The Effect of Clay and Iron Cooking Plates on Mogogo Efficiency and Energy Use: Experimental Results

Robert Van Buskirk
Department of Energy, Government of Eritrea
Haile Teclai
Department of Energy, Government of Eritrea
Ezana Negusse
Physics Department, University of Asmara
Energy Research and Training Center
Department of Energy
P.O. Box 5285
Asmara, ERITREA

ABSTRACT

Since October 1996, over 40 experiments have been performed with a variety of mogogos in order to test the hypothesis that improved cooking plate conductivity improves efficiency. Three general types of mogogos were tested: electric, gas, and wood mogogos. Comparisons were made between the performance of clay and iron cooking plates, where the iron plates were either 5 mm or 9 mm thick. The results show that the use of iron plates saves energy in two ways. First, energy is saved through an increase of mogogo efficiency. For electric, gas and wood mogogos, the use of an iron plate results in a 25% to 50% increase in mogogo efficiency compared to clay plate mogogos. Second, energy is saved because the use of an iron cooking plate results in more moist *enjera*. Moist *enjera* utilizes less energy than drier *enjera* because less water is boiled during cooking, and this results in a 15% to 30% energy savings. The combined effects result in a 30% to 50% energy savings from using iron mogogo plates.

Introduction

Taita (*enjera* or *injera*) is the staple bread in Eritrea, Ethiopia and parts of the Sudan. It is perhaps consumed by over 50 million people on a daily basis, and is a major element of the diet and household energy use in this region.

The task of developing and designing an improved efficiency *enjera* cooker (mogogo) is one of the top priorities of the Department of Energy of the Government of Eritrea. Recent energy use surveys conducted by the Department of Energy show that about 50% of the energy used by Eritrean households is for cooking *enjera*.

Mogogos to date utilize three main forms of energy: electricity, gas (liquid petroleum gas, LPG), and biomass. Biomass fuel can consist of either wood, crop residues, or dried animal dung, and these fuels can be used interchangeably in the same stove. Electric and gas cookers are mainly used by people in the urban and near urban towns where either electricity is available or the refilling of gas cylinders is relatively inexpensive. Whereas the majority of people nationally (more than 80%) use wood or biomass fuel mogogos.

The wood cookers are the least efficient and thus present the following problems: First, since they use fuel wood, they are a primary cause of deforestation nationally. Such deforestation has wide-ranging detrimental impacts. It is estimated that approximately one million metric tones of biomass are used in cooking *enjera* annually, while national biomass production is roughly estimated at between 8 and 20 million tones annually. It is generally considered that these levels of biomass use are unsustainable. Secondly, compared to electric and gas mogogos, wood mogogos are inefficient with regards to the fraction of available energy utilized. Traditional mogogos with clay plates have estimated efficiencies of 10% - 15%. As a result the scarce wood supplies which are available are not being used to the maximum benefit of rural households. This contributes to rural poverty by increasing household energy costs. In remote villages where either electricity or transportation facilities are not available, wood (and dung) mogogos are the only choice.

In urban areas, wood, dung, liquid petroleum gas (LPG), and electricity are all used for *enjera* production. It is national policy to decrease the pressure on the Eritrean environment by encouraging use of commercial energy supplies such as LPG and electricity instead of wood. This policy is also enforced by restricting wood harvesting and wood supplies. There is at the same time the policy of not subsidizing the energy sector so that the consumer pays the real cost of energy supplies. Commercial energy subsidies are avoided because: (1) the country cannot afford to pay for such subsidies, and (2) such subsidies distort the economics of energy supply and can encourage waste. Hence, commercial energy (especially electricity) can be quite expensive ($10 -$15/month for electricity) for urban households which may have incomes of the order of $70 per month. This makes improving all forms of cookers a strategic necessity because of both the impacts on household income and the national environment.

Theoretically, mogogo efficiency improvements can have a large positive national economic impact. If we consider that wood has an approximate average value of US$ 4/quintal, (ranging from free in remote areas to US$ 15/quintal in the capital) the value of wood consumed is about US$ 80 million per year. If a 50% savings can be obtained through efficiency improvements, this is equivalent to a savings of $40 million per year or about 9% of the National Gross Domestic Product. Whether such benefits can be realized in practice will depend on the cost of such improvements, the practical amount that efficiency can be improved, the acceptability of the improved designs, and the ability to facilitate wide-spread adoption of improved-efficiency designs.

It should be noted that from a national economic perspective, it does not matter if mogogo efficiency improvements actually result in reductions in wood use. An improved efficiency stove can either (1) use less wood, or (2) deliver a greater amount of useful energy or energy services for the same amount of wood.

Studies on the economic impact of improved stove efficiency in the Sudan and other parts of the Sahel [Dufournaud, et.al, 1994], indicate that much of the benefits from improved in stove efficiency are in the form of increased energy services to the household rather than decreased consumption. For Eritrea, forest resources are being managed through both restrictions on harvesting (which decrease wood supplies to households over the short- term), and in the development of forestry resources with controlled har vesting. The decrease of wood supplies in deforested areas is adversely affecting the rural standard of living. If stove improvements allow households to receive greater energy services from the currently limited rural wood supplies, then the rural standar d of living is increased. If improved stove efficiency increases the rural standard of living in the face of limited and decreasing wood supplies, then this complements national energy policy. It is not expected that improved stove efficiency alone will so lve deforestation and environmental problems in Eritrea. But it will help maintain the rural standard of living as controls are placed on wood harvesting and biomass use.

Previous Research

The results presented in this paper are part of a systematic mogo go research program in Eritrea that began in July 1995. The research began by first analyzing in detail the operation and efficiency of electric mogogos [Negusse & Van Buskirk, 1996]. Then based on the initial research with electric mogogos we organized the current investigation into the effects of using iron mogogo plates.

Electric mogogos were studied first because of the ease of analysis. This research produced an initial base-line study of normal el ectric mogogo operation. The electric mogogo study analyzed empirically the effect of different cooking styles on energy use. It also produced a relatively accurate numerical model of electric mogogo operation. The numerical model, which was validated by e xperiment, provided a detailed breakdown of the proportion of heat utilized or lost in the different heat flow paths. Furthermore, the model was able to provide predictions of the impact of different mogogo design changes

The electric mogogo study [Negusse & Van Buskirk, 1996], supported by the theoretical computer calculations, showed that the following energy saving strategies could be used:

Table 1: Energy savings strategies for *enjera* production

Savings Method	**Proportion of Energy Saved**
Cooking thick/moist *enjera*	20% - 50%
Long/shared cooking sessions	10% - 15%
Greater plate conductivity	10% - 20%
Increased insulation	5% - 10%
Combined measures	40% - 70%

Of the different energy savings methods, the first two, which are the most significant, depend on household cooking styles. And these methods are in wide -spread practice in Eritrea. It is possible that educational activities could increase the prevalence o f such energy savings methods.

The last two measures: increased plate conductivity and increased insulation are design features that can be built into the mogogos. Based on theoretical computer simulations, it was estimated in October 1996 that these desi gn changes could save 15% to 30% of the energy used in mogogos.

This article reports on the results of experiments that tested the conclusions of the October 1996 study. The recent experiments on *enjera* cooking, which we describe below, focus on the impact of different cooking plate materials on mogogo efficiency and energy use. The experiments have been carried out on three types of mogogo: electric, gas and wood, with two different cooking plate materials: iron and clay. The recent experiments indicate that higher-conductivity cooking plates result in a 25% to 75% increase in efficiency which is equivalent to a 20% to 45% energy savings --slightly greater than predicted. An unexpected result from the recent experiments is that iron plates also result in more moist *enjera*. By cooking more moist *enjera* an additional 15% to 30% energy savings is recorded. The total energy savings from the use iron cooking plates is greater than the predictions of the October 1996 study, in part because of the combined effects of improved efficiency and moist *enjera* production.

Background:

<u>The cooking of *enjera*</u>

Enjera is a local bread served with most traditional Eritrean dishes. Preparation of *enjera* is a rather a long process; it usually takes two to four days from mixing to cooking. *Taita* can be produced from almost any staple grain, with sorghum, millet and *taff* being the most common in Eritrea. *Taff* is a very fine staple grain common in the Ethiopian Plateau, which has grains approximately 1 mm in diameter. The flour is mixed with water at a ratio of 1:2 by weight and, in the Highlands, left to ferment for two to four days (less time in warmer locations). Starter (left-over dough) may be added to trigger fermenta tion. Four to eight hours before cooking, a layer of fermentation product, (locally known as *tsilal*) is removed and hot water is added to reactivate fermentation. This process, *laffa*, is done to remove some of the bitter fermentation products and to reacti vate the leavening action to produce a light moist bread. The *enjera* batter or *buhuQ* is poured on top of the hot cooking plate at a thickness of three to five liters per square meter of plate surface. The individual pancakes or pieces of *enjera* are called *taita*. When the *taita* is cooking, the cooking plate surface ranges from 90 to 170 degrees C. The power deliver to the *taita* is approximately six kilowatts per square meter of plate surface. The total power of the mogogo is the power delivery to the *taita*, divided by the efficiency of the cooker.

As stated above heat supplied to the plate either comes from burning fuel wood, dung or agricultural residue for wood mogogos, the burning LPG for gas mogogos, or the heating of electrical resistance elements in the electric cooker. This heat is then conducted through the cooking plate to the cooking surface where it cooks the batter. The heat supplied to the *enjera* is used for raising the temperature of the batter from room temperature (25 to 32 degrees C) to the boiling point of water (in Asmara, about 92 degree C). and for boiling a portion water in the batter (17% - 24% of the batter by initial weight). The rest of the heat supplied to the mogogo is lost through a variety of paths such as: through the sides, through convective and radiative heat losses from the plate surface, through the exhaust gases from the fuel, etc. The fraction of energy that flows into the *enjera* batter relative to the total energy used determines the efficiency of the mogogo.

Energy use and efficiency

There are three quantities of interest with regards to the energy use of a mogogo: the total energy intensity, the utilized energy intensity, and the efficiency. These quantities measure the performance of any cooker and thus the cost of *enjera* production. The total energy intensity is the total amount of energy used to cook one kilogram of *enjera*. It includes both the energy actually utilized in cooking the *enjera* and the energy which is lost. This is the quantity which most affects the house hold energy budget. It depends strongly on the cooking style, especially the water content of the initial batter or *buHuQ*, and the thickness of the *taita*.

The second quantity of interest is the utilized energy intensity. This is the amount of energy which is actually used in cooking one kilogram of *enjera*, not including any of the energy losses. It is the amount of energy that would be used in cooking one kilogram of *enjera* on a 100% efficient mogogo.

The third quantity of interest is the efficiency of the cooker, or the ratio of the energy utilized in cooking to the total energy consumed in the mogogo. This quantity depends on the design of the mogogo, and particular features of the cooking style including the length of the cooking session, and how carefully energy is controlled and regulated during the cooking process.

Thermal resistance of the cooking plate

The mogogo design parameter which most effects the efficiency and energy intensity is the thermal resistance of the cooking plate [Negusse & Van Buskirk, 1996]. A cooking plate with a low thermal resistance will deliver large amounts of heat to the cooking plate surface given a relatively small temperature difference between the bottom and the top of the plate. If we consider a wood mogogo for example, a relatively small, cool fire under an iron cooking plate can heat up the plate surface quickly because of the ease with which heat is conducted from the bottom of the plate to the cooking surface. Thus for an iron-plate mogogo, the heat source can operate at a lower temperature.

Because of the lower operating temperature of an iron-plate mogogo, the efficiency is increased in several ways. Firstly, because the heat source is at a lower temperature, the rate of heat loss is lower. For example, calculations for electric cookers indicate that since the cooker can operate at lower temperature, the radiation heat losses from the upper surface of the cooking plate, sides of the cooker and the supports at the bottom of the cooker will be less by a factor of two. Model calculations show that for an electric cooker with a clay cooking plate, the temperature of the coils goes up to 360 -400 degree C. With poor insulation, losses from the bottom will be as high as 11% of the input energy. On the other hand, for a plate with low thermal resistance and proper insulation the losses from the bottom can be reduced to about 2% of input energy.

Secondly, when the cooking session is over, the lower operating temperature of the high conductivity plate will reduce the amount heat stored in the plate. The unused heat at the end of a *enjera* cooking session accounts for 15%-20% of the total heat supplied in the case of a clay cooking plate and a relatively short cooking session of 9 *taita* [Negusse & Van Buskirk, 1996]. According to model calculations, this can be reduced to less than 10% of the total heat supplied when an iron plate is used instead of a clay plate.

Experimental Methods

In our cooking experiments we compared the energy consumed by the different types of mogogos to the energy actually utilized in the cooking process. The ratio of the energy utilized in cooking to the energy consumed by the mogogo is the efficiency of the mogogo.

For the electric mogogos the energy consumed is the electric power from the electric supply. For LPG mogogos the energy consumed is determined by the amount of LPG burned. And for wood mogogos it is determined by the amount of wood burned.

We defined the energy utilized in cooking as the amount of energy necessary to raise the batter to the boiling temperature, plus the amount of energy necessary to boil the water which evaporated during the cooking process.

To measure the energy consumed by the electric mogogo, we measured the current with an inductive ammeter and measured the voltage of the power supply to calculate the power of the electric mogogo. We then timed how long the electric mogogo was turned on during the cooking session and multiplied the power times the time of consumption to get the total energy consumed by the cooker.

To measure the energy consumed by the LPG mogogo we weighed the LPG container before and after the cooking session on an electric scale with a precision of 1 gram, and assumed that the difference in the weight was equal to the weight of the LPG consumed. Then using the specific (i.e., per kilogram) energy content of LPG, we calculated the energy consumed by the stove.

To measure the energy consumed by the wood mogogo, we weighed the dry wood before the cooking session. After the cooking session we dried any wood that got wet, and also dried any charcoal that was left in the stove. We weighed the remaining wood and the charcoal which was produced. Using specific energy content values for wood, and for charcoal, we calculated the energy consumed by the stove as the energy content of the wood consumed minus the energy content of the charcoal produced.

To measure the energy utilized in cooking *enjera*, we weighed the initial *enjera* batter, and the total amount of *enjera* produced from this batter. We assumed that the energy utilized in cooking the *enjera* was the energy required to raise the batter from room temperature to the boiling point of water, plus the energy required to boil the water that evaporates. We assumed that the heat capacity of *enjera* batter is the same as that of water in order to calculate the energy required to raise the batter temperature to boili ng. We also assumed that the difference in weight between the final *enjera* and the initial batter was equal to the weight of water that was boiled in cooking. Therefore, the utilized energy is:

$$\text{Energy Utilized} = M_{batter} * (T_{boil} - T_{room}) * Cp_{water} + (M_{batter} - M_{enjera}) * H_{vaporization}$$

where M_{batter} is the mass of the batter, T_{boil} is the boiling temperature of water in Asmara, T_{room} is the room temperature in the mogogo test room, Cp_{water} is the heat capacity of water, M_{enjera} is the mass of the *enjera* produced and $H_{vaporization}$ is the heat of vaporization of water.

Surface preparation of iron plates

In our experiments, the iron plate surface was initially prepared by rusting in order to create a low thermal conductivity surface coating, which coul d also be used for making a traditional no-stick surface with burnt oil seeds. The rusting and plate preparation procedure is not very different from the one used for hundreds, if not thousands of years for the preparation of cast iron pots and pans.

It has been found by many, that iron mogogo plates have difficulties cooking good *taita* if used directly without proper plate preparation. This was also confirmed in our experiments where cooking on an untreated iron plate resulted in sticking and problems with leavening and the development of bubbles or 'eyes' in the *taita*.

This issue was discussed theoretically in the previous simulation study [Negusse & Van Buskirk, 1996]. The simulations in this study indicated that the power delivery to the *taita* is very rapid during the first three seconds, and then becomes quite slow for the following 5-10 seconds. Meanwhile power delivery for the clay plates is more even and gradual. Theoretically, one could provide a smoother more gradual power delivery curve for the iron mogogo by putting a low thermal conductivity surface on the plate. This lower conductivity surface slows the initial power delivery to the *taita* and produces a power delivery function which is closer to that of the clay (which produces high quality *taita*). One method traditionally used for putting coatings on iron cooking plates is to initially rust the surface by burying the plate in the soil with salt for several days. This method was employed with some modifications.

The steel plate surfaces were prepared in the following manner: Initially a grid of scratches was made in the plate surface which were approximately 0.2 mm deep and separated by 3 to 5 mm. Then the plate was painted with a layer of clay, salted and buried in moist ground for a week. After the plate was removed, it was washed and the traditional no-stick surface was prepared. To prepare the no-stick surface, initially a layer of vegetable oil was painted on the plate and the plate was heated until the vegetable oil burned and created a black organic tar which filled in the rough areas of the rusted surface. Then after this surface cooled and hardened, crushed *gu'li'* (a traditional oil seed) and flax seed was burnt on the heated surface and the burning seeds were rubbed into the surface to create the final black no-stick coating. After such coating, iron plates cooked good quality *taita*, though the quality remains less (traditionally speaking) than the *taita* cooked on clay mogogos.

Experimental Results

<u>Presentation of Results</u>

So that we can properly interpret our experimental results, we present our results in terms three important quantities:

- The total energy consumed per kilogram of *enjera* produced
- The energy utilized in cooking per kilogram of *enjera* produced, and
- The energy efficiency of *enjera* production

We present the performance of the different mogogos in terms of these quantities for several reasons.

First, since the energy cost of producing a kilogram of *enjera* is proportional to the total energy consumed, we need to present the energy consumed per kilogram of *enjera* produced in order to evaluate the economic benefits of different types of stoves. We refer to this quantity as the **Total Energy Intensity** of *enjera* production and measure it in units of megajoules per kilogram (MJ/kg).

As for the second quantity: the energy utilized in cooking per kilogram of *enjera* produced, we normally would expect this quantity to be constant on average in any set of stove experiments. But to our surprise we find that there are important, systematic variations in this quantity because different types of mogogo tend to produce *taita* with different physical properties. We refer to this quantity as the **Utilized Energy Intensity** of *enjera* production and measure it in units of megajoules per kilogram (MJ/kg). Some of the difference in performance between the energy use of iron - plate and clay-plate mogogos is due to differences in utilized energy intensity.

The energy **Efficiency** of the mogogo is simply the utilized energy intensity divided by the total energy intensity. It is also equal to the energy utilized in cooking during a cooking session divided by the total energy consumed by the mogogo.

Efficiency and Energy Intensity Averages

Table 2 summarizes the performance of the different mogogo types in terms of their mean efficiency, mean total energy intensity, and mean utilized energy intensity. In the table we express efficiency as a decimal fraction rather than as a percentile. There are several clear trends evident in the data.

The first evident trend is that electric mogogos are more efficient than gas mogogos, and that gas mogogos are more efficient than wood mogogos. For standard clay-plate mogogos, electric mogogos tend to be between 50% to 60% efficient, while gas mogogos are 30% to 40% efficient, and wood mogogos are 10% to 15% efficient.

(The type of wood mogogo that was tested in these experiments had an enclosed firebox made from clay and stone, and a chimney that vented through the roof of the cooking shelter. This is the type of mogogo in common use in the highlands of Eritrea and Tigray).

Table 2: Mean Efficiencies and Energy Intensities for Different Mogogo Types

Mogogo Type	Mean Efficiency	Mean Total Energy Intensity	Mean Utilized Energy Intensity
Electric-Iron Plate	0.75	1.2 MJ/kg	0.90 MJ/kg
Electric-Clay Plate	0.53	2.4 MJ/kg	1.27 MJ/kg
Gas-Iron Plate	0.45	2.1 MJ/kg	0.94 MJ/kg
Gas-Clay Plate	0.36	3.1 MJ/kg	1.12 MJ/kg
Wood-5mm Iron Plate	0.20	4.3 MJ/kg	0.86 MJ/kg

Wood-9mm Iron Plate	0.19	5.0 MJ/kg	0.95 MJ/kg
Wood-Clay Plate	0.11	9.4 MJ/kg	1.04 MJ/kg

The second trend evident from the table is that the iron -plate mogogos use 30% to 50% less total energy than the clay-plate mogogos. For electric mogogos, the iron -plate type uses 50% less energy than the clay plate type. For LPG mogogos, the iron -plate type uses over 30% less energy than the clay plate type. And for wood mogogos the iron - plate type uses about 50% less energy than the mogogos of the clay -plate type.

A third feature of the data is that the efficiency is consistently lower for the clay -plate mogogos than it is for the iron-plate mogogos. But the fractional difference between efficiency values is not as great as that observed for the total energy intensity. For electric mogogos, the clay-plate type has an efficiency value about 30% lower than that of the iron plate mogogo. For gas mogogos, the efficiency is 20% lower for the clay -plate mogogo than the iron-plate mogogo, and for the wood mogogo, the clay plate efficiency is 45% lower than the iron-plate efficiency.

The fourth feature of the data presented in the table is that *enjera* produced by iron-plate mogogos consistently utilizes less energy during the cooking process. The mean utilized energy intensity for the iron- plate mogogos is 0.91 MJ/kg, which is approximately 20% less than the 1.14 MJ/kg utilized by *enjera* in the clay-plate mogogos on average. The lower utilized energy intensity of *enjera* produced in iron-plate mogogos is presumably due to the resulting *enjera* having a higher water content. Because of the higher final water content, less water is boiled from the batter, and less energy is utilized. It was observed during experiments that the iron plates often did not deliver heat to the *taita* as consistently as the clay plates did. This produced *taita* of significantly lower quality compared to that produced by the clay -plate mogogos. But observers still considered the quality of the *taita* produced by iron-plate mogogos to be acceptable.

When we plot energy intensity (Energy used per kilogram of *enjera*) versus efficiency, we notice that the data points of the different mogogos falls within different ranges. But in spite of the experimental scatter, observed in the data, the iron -plate data is consistently of higher efficiency and lower energy intensity. Figure 1 shows the efficiencies and energy intensities of the electric mogogos. There is significant scatter, but the iron-plate tests range from 60% to 90% efficiency, while the clay -plate data ranges from 40% to 70% efficiency. Meanwhile, figure 2 illustrates the same results for gas mogogos. For gas mogogos, the differences between iron and clay -plate performance is less, but it is still quite significant. Finally, in figure 3 we present the wood mogogo data which shows the largest relative difference between clay -plate and iron-plate performance. Note that in these figures, we illustrate the results for only those tests where 8 or more *taita* have been cooked, because cooking sessions with only a few *taita* have unusually low efficiencies (due to the heat left over in the plate which is wasted).

Figure 1

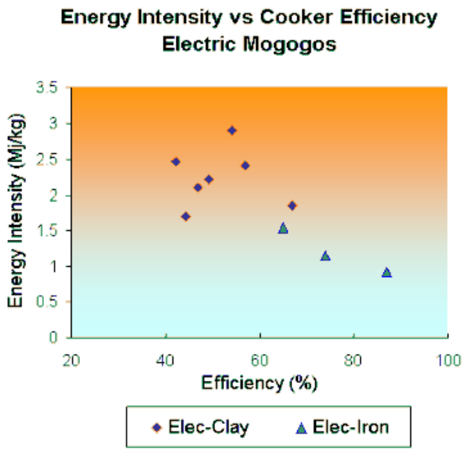


Figure 2

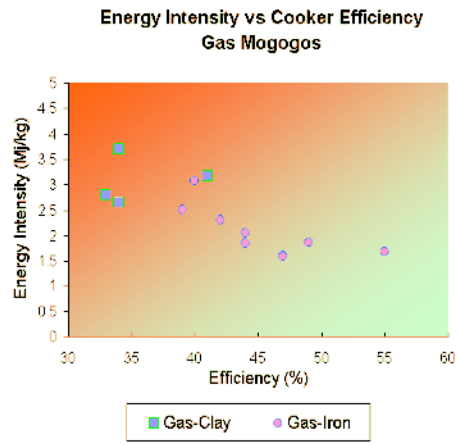
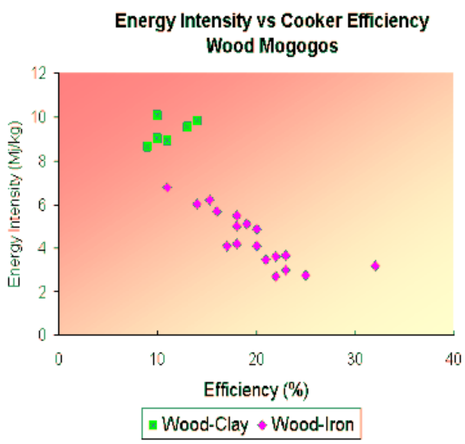


Figure 3



Conclusion:

Earlier theoretical work predicted that the largest improvements in mogogo efficiency could be obtained by increasing the thermal conductivity of the cooking plate. These predictions have been firmly verified by recent experiments at the Department of Energy in Eritrea. In addition, we find that the use of iron -plate mogogos also results in moist *enjera* which is less energy-intensive the drier *enjera*. This results in further energy savings. There are some chall enges presented by iron-plate mogogos. The first is that the plate surface needs to be prepared well with a no -stick low-conductivity surface. We prepared such a surface by scratching grooves in the iron plate, rusting it in wet clay for several days to two weeks, and burning oil into the rusted surface. In addition, it is necessary for the plate to be reasonably thick (5mm to 9 mm thick) in order to produce acceptable quality *taita*. And the final challenge is that even with these measures, the quality of the *taita* is slightly lower than that produced with clay -plate mogogos.

In spite of these challenges it is very important to aggressively pursue the introduction of iron-plate mogogos. The energy savings from the use of iron cooking plates ranges from 30% to 50% depending on the type of mogogo (electric, gas, or wood). Because of this large savings in energy, a slightly lower *taita* quality may be acceptable. Furthermore, with practice and experience, Eritreans may develop the cooking techniques that will enable them to cook very high quality *taita* on iron plates.

Future Work:

The next step in this research is to conduct field trials that examine the social response to iron-plate mogogos. These field trials should consist of the distribution of 9 mm iron mogogo plates in selected villages in order to examine the peoples' response to iron - plate mogogos and measure the energy savings in a village setting. In the field trials, participating families should be recruited to keep track of the approximate amoun t of wood used, the number of *taita* that are cooked, and the amount of flour used in cooking the *enjera*. Since the expected savings from an iron-plate mogogo is 50%, the field trials can measure the different quantities in whatever units are in common use in the country - side and measure the relative fuel savings in those units. The field trials should be conducted in two phases: a calibration phase, and a test phase.

During the calibration phase, the participating families should record their current wood use, and current *taita* production for a minimum of one month. For each cooking session, the date of the session, the amount of wood and flour consumed, and the number of *taita* produced should be recorded. Also, whenever wood is gathered, or dung is dried, the date and amount of gathered wood or dung should be noted.

During the test phase, the clay plate in the family's mogogo will be replaced by an iron plate provided by the agency conducting the field trials. The iron plate that is provided needs to be the same size at the clay plate that was originally in the family's mogogo. Furthermore, the family participates in the test phase, only if it successfully collected data for the calibration phase. The family, then records the same data as during the calibration phase: the date, the wood consumed, the flour consumed, the number of *taita* produced, and the wood or dung gathered. In addition, they record whatever comments they may have on ease of use and the quality of *taita*.

After successful field tests of iron-plate fuel savings, the final stage is production and promotion of energy-saving iron mogogo plates. If these iron plates actually save as much energy as indicated by these preliminary tests, a nd if they are socially acceptable to Eritreans, then iron plates hold the promise of saving precious wood resources and raising the rural standard of living throughout Eritrea.

REFERENCES

[1] Dufournaud C M, Quinn J T & Harrington J J, 1994, "an applied general equlibrium (AGE) analysis of a policy designed to reduce the household consumption of wood use in the Sudan," *Resource and Energy Economics* **16**(1) 67-90.

[2] Negusse E & Van Buskirk R, 1996, *Electric Enjera Cooker (Mogogo) Efficiency*, Energy Research and Training Division, Department of Energy, Ministry of Energy Mines and Water Resources, P.O. Box 5285, Asmara, Eritrea, October 1996.

Table 3
Experimental Results Electric and Gas Mogogos

Mogogo type	# of Taita	Taita Wt (kg)	Input Energ (MJ)	Energ Int (MJ/kj)	Effic (%)
Electric-Iron	18	9.77	9.11	0.93	87
Electric-Iron	14	6.78	10.49	1.55	65
Electric-Iron	13	7.35	8.51	1.16	74
Electric-Iron	5	2.36	3.96	1.68	50
Electric-Clay	25	7.74	14.29	1.85	67
Electric-Clay	12	5.63	16.34	2.90	54
Electric-Clay	11	5.81	14.00	2.41	57
Electric-Clay	10	5.14	12.56	2.44	51
Electric-Clay	10	5.56	13.74	2.47	42
Electric-Clay	10	5.62	12.47	2.22	49
Electric-Clay	7	6.06	12.78	2.11	47
Electric-Clay	7	4.62	7.32	1.58	60
Electric-Clay	6	5.88	10.02	1.70	44
Electric-Clay	4	2.52	6.73	2.67	38
Gas-Iron	18	11.57	19.53	1.69	55

Gas-Iron	16	10.26	31.64	3.08	40
Gas-Iron	16	9.70	18.08	1.86	49
Gas-Iron	15	11.34	26.13	2.30	42
Gas-Iron	15	10.86	20.11	1.85	44
Gas-Iron	13	9.52	15.40	1.62	47
Gas-Iron	11	7.94	19.89	2.51	39
Gas-Clay	19	9.86	31.19	3.16	41
Gas-Clay	14	8.79	24.68	2.81	33
Gas-Clay	13	8.41	31.10	3.70	34
Gas-Clay	10	7.49	19.84	2.65	34
Gas-Clay	8	5.34	9.72	1.82	50

Table 4
Experimental Results: Wood Mogogos

Mogogo type	# of Taita	Taita Wt (kg)	Input Energ (MJ)	Energ Int (MJ/kj)	Effic (%)
5mm Iron Wood	11	7.23	23.08	3.19	32
5mm Iron Wood	15	11.05	30.43	2.75	25
5mm Iron Wood	13	9.73	29.49	3.03	23
5mm Iron Wood	12	8.01	29.37	3.67	23

5mm Iron Wood	11	8.17	22.20	2.72	22
5mm Iron Wood	15	10.37	35.96	3.47	21
5mm Iron Wood	10	7.36	30.27	4.11	20
5mm Iron Wood	15	10.20	42.82	4.20	18
5mm Iron Wood	12	8.01	35.84	5.01	18
5mm Iron Wood	10	5.50	30.25	5.50	18
5mm Iron Wood	13	9.98	41.24	4.13	17
5mm Iron Wood	10	6.25	35.41	5.67	16
5mm Iron Wood	10	6.08	36.52	6.01	14
5mm Iron Wood	10	6.71	45.60	6.80	11
9mm Iron Wood	17	11.18	40.54	3.63	22
9mm Iron Wood	13	7.91	38.39	4.85	20
9mm Iron Wood	12	7.61	38.90	5.11	19
9mm Iron Wood	10	6.09	37.78	6.20	15
Wood-Clay	16	9.84	96.93	9.85	14
Wood-Clay	15	8.00	76.40	9.55	13
Wood-Clay	12	6.92	61.72	8.92	11
Wood-Clay	13	6.75	61.07	9.05	10
Wood-Clay	9	4.40	44.42	10.10	10
Wood-Clay	10	5.19	44.88	8.65	9