specific wavelengths, which is the well-known origin of spectral lines. A specific wavelength of microwave light can provide vibrational energy to water molecules. By irradiating food with light of exactly this wavelength, energy can be imparted to water molecules generally present in most kinds of food. Note that since it is the vibrational modes of the water molecules that is being excited, *only foods with some liquid water in them* can be heated in the microwave. Many dry foods actually contain liquid water. Ice and steam cannot be effectively heated.

The actual microwave radiation itself is generated by a magnetron. This relatively high-tech device uses electron beams, magnetic fields, and resonance to create a large amount of microwave radiation at a specific frequency. Raw efficiencies are around 80% and lifetimes about 5000 hours. The other 20% of input electrical energy is dissipated as heat and a fan is used to keep the magnetron cool. Including energy losses from running the fan and other minor electrical drains, the efficiency of microwave radiation production is 50-60%, depending on the design. (This may seem low, but is actually quite good.)

One extremely efficient aspect of microwaves is that virtually all of this energy in converted entirely to heating the food/water/object in the microwave. The overall conversion of electricity to heat is therefore 50% or better and this is much more efficient than any other cooking means (Wikipedia; http://www.aceee.org/consumer/cooking). This is another strong argument for a bush microwave.

## Possible Uses of Bush Microwave Ovens

A working microwave in the bush (i.e., a third-world country or situation) can provide an enormous range of useful functions. Boiling unclean water for biological decontamination is an obvious possibility and the importance of clean water cannot be understated. Another method for biological decontamination are new water filters that can remove all biological materials from water, e.g., “Lifesaver” Ultra Filtration Water Bottle. In both of these cases, serious chemical impurities may remain, but there is no question that the ability to boil potentially unclean water is an enormous benefit. Most forms of food need to be cooked in some way for reasons of health, sanitation, and flavor. This may also be seen as a form of biological decontamination and here, again, bush microwave ovens could significantly increase the quality of life for untold millions of individuals with substandard fuel or food.

Another less obvious application is the use of microwaves to provide heat, e.g., during colder winter nights. Heated water, dry rice, clothes, and other materials can be used as a heat source during the night. I've had some cold nights where bottles filled with hot water placed at my feet under the covers added significant warmth and comfort. This would not be plausible for many climates, but the point is that there are some individuals who could and would use bush microwave ovens as an additional component of shelter.

Like all tools, microwave ovens can be used improperly. In modern microwaves, the greatest concerns are burns from hot materials after removal and metallic objects causing sparks and, potentially fire. With minimal training, these negative uses pose minimal threat; as mentioned earlier hundreds of millions of individuals have used microwaves with nary a second thought. See Wikipedia for more on this.

In first-world countries, microwaves provide on a small part of the basic need for fuel, with electric and natural gas-powered ovens, ranges, water heaters, and other devices providing the majority of needs. In the bush where these products aren't available, a microwave could conceivably replace almost all of the uses of each of these appliances.

## Deployment to Third-World Countries

There are two major considerations when thinking about the practical wide-scale use of microwave ovens in the third-world countries of situations. First, is distribution of the microwave oven unit itself. Second, is determining how the electricity to run the microwave will be obtained.

### *Microwave Oven Unit*

Microwaves can be purchased and shipped in the U.S. for under $100 (USD) a piece. This is prohibitively expensive for any individual in the third-world and for a large scale solution to this problem. Therefore, additional considerations need to be taken.

Poly, the launcher, sketched out a design for a bush microwave oven. It was a partially buried ceramic stove with a “high-tech” cap that produced the microwaves. Based on how microwaves work, this suggests that delivery of the magnetron itself might be a way to reduce costs, with the rest of the microwave assembled from local materials.

However, this is very difficult in practice. First, the microwave oven needs to be a rectangular conductor of a specific size in order for the microwaves to efficiently heat the food. The door needs to be specifically designed, so that microwave radiation cannot leak during use and to turn off the magnetron when opened. The magnetron needs additional equipment such as a fan to circulate air and a specifically-sized waveguide to channel the microwaves from the magnetron into the unit. Distribution of only the magnetrons without the rest of the housing increases susceptibility to intentional or unintentional misuse. Though the entire microwave needs specifically designed components, the most expensive part is the magnetron, which is essential; therefore distribution of individual parts may not significantly reduce the cost.

While there may be a way to optimize the design of a microwave unit for use in the bush, this might be reinventing the wheel. Millions of microwaves are already in use all over the world and their manufacture has already been optimized in many ways. It is not clear that re-engineering will lead to significantly lower costs.

Instead, I think a good way to investigate the plausibility of using bush microwaves is to employ used, discarded, or refurbished microwaves from first-world countries. People who are moving often leave microwaves; I once had difficulty giving one away. Discarding microwaves properly involves a non-negligible cost, so microwave donations seems like a plausible idea. Costs for such microwaves are much less, in the $10-30 range. The expense of shipping an entire bulky microwave must be higher than compared to shipping just the magnetron, but as mentioned above a magnetron alone is not sufficient. If shipping cost is determined by volume, the metal box and door, which are necessary ingredients, dominate the cost.

If sending to a third-world country, it probably makes sense to include inside the microwave oven door a set of sturdy microwave-safe containers and other equipment that would make for optimized use.

A search for “low-tech microwave” and “portable microwave” didn't really yield any interesting exciting solutions to this problem. Howver, “portable microwave” did show a couple existing portable microwaves, like the iWaveCube, an oven smaller than 1 cubic foot for only $100 and the “WaveBox” which can take in a variety of power sources, including car batteries (but has only bad reviews on Amazon).

Additional searching for this specific idea of using microwaves in third-world countries was not seen. This suggests that Poly has conceived of a unique idea, which in my opinion is certainly worth more detailed consideration.

*Source of Electricity*

Of course, microwaves require electricity. They are very efficient in terms of the conversion of electricity to useable heat, but one drawback is that they require large bursts of electricity in short

timeframes. Typical ovens require 1000 W to produce 600-700 W of heating power. It might be possible to use less power over a longer interval to create a similar heating effect, but increasing the cooking time by more than a factor of 2-3 would likely lead to multiple disadvantages, such as wasted heat. This would also begin to require significant modifications to the microwave design. (http://microwaveexpert.wordpress.com/2011/04/14/low-power-microwaves-for-caravans/)
Furthermore, reducing the power need by 25% still requires 250 W of power, which is difficult to deliver.

There may be regions in the world where electricity is available somewhat locally and a microwave would find great use for cooking food, water, and providing heat. This is obviously a first place to start. But, of course, the vast majority of third-world countries have no ready electricity. The electricity to run the microwave would then need to be generated somehow. Certainly, this is a disadvantage, but I think it should not overrule many of the advantages bush microwave ovens have to offer.

Let us consider ways that this electricity can be acquired. Fuel-based generators are possible and it might even be the case that powering a microwave with a generator to cook food is more efficient than a kerosene-based cooking stove. But, we would like to be able to avoid the use of consumables that are expensive and hard to deliver. Due to their low efficiency per cost, solar panels, wind power, and other such methods are also not effective. A 100 W solar panel is 1.5 x 1 m, weighs 20 kg, and costs ~$100-200 USD. This might be a plausible solution. (Not as futuristic as it sounds, it is possible to beam electricity to remote locations using long-wavelength rectannas, a concept I am familiar with in a previous study of solar power satellites (e.g., solar power generators in space that then beam their energy down to the ground).)

I'll note here that a possible modification to a standard microwave is to make an attachment that can turn the microwave into a solar oven. Solar ovens (or solar cookers) use sunlight to cook food. The central portion is a sealed box with a transparent lid; this is very similar to a microwave. The attachment would be a set of mirrors that reflect sunlight into the oven. It might even be possible to run the microwave while the Sun is also heating the oven.

Keeping in mind that many individuals spend most of their days searching for fuel, what if we utilized human-based power? An active person pedaling a standing bicycle can produce about 100 W of electricity for long periods of time. Cooking food or boiling water requires 1000 W of electricity over ~300 seconds to cook food, requiring 3*10^5 Joules. So, individuals pedaling on a bike could produce a warmed meal in 50 minutes of relatively hard work. Note that accomplishing this task on a regular basis would probably require increasing the caloric input of the individual, which would then require more work. But if the option is riding a bike for a few hours a day for clean fuel or walking all day kilometers to find unsustainable and environmentally damaging fuel, then this is still a viable system. 100 W for 1 hour is 360000 J or less than 100 calories, though it would require ~500 calories of food to provide this, considering the inefficiency of energy conversion from ingestion to electricity.

It goes without saying that providing bikes that can create electricity has major secondary benefit of providing power for other devices beyond microwaves. Unfortunately, the bikes add a major manufacturing and shipping cost.

*Storing Electrical Energy*

Whether solar-powered or human-powered, only about 100 W of energy can be created at any one time, but the microwave needs 1000 W to operate. I don't think that cooking the food 10 times as long as 100 W is a viable solution, but it might work. In particular, the methods used in solar cooking (especially "integrated solar cooking") may be sufficient for cooking food or sterilizing water at low power rates that can be generated by humans without the use of energy storage.

Supposing this is not possible, however there needs to be a way to store electrical energy that can then be ~rapidly released in the microwave. This also helps to multiplex the microwave so that it can be used by multiple individuals/families, thus lowering costs overall.

Launcher poly suggests using a large water-filled circle as a flywhell that can store mechanical energy. A 10 cm radius pipe holding water in a 1 m diameter circle would contain ~500 kg of water. The rotational kinetic energy is 0.5*Mass*Radius^2*(Angular Velocity^2), where Radius is the radius of the circle, not the pipe, so that produce 10^5 Joules would require something like 10 revolutions per second, too fast to be practical. A 20 cm radius pipe would increase the mass by a factor of 4, reducing the energy storage rate to ~3 revolutions/second, which is still pretty fast. A major issue is also frictional energy losses in the flywhell as well as turbulence generated in the water. A solid flywheel would work better.

When considering energy storage, an obvious solution is batteries. We want to use a ~few kg object to store 300000 J, i.e., 100000 J/kg or 27 Wh/kg. We want to release this energy over the course of 300 seconds or 1000 W or ~300 W/kg. In a Ragone chart, this puts us in the regime of conventional batteries (instead of, say, fuel cells or ultracapacitors). A car battery would be more than sufficient, something smaller would be possible, possibly multiple Lithium-ion batteries. Other than the difficulties in transporting batteries, their purchase and shipping cost is not so high compared to the other aspects of this particular problem.

The problem, of course, is that the energy source needs to be efficiently collected, stored, and then used in a sustained burst of microwave power. Probably the only practical solution here is to use batteries.

**Conclusions**

There are many potential benefits to using a microwave oven in the bush. It completely eliminates the need for gathering fuel and has a wide range of health and environmental benefits. The costs would be relatively high, but could be shared among groups of people, as the microwave/bike/battery, lowering the costs per person. I think it would be possible to reach a cost of less than $50/person for a solution that would probably work well for at least a few years, i.e., less than $2/person/month. That seems like a viable price point, even if it needs to be initially funded by charitable organizations or microloans.

I think the combination of materials I like most is a microwave oven that can also be used as a solar cooker. (Perhaps it is even better to think of it as a solar cooker than doubles as a microwave.) Used, discarded, and/or refurbished microwaves are probably the cheapest source, at least initially. The microwave comes with an energy-producing exercise bike (or a smaller more efficient human-powered energy generation device) and some batteries, to provide or supplement electricity and heat when the solar cooker is insufficient. The bike/battery solution also allows multiple individuals/families to share the microwave.

I think that it is important to get this idea out to the world as it has great potential for positive benefits to a large number of people.

I believe that the above answers the questions posed in this Zomb, along with given significant explanation. Please let me know if any of the above arguments are unclear or if you have any other questions or zombs. Doing a Google or Wikipedia search on most of the above concepts will provide helpful insights and references. Other bibliographic citations are available upon request.

Thank you for this opportunity.

Dr. Ragozzine is a Postdoctoral Researcher in the Astronomy Department at the University of Florida. He is currently funded by the United States National Aeronautics and Space Administration (NASA) to work on the NASA Kepler Space Mission. This document is his personal composition and reflects his personal opinion, not that of the University of Florida, NASA, or any other party. He has many years of research experience in the orbital dynamics of planetary systems, the Kuiper belt within our own solar system, and extra-solar planets observed around other stars.