Bio-Ethanol as a Household Cooking Fuel:
A Mini Pilot Study of the SuperBlu Stove in Peri-Urban Malawi

James Robinson[1]
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Abstract: Malawi is one of the world's least developed countries where population pressures and an over reliance on traditional biomass fuels have led to deforestation. The combustion of unsustainably harvested biomass releases large quantities of greenhouse gases into the atmosphere and when burnt indoors has been strongly linked to acute respiratory infections, a major cause of death in developing countries. This report presents an assessment of the SuperBlu Stove, developed to use bio-ethanol already produced in Malawi from sugar industry waste as part of a fuel-blending programme. The stove was evaluated against an improved ceramic charcoal stove with both units undergoing field testing in twenty peri-urban households as well as safety, water boiling and controlled cook tests. The prototype stove was found to be potentially appropriate for use but suffered from manufacturing problems, with further work required on safety, performance and emissions. However, the SuperBlu Stove can be made appropriate with some seemingly achievable development. For the stove to be made both affordable and accessible to users, the ethanol market would need some marked changes to reduce price, increase available volumes and develop alternative feedstocks.

Keywords: Ethanol Stove Charcoal Urban Malawi Bluwave

[1] The author can be contacted at jamesrobinson77@gmail.com

List of Abbreviations

ARI	Acute Respiratory Infection
CCT	Controlled Cook Test
CO_2	Carbon Dioxide
CoV	Coefficient of Variation
FCR	Fuel Consumption Ratio
GFS	Gel Fuel Stove
GHG	Green House Gas
ICS	Improved Charcoal Stove
KPT	Kitchen Performance Test
kW	Kilowatt (1,000 W)
LHV	Lower Heating Value
LPG	Liquid Petroleum Gas
MJ	Mega Joule
MK	Malawian Kwacha
MW	Megawatt (1,000,000 W)
SA	Standard Adult
SBS	SuperBlu Stove
SD	Standard Deviation
SFC	Specific Fuel Consumption
SHFC	Specific Household Fuel Consumption
W	Watt
WBT	Water Boiling Test

1. INTRODUCTION

1.1 General Background

Malawi is one of the world's least developed countries with a gross national income per capita of $160. Subsistence agriculture dominates the economy and about 84% of the population live in rural areas [1]. With over 12 million people and a land area of 94,000 square kilometres, Malawi is one of Sub-Saharan Africa's most densely populated countries. This has put the environment under great pressure with extreme poverty, the demand for farmland and an overdependence on traditional biomass fuels, in both the agro-industrial and domestic sectors, resulting in an increasing deforestation rate and an estimated loss of 500 square kilometres of forest per year [2]. The country's main source of energy is biomass, accounting for 93% of total supply while petroleum products, all imported, account for 3.5%. Electricity constitutes only 2.5% of the total with an installed capacity of 305MW, generated mostly from hydroelectric stations which provide energy to 5% of the population [3]. The remaining 1% comes from coal, ethanol and other energy sources with the country having no known reserves of oil or gas. A map of the country can be found in Appendix 1.

In urban areas, the lack of access to sustainable forestry and modern energy services has led to a high demand for charcoal amongst the 16% of the population who live there. However, due to the relative inefficiencies of production in traditional earth moulds, where 7 tonnes of firewood can produce 1 tonne of charcoal, the annual urban per capita wood usage is $1.56m^3$ equivalent, almost double the rural figure of $0.85m^3$ [3]. In towns and cities it is the peri-urban areas, characterised by lower incomes, a lack of access to infrastructure and poor quality housing, that are more affected by energy issues as a bigger share of their income is spent on fuel. Even in middle-income areas the high price of electricity and electrical appliances, together with a poor reliability of supply, mean that charcoal remains the main cooking fuel. On a global level the combustion of biomass has major implications for climate change due to the release of large amounts of Carbon Dioxide (CO_2) and other greenhouse gases (GHG's). Whilst much of the CO_2 is absorbed back into plants during photosynthesis, if it is unsustainably harvested this absorption effect is largely negated. In addition, the use of open fires and cook stoves makes household energy usage a large source of pollution [2, 4, 5], with the burning of biomass indoors being strongly linked to acute respiratory infections (ARI's) and other health problems. As cooking is mostly a task undertaken by woman this particularly affects them, and more so their young children who often spend long periods of time at their side. It is estimated that ARI's are the biggest killer amongst children under the age of five world wide, resulting in over 2 million deaths annually [6-8].

1.2 Terms of Reference

This project supports the drive to substitute unsustainably produced charcoal and fuelwood with bio-ethanol, already produced in Malawi from sugar industry waste as part of a fuel-blending programme (Box 1). This should result in lower levels of GHG emissions and considerable benefits to public health, the environment and also to the local economy. The work is based around the SuperBlu Stove (SBS) which, although at a prototype stage, was sufficiently developed to undergo a mini pilot study to assess its viability for use in peri-urban households in Malawi. However, whilst the stove may be technically viable, for it to be disseminated successfully and remain in use it must meet the three criteria of being appropriate, affordable and accessible to users [9]. Consequently the research was carried out in a series of laboratory and field tests, together with ethanol market research, to answer the following aims:

1) Is the prototype SBS appropriate for use?

2) Can the SBS be made more appropriate?

3) Can the SBS be made affordable?

4) Can the SBS be made accessible?

The SBS was assessed against the Improved Ceramic Charcoal Stove (ICS), a unit in widespread use across Southern Africa [10], including all field test households. This research follows some of the findings of an international study on improved stove programmes [11], which concluded that they should be focused on users who already spend a substantial proportion of their income on cooking fuels and so would "most likely benefit from and consequently adopt improved stoves". The field test will also allow for interaction and feedback between stove designers and users, another finding of the same report. In addition, guidance on the monitoring and evaluation of household energy projects was taken from several reports [12, 13]. This research is aimed at informing future SBS development and a more extensive pilot study, it is not an assessment of the novel SBS technology. A description of all the stoves and fuels under test can be found in Appendix 2 and 3.

The SuperBlu Stove

1.3 Other Alcohol Stove Programmes

Compared to traditional fuels, more modern energy sources such as paraffin (kerosene) and liquid petroleum gas (LPG) offer increased efficiencies, reduced emissions and are more user friendly, with the additional benefit of reducing the workload of woman and children. However they release fossil fuel derived GHG's and are often more expensive to both the national economy and the user, with poverty being one of the main barriers to their uptake [3, 4]. Liquid biomass cooking fuels combine some of the advantages of both traditional and new fuels and one such scheme is Project Gaia, an Ethiopian based programme which has developed an alcohol stove which runs on either methanol or ethanol [14]. The stove promoters have found the household liquid fuel market difficult to create as both a critical mass of stoves, and hence fuel, as well as government support is needed to gain the interest of private fuel companies. They also found that aside from cost the stove quality and functionality are key to appealing to the household cook [15].

The Project Gaia Cook Stove

Another project of relevance to the SBS is the Millennium Gelfuel Initiative, a public-private partnership set up to adapt and disseminate an ethanol cooking fuel for use in the African household sector [16]. The programme developed a low cost gel fuel, produced by adding a thickening agent to ethanol, which achieved a step increase in safety over a liquid fuel due to it's high viscosity. So as part of this research a Gel Fuel Stove (GFS) underwent technical tests with the results listed in Appendix 10 and the main points of interest included in the main body of the report. In Malawi a gel fuel factory has been set up near Lilongwe with the capacity to produce 1000L/day. Unfortunately production was halted in 2005 due to increases in the price of ethanol and changes to tax and duty exemption that made the fuel unaffordable to most [17].

Box 1: The Current Ethanol Market in Malawi

Due to both the lack of a developed infrastructure and a landlocked status, Malawi suffers from high transportation costs [2], which only increases the impact that imported petroleum has on the economy. Since 1982 the country's fuel-blending programme has taken advantage of the economically favourable conditions for ethanol production from sugar industry waste. Government policy has been to blend ethanol with petrol in a 2:8 ratio [3] but a recent switch to unleaded petrol has dropped this to 1:8, reducing total national ethanol demand by half [18]. The production of ethanol is achieved by the fermentation and then distillation of molasses to its maximum azeotropic mixture of 96% alcohol by volume (hydrous ethanol). Further processing is required to make fuel grade ethanol of 99.5% concentration which has an energy per unit volume, or heating value, some two-thirds that of petrol and paraffin. Illovo Sugar Ltd operate the two main sugar growing areas in Malawi, at Dwangwa and Nchalo (Appendix 1), and in 2004 the total output from 18,100 hectares was 2,020,000 tonnes of sugarcane which produced 260,000 and 80,000 tonnes of sugar and molasses respectively [19]. In the same year ethanol production at Dwangwa was 10 million litres from 40,000 tonnes of molasses [18]. Production at this plant is batch type and the majority of output is fuel grade ethanol which is transported by road tanker to oil company depots near the main urban areas. A lesser volume is exported to East African countries and hydrous ethanol is sold to smaller customers such as the drinks industry and a gel fuel company. In 2004 the Chikwawa ethanol plant was built near Nchalo with a production capacity comparable to Dwangwa but with a continuous production process and molecular sieve technology [20]. As the majority of ethanol is used for fuel blending its price is pegged to the 'in board landed cost' of petroleum in Malawi, essentially the world market price plus an import margin to cover transport, insurance etc. In recent years, the price of ethanol has increased due to a rising world oil price and the depreciation of the Malawian Kwacha (MK) against the US Dollar. Consequently the retail price has risen by 50% over the past four years to 85MK/Litre in August 2005, 57MK/L without the 17.5% Surtax and Duty [17]. The Press Corporation, a listed company, and a small group of private investors have stakes in both Chikwawa and Dwangwa facilities, with Illovo Sugar Ltd part owning the latter.


The Chikwawa Ethanol Production Facility

2. METHODOLOGY

2.1 The Assessment of Criteria

To test and compare the performance of the stoves against the three criteria, it was necessary to introduce a series of indicators that covered both qualitative and quantitative data (Table 1). For each indicator, the SBS was assessed relative to the ICS and graded on a scale of 1 to 3. A grade 3 meant that the SBS was better than the ICS, 2 was similar or unproven, and 1 was worse. Due to the more general nature of the accessible indicators, a different method was used with the SBS being assessed in absolute terms and for each indicator judged to be unlikely, marginal or likely and graded 1 to 3. Each criteria was then assessed on the average grade of its indicators, rounded to the nearest whole number, with a middle ranking score resulting in a partial confirmation and scores either side yes or no.

Table 1. Criteria and Indicators

Appropriate	Safety
	Usability
	Performance
Affordable	Operating Costs
	Initial Investment
	Lifecycle Costs
Accessible	Fuel Supply Chain
	Stove Supply Chain

2.2 Test Methodology

For over 20 years there have been attempts to define a standard test for cook stoves so that data could be shared and understood on an international level [21, 22]. These tests were to be simple and repeatable in the field and it is from one of the more recent procedures that the author's own tests were based [23], with some modification to allow for the differing fuels, stoves and cooking practices under test. However, stove test results are not often directly transferable to a different environment [24] and so the test data in this report is for comparative purposes only. Therefore it was necessary to adopt a variety of tests to assess both the technical performance of the stove and, more critically, its performance in everyday use[2].

2.2.1 The Water Boiling Test

The Water Boiling Test (WBT) measures the thermal efficiency of the stove, the specific fuel consumption and both maximum and minimum power. To cover all areas of use the stoves were tested when started from cold, when fully operational and for a 45 minute simmering period. The WBT gives a laboratory based performance, useful for the design process, but rarely reflecting the true performance of the stove. It is of note that the thermal efficiency is a combination of both the efficiency of combustion as well as heat transfer to the cooking pot. However this is rarely a good indicator of stove performance as it is a measure of the work done to heat and then evaporate water, so unless steam is part of the cooking process the energy is being wasted. The specific fuel consumption (SFC) is the fuel used to boil one litre of water with test conditions corrected to a standard ambient temperature. Generally the higher a stoves thermal efficiency, the lower its SFC. The stove firepower is the rate of fuel energy consumed over the full test duration and not the output power to the pot.

The adopted WBT procedure called for a standard 5 litre pot to be used with no lid [23]. This did not reflect local cooking practice and the author found it impossible to boil water under these conditions. Therefore the method was adapted to use a 2 litre pot with a lid as this was how nsima, the staple food in Malawi, was cooked for a typical family. When consulted, another stove expert also found the 5 litre method impractical [25]. These modifications will have an effect when comparing results from other studies but for the purposes of this comparative research were justifiable. Limited WBT data of the SBS with the pot lid off is listed in Appendix 4. In the simmering phase the thermal efficiency, SFC etc reflect the stoves ability to maintain the pot at around 3ºC below the local boiling temperature, therefore they are not directly comparable to the higher power results where the ability to boil is being measured. It was found that the performance between individual SuperBlu Stoves varied and so a stove of 'average' fuel consumption was selected for the WBT. Each test was repeated three times and the average taken. More details of the WBT can be found in Appendix 4 and full performance equations can be found in Appendix 5.

2.2.2 The Controlled Cook Test

The Controlled Cook Test (CCT) assesses the stove performance according to local conditions by measuring both the mass of food and fuel used, as well as the time taken, to cook a typical meal. The test gives a more realistic idea of performance than the WBT, but still with control over the variables, and returns the SFC in grams of fuel used per kg of food cooked. The meal chosen was typical for a poor urban family in the test area and included nsima (maize porridge), dry fish, rape (a green leaf vegetable), a tomato and onion sauce and was over 5kg in weight, enough to feed 5 adult men. At no point in the test were any of the stoves reduced from maximum power, in line with local practice for that specific meal. The test duration included the time spent starting and refuelling the stoves. Unfortunately due to the failure of the SBS used in the CCT another stove of 'average' fuel consumption was selected for testing and the experiment repeated three times for each stove. Further details of the CCT can be found in Appendix 6.

[2] Help during testing was provided by a local energy expert (Magi Matinga), an enumerator and the staff at Bluwave Ltd. The testing was conducted in August 2005, between cold and rainy seasons, when the exchange rate was 223MK/GBP, 124 MK/USD and 153MK/Euro.

2.2.3 *The Kitchen Performance Test*

In reality, a stove will not perform as it does under laboratory conditions due to many factors such as user habits, cooking practice etc. and this leads to a requirement for a field test, called the Kitchen Performance Test (KPT). The method used was a paired study sample, a two phase test where individual households first took part in a baseline fuel use survey to assess existing fuel consumption patterns and users' views of their current stoves. Then a second phase was conducted, similar to the first, but with each household being provided with a SuperBlu Stove and ethanol fuel. In this way the impact of any user specific factors was minimised as they would be present in both parts of the test. In line with other stove surveys, household numbers were measured in terms of standard adult equivalents (SA) with a man of age 15-59 years having a weighting of 1, a woman over 15 or a man over 59 a factor of 0.8 and children under 14 a weighting of 0.5. Fuelwood was converted to equivalent charcoal units by means of typical fuel heating values and stove efficiencies. To ensure a reliable comparison between data sets the following filtering was undertaken:

- Bad data was screened out (i.e. same daily data)
- In the baseline survey charcoal had to be used in any given day
- In the SuperBlu survey only ethanol could be used in any given day
- In each test phase the difference between average SA for each household could be no more than 1 to ensure similar cooking conditions
- A household's results were used only if there was valid data for 3 or more days in both test phases

The KPT measures the specific household fuel consumption (SHFC) and gives the mass of fuel used per standard adult per day. To give a direct comparison of ethanol to charcoal usage the fuel consumption ratio (FCR) was used, a ratio of the SBS to ICS SHFC. The baseline fuel survey and further field test details can be found in Appendix 8 and 7.

The field test was conducted in the Chemussa area of Mbayani, a township of some 43,000 people on the edge of Blantyre City. With help from some local woman who regularly assist the chief, a total of twenty households were selected in two areas by systematically identifying every fourth house. Households were first briefed on the project and made fully aware of the format, commitments, safety and privacy issues before being asked to sign a consent form. An initial meeting was held where stove operation was explained and people were given a chance to use the unit. Then for one week each household was given a daily sheet on which to record fuel use and expenditure, cooking times etc. For logistical and financial reasons households were not supplied with free and pre measured fuel but instead were given a plastic pot to act as a standard measure for charcoal and also asked to record the number of bundles of wood they used. The enumerator visited each household every few days to check for any problems, collect data sheets and also to ask a series of qualitative and quantitative questions to gauge users opinions and habits. Another meeting was then held where participants collectively cooked a meal on some SuperBlu Stoves and were then issued with their own units and fuel. They were also given a bucket and cloth to act as a safety backup. It was planned that for a second week households would get accustomed to using the stove and in a third and final week would then reproduce the baseline survey but with household fuel usage and views on the ethanol stove being recorded. However, due to stove manufacturing problems the KPT was delayed and consequently the SBS trial week and the training time were reduced. Each bottle of fuel contained 250 ml of ethanol and users were also given bottles marked in 45ml gradients for use when starting the stove. The enumerator again visited households on a regular basis to check on safety and gather data. At the end of the field test a series of workshops were held where users gave their more general views and key or unexpected data was checked. At all times communication was in Chichewa, the main language in Malawi, and no payments were made as part of this research with users receiving only free ethanol fuel for one week.

2.2.4 *Other Tests, Statistics and Error*

Before any other tests, each SBS underwent a basic safety test which involved visual inspection, temperature measurement and both normal and abnormal operation. One stove underwent a more in depth safety test, based around a South African test procedure [26] with modifications to allow for available resource and the differing design of the SBS (Appendix 9). To ensure safety with continued use one stove was run for over 100 hours. Fuel samples from each of the three stoves were tested and lower heating values (LHV) were used in all performance analysis (Appendix 3). Of all the tests conducted, the laboratory based assessments will give more repeatable results as variables and measurement can be controlled. For each test variable the ratio of its mean to standard deviation (SD) was used to give a coefficient of variation (CoV), a normalised measure of variability. Other stove research has returned CoV's of 5-10% for the laboratory based CCT and WBT [21, 27] and over 40% for the KPT [27, 28], where error will also be larger due to the requirement for users to measure and record fuel use. In order to assess the statistical significance between results the student t-test was used with a 95% confidence limit. In the WBT and CCT, error was limited to the electronic scales, which measured to the nearest 5 grams, and to the digital thermometer, where error was approximately 3% of the reading. The lack of calibration was not an issue as the tests were identical, repeated and the results used for comparative purposes only.

3. ANALYSIS AND DISCUSSION

3.1 Appropriate

3.1.1 Safety

The ICS proved stable under rough use but the high temperatures to which the user was exposed presented a risk. The ceramic liner reached temperatures in excess of 300°C, the charcoal fuel well above even this, and once cooking was finished both retained heat for a relatively long period. The fuel was stable unless it was of poor quality, which tended to fracture and spit. The stove's portability allowed for its use in outside semi-sheltered areas so reducing the effects of emissions on the survey households. The SBS was stable up to a tilt angle of 60 degrees, proved very stable under rough use, showed no sign of wear or damage after 100 hours of operation and was difficult to test to destruction. However, on impact the stove flame would flare for around five seconds before returning to normal. On being inverted the stove would behave in a similar manner but would also spill the moderate amount of fuel contained within the burner cup. Any spilled ethanol would evaporate or if alight would burn in a stable manner, with the fuels miscibility with water enabling easy extinguishing. However, its low viscosity and surface tension presented a larger hazard as it allowed the fuel to flow freely or 'splatter'. Of note is the experience in Brazil where liquid ethanol is a major cause of domestic burns [29]. The dangers posed by accidental consumption are reduced but not negated by the addition of denaturing and colouring agents. The SBS body achieved a maximum temperature of 70°C and the nozzle reached 300°C, retaining heat for about ten minutes after use although it was largely protected by the stove stand and plate ring. During the field test several users had to stop their stoves as they were not operating safely and upon examination had suffered soldering failures around the cup/tank join (Appendix 9). Other safety defects included size mismatches between components and blocked fuel pipes. This led to around half of the 29 manufactured stoves being failed during the safety test and then either repaired or scrapped. None of the users or their families hurt themselves on the stove and only two households spilt any fuel, both instances posing no danger. This report does not address the health impacts of either stove but it was the authors' opinion that the SBS emitted considerably less smoke than the ICS, however users complained of an ethanol smell, eye irritation and soot which were also observed during laboratory testing. Overall, the SBS showed some good safety features but the fuel flaring behaviour and the low viscosity of ethanol reduced the stoves safety to less than the ICS, scoring 1.

3.1.2 Usability

The baseline fuel use survey underlined the importance of charcoal as the main cooking fuel in all field test households (Appendix 8). The three most common stove tasks by incidence were cooking nsima, making tea and heating water, all of which required high power. Only approximately 20% of cooking tasks required low power (i.e. cooking beans or rice). Prior to receiving the SBS users were asked their views on the ICS and the responses are listed in Table 2. Whilst the ICS does offer some advantages, such as a low fuel consumption and relative ease of use, problems still exist with the stoves operational flexibility and emissions. When asked how they simmered rice 55% of users said they removed some charcoal from the stove and the rest raised the pot higher or put water on the charcoal.

Table 2. Users' views on the Improved Charcoal Stove

Like	Dislike
Easy to start	Takes time to start
Easy to tend	Problem regulating heat
Low fuel consumption	Waste charcoal if cook for short time
Lower soot levels	Soot on pot
Fast/more heat	Burns for a long time
Retains heat for cooking	Smoke, has to be used outside
Use as heater	Fuel quality
	Ceramic gets damaged

Some replies given in comparison to traditional stoves

When given the SBS, two users had problems learning to use the stove but, due to manufacturing problems, only 65% of the stoves started working first time. Half the users experienced problems at low power and one quarter of users could not stop the stove easily. Users likes and dislikes are listed in Fig. 1 and the main issues were around starting, fuel consumption and stove emissions. More specifically a limited number of users said the stove was not good because; the simmer power was too high to steam rice or deep fry, fuel consumption was not good enough to simmer beans and they were unable to bake (a task difficult in the ICS). When asked what would make them buy the stove the four most popular replies were portability, the ability to cook indoors, time saving and ease of use. Aside from starting, simmer power and emissions problems an overall positive response from users means that the SBS scores better than the ICS, a 3.

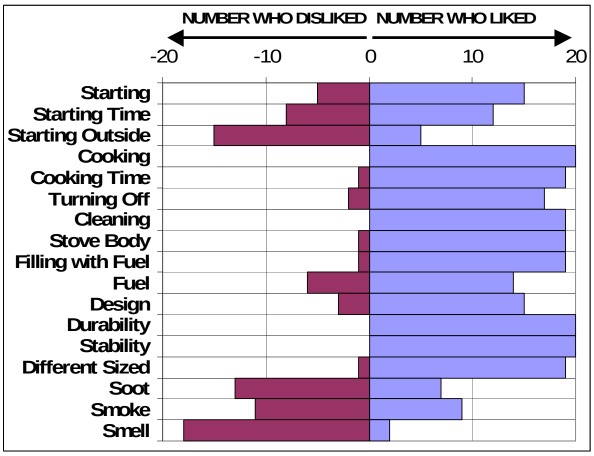

Figure 1. SuperBlu Stove – Users' Likes and Dislikes

3.1.3 Performance

From a hot start the ICS gave a firepower of 2.5kW and a thermal efficiency of 23%, boiling 2 litres of water in 18 minutes with the lid on (Table 3). Although these results were generally in line with other surveys the efficiency was at the lower end of stated values [10, 30] with the difference likely to be due to differing test conditions or ICS quality. From cold the stove took 15 minutes to reach full power, as the charcoal needed time to reach combustion temperature and the ceramic liner absorbed heat. This stored heat lead to difficulties when simmering, which was made worse by the poor fit of the stove door. At low power the ICS gave an efficiency of 41% and a firepower of 1kW, too high for a controlled simmer and hence the user adaptation when simmering rice (Section 3.1.2).

Table 3. Water Boiling and Controlled Cook Tests

WATER BOILING TEST		ICS		SBS		Significant Difference
2L of water in 3.3L pot		Mean	CoV	Mean	CoV	@ 95%
COLD START						
(including starting period), Lid on						
Thermal Efficiency	LHV	15%	4%	40%	5%	yes
Duration of Phase	minutes	32.8	8%	33.4	12%	no
Temp corrected SF	g/kg Water	83	5%	36.2	5%	-
Power	kW	2.1	11%	0.8	12%	yes
HOT START						
(excluding starting period), Lid on						
Thermal Efficiency	LHV	23%	7%	43%	8%	yes
Duration of Phase	minutes	17.8	7%	16.1	7%	no
Temp corrected SF	g/kg Water	57	6%	34.0	9%	-
Power	kW	2.5	2%	1.4	2%	yes
SIMMER						
45 Minutes, Lid off						
Thermal Efficiency	LHV	41%	10%	32%	3%	yes
SFC	g/kg Water	66	6%	95.3	5%	-
Power	kW	1.0	3%	1.2	4%	yes
Cold/Hot Significant Difference@95%						
Thermal Efficiency		yes		no		
Duration of Phase		yes		yes		
Temp corrected SFC		yes		no		
Power		yes		yes		
Hot/Simmer Significant Diff@95%						
Power		yes		yes		

CONTROLLED COOK TEST		ICS		Simmer		Significant Difference
5.25kg Cooked Food		Mean	CoV	Mean	CoV	@ 95%
Duration	minutes	123.7	5%	107.3	3%	yes
SFC	g/kg food cooked	93.0	5%	54.1	1%	-

All tests were conducted at an altitude of 1064m. Ambient air temperatures were typically 30ºC. The charcoal fuel used had an average LHV of 26.7 MJ/Kg and the SBS fuel 23.2 MJ/kg.

From a hot start the SBS gave a thermal efficiency of 43%, similar to the 40% of the gel fuel stove, which also burns ethanol vapour (Appendix 10). The stove firepower was 1.4kW and the test duration was statistically inseparable from that of the ICS. So in this test both stoves were of a similar 'output' power to the pot, around 600W. The higher thermal efficiency of the SBS is partly due to the more efficient combustion of ethanol vapour, when compared to solid charcoal, and in the CCT it consumed half the energy of the ICS. From cold the SBS took the same time to boil as the ICS but in the CCT its duration was 13% less, showing the stoves marginally better starting and refuelling characteristics. Little fuel was used during starting, as indicated by the efficiency and SFC showing a minimal change between hot and cold tests (Table 3, Fig. 2). This is due to the starting process being governed by the heat transfer rate from the nozzle to the burner cup, with fuel consumption gradually increasing due to a rising stove temperature, which in turn increases the vaporisation rate and hence the power output. However, the stove experienced a long starting period due to badly fitting components causing a lack of thermal contact inside the stove and, when used outside, this problem was compounded by the convection of heat away from the nozzle.

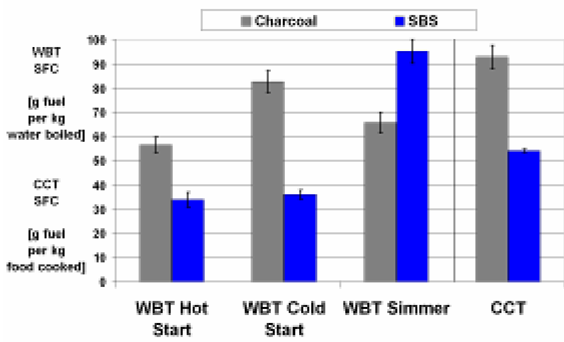

Figure 2. Specific Fuel Consumption Results

Once operational it is thought that design and manufacturing errors resulted to an incorrect air/fuel mixture, and subsequent incomplete combustion, which increased the SFC and led to the emission of both ethanol vapour and increased levels of particulates. The SBS gave a minimum firepower of 1.2kW, too high for some users who complained that it made certain cooking tasks unachievable. Unlike the ICS the thermal efficiency at simmer was lower than at full power and the SFC much higher, with this unusual behaviour better illustrated in Fig. 2. Given that minimum power is only 85% of maximum it is apparent that the ethanol vaporisation rate at simmer is too high and the air-fuel ratio probably incorrect. In the SBS duration test it was found that the running time on one tank of fuel reduced by 10-15% in the first 30 hours of operation. It is thought that this change was due to stove components, made from different metals, undergoing thermal cycling and so loosening a critical joint between the capillary feed pipes and the flash plate.

As in other surveys the CoV recorded in the laboratory tests were mostly within 5-10% [21, 27] but both the variable energy in charcoal, the inaccurate scales as well as the SBS starting issues caused some values in excess of 10% (Table 3). At an altitude of 1064m the local water boiling temperature was recorded at 96.5 °C. When compared to testing at sea level this will cause a minimal change in the WBT thermal efficiency but there will be a larger effect on the CCT results, due to the need to cook food for longer at the lower temperature. However as the tests in this report are comparative altitude will have had no effect.

In the KPT half the households produced valid data, once filtered, and this is shown in Fig 3. with each point representing one household's average specific fuel consumption, with +/- one SD, from both parts of the field test. Of the ten households three suffered from stove performance problems due to the progressive failure of the solder around the burner cup (Appendix 9). The corresponding data sets all returned a notably higher ethanol fuel consumption and so were omitted from further analysis. The remaining seven data points gave an average FCR of 0.54 with a SD of 0.17, or 1kg of charcoal equating to 0.54 Litres of ethanol.

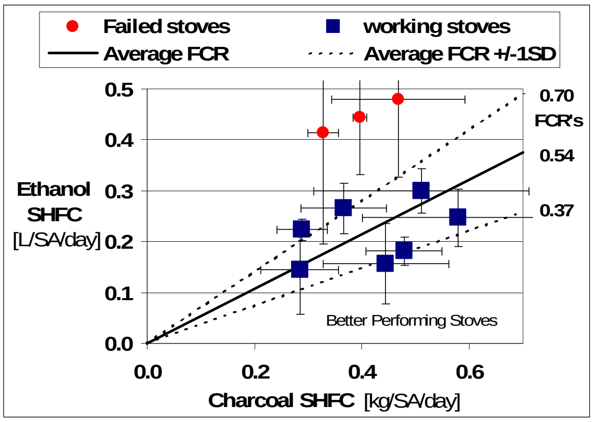

Figure 3. KPT Household Fuel Consumption Ratios

The laboratory based assessments both returned FCRs either above or equal to the KPT average, with the cold WBT giving a value of 0.54 and both the hot WBT and CCT a value of just over 0.70 (Fig. 2). Whilst there are many reasons for these differences it is thought that the main factors are: user behaviour, SBS time-performance drop, ICS efficiency and use, charcoal measurement and differing test conditions. A more detailed explanation is given in Appendix 7. Whilst the KPT's 'real life' conditions did lead to a larger variance than the laboratory tests the CoV for both the charcoal and ethanol data sets was 27%, less than in other surveys [27, 28]. It is hoped that by filtering each household's data the results were standardised and by using the paired study sample a fair comparison has been made that also minimised variance. As the above factors would have resulted in both an increased and decreased FCR the overall effect can be assumed to be minimal. Therefore it is valid to assume that the differing SBS performance is the main cause of variance in the KPT data, especially given the higher FCR of the failed stoves. So the lower SD line in Fig. 3, with an FCR of 0.37, reflects the performance given by the more efficient SBSs. Whilst the ICS took time to start, once operational gave an adequate performance but proved difficult when trying to maintain low power. The SBS gave a similar performance with stove design and manufacturing problems leading to a high fuel consumption during simmer. Overall the SBS scores a 2 as the performance of the two stoves was similar.

3.1.4 Future Development

One of the main safety problems with the SBS was its flaring behaviour on impact or inversion. The stove design intended for a minimal amount of fuel in the burner cup but manufacturing defects caused too high a level and subsequent excess flaring. Any increased flow of fuel into the burner cup could be controlled by a throttle in the form of a contraction in the fuel feed tube. Another more expensive option would be a replaceable fuel valve which could not only close the fuel feed on inversion but could also allow the user to manually seal the stove to allow for safer transport and storage. As with the GFS the addition of gelling agents would greatly enhance safety (Appendix 10) with even a moderate viscosity reducing the impact of a fuel spill. However the effect this would have on the stoves ability to transfer and then vaporise the fuel in the burner cup is unknown and requires further research, as does the impact on both fuel production and stove operating costs. One solution to this problem may be the addition of a temperature dependant thickening agent.

Although the stove nozzle is largely protected by the stand, windshield and plate ring the addition of a slide-back cover would minimise the risk of burns soon after operation. In addition a redesigned plate ring with a reduced surface area would minimise the contact area for burns. The safe fuelling of the stove poses more of a problem as the requirement to restart the stove mid operation leads to the addition of fuel to a hot nozzle and possible instant ignition. A more viscous fuel might also prevent the unstable combustion of the ethanol in the nozzle. The ability to start with both matches and starter stick should be retained and the overall ease of operation should be made as near as possible to that of the GFS. The lack of thermal contact within the stove assembly led to starting problems, in terms of time taken and outdoor use, so this area needs attention. The casting of the breather tubes, flash plate and element as one unit would stop the performance drop caused by thermal cycling and would also guarantee a better heat transfer. With a larger single screw thread in the bottom of the burner cup the entire assembly could be easily assembled and also removed for cleaning. The problems experienced with blocked fuel pipes could be overcome by a better quality chemical coating on the inside of the fuel tank. The stove could also be made less susceptible to blockages if the fuel feed and exhaust pipes could be made into broader horizontal slits, integral to the burner cup wall. This would also ensure that a minimal amount of fuel was present in the burner cup at any one time so reducing the flaring problems. The addition of a secondary fuel exhaust pipe higher up the burner cup wall would offer a safety backup in case of blockage. Other areas that may require attention are; the interaction between the flame and the pot ring, more definite control levels between simmer and full power and the jamming of the regulators during operation.

It is thought that the emissions from the stove were due partly to manufacturing errors but also due to a miss-match in the stove air-fuel ratio at maximum power. An area of concern is the health effects of the possible by-products of both incomplete combustion (formaldehyde) and also the de-hydrogenation of ethanol (acetaldehyde, ethyl acetate, butanol and acetic acid) and so this requires a more detailed analysis, as does the combustion efficiency across the operational range and especially at simmer. The high fuel consumption at a low power setting could be overcome by controlling the cross sectional area of the capillary feed tubes, in a similar proportion to the air regulator, so as to maintain the ideal combustion ratio. A bigger fuel tank combined with a better fuel consumption should address most of the users concerns on the issue. Users found the SBS power output adequate and any increase in power will have resulting fuel consumption and cost implications but would offer a quicker cooking time, a tangible benefit to users. One feature that should not be lost in any future development is the portability of the stove as it represents a real benefit over the ICS. So with future development it should be possible to improve the safety of the stove to a level where it is better than the ICS. Similarly the usability and performance can each be made a step better so making the SBS appropriate for use.

3.2 Affordable

3.2.1 Operating Costs

The mean charcoal price recorded by users was 27MK/kg and the authors' observation was 20-30MK/kg depending on location and quality. If the average FCR of 0.54 L/Kg is assumed, then the ethanol fuel would only be competitive with charcoal if it could be produced for 50MK/L (Fig. 4). However if the relationship shown by a better performing SBS is assumed, the upper SD line, then the ethanol fuel would be competitive at 73MK/L at the average charcoal price and 80MK/L at the higher 30MK/kg charcoal value.

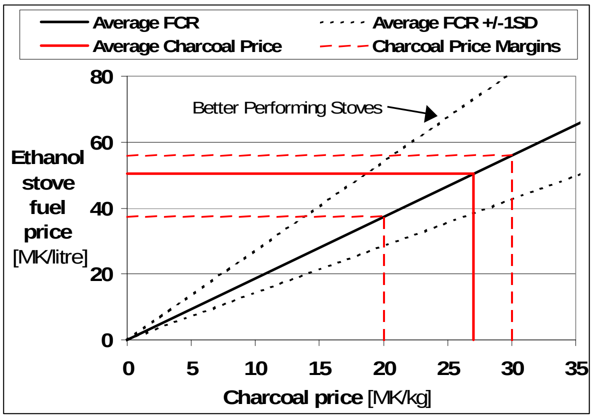

Fig. 4. Competitive Stove Fuel Price

Estimated fuel production costs are listed in Table 4 and are based on the Malawian ethanol market in 2005 and the experience of a gel fuel manufacturer (Box 1). With various market barriers keeping the pre tax price of ethanol high at 57MK/L (Box 2), and estimated processing costs likely to double this to 119MK/L, it is apparent that any ethanol fuel scheme cannot compete with charcoal. However, if these issues could be overcome then the SBS fuel could be produced at 79MK/L, in line with the 60-100MK/L that field test participants were willing to pay.

Table 4. SuperBlu Stove Fuel Price

All Prices in MK/L	GFS 2005	SBS 2005	SBS FUTURE
Ethanol Production			
Production Cost	23	23	18
Operating Cost	6	6	6
Net Margin	28	28	6
Ethanol Price (pre tax)	**57**	**57**	**30**
Stove Fuel Production			
Ethanol	48	57	30
Processing Cost	23	15	11
Operating Cost	23	23	17
Distribution Cost	12	12	9
Net Margin	12	12	12
Retail Price (pre tax)	**117**	**119**	**79**

2005 Ethanol Production: Production cost is taken from Liwimbi [18] and is in line with current world prices [16, 31]. Final ethanol price is from Liwimbi and Wynne-Jones [17]. GFS 2005: Data is from both Wynne-Jones and the authors' inference. The reduction in ethanol price is due to 1L of ethanol making 1.2L of gel fuel. Processing and operating margins set at 20% of retail price. Distribution margin and Net margin set at 10% of retail price. Overall retail to ethanol price ratio of 2 is as in Utria [16]. SBS 2005: Processing cost is 2/3 of GFS 2005 due to a simpler process. Future Ethanol Production: Production cost is 20% lower then 2005 due to industry improvements. Ethanol producers net margin set at 20% of ethanol price. SBS Future: Processing, operating and distribution margins reduced by 25% from 2005 levels due to new, larger processing facilities with a larger capacity.

With a future urban charcoal price likely to be in excess of 27MK/kg, due to limited availability and increased transportation costs [32], then the SBS would become competitive. In addition, if the development of the SBS could lead to an 8% reduction in SFC, then fuel savings of 10% over the ICS would be possible. However, it is not known if this margin would be enough to persuade users to switch stoves and greater savings seem unlikely given the previous assumptions. Although direct subsidies are generally not recommended for a stove programme [11], the current market position may necessitate the addition of a small tax on the ethanol used for domestic petrol blending to offset losses from ethanol for household use. Depending on the relative volumes this could have the effect of reducing the price of household fuel ethanol whilst still maintaining the export price and total sales revenue. Overall the SBS was rated the same as the ICS on operating costs, a 2.

3.2.2 Initial Investment

Whilst the promise of fuel savings will be a strong motivator for the adoption of a new stove, the initial cost will also play a part. The ICSs used in the field test households varied in price but the average was 150MK, although when compared to an average monthly fuel expenditure of around 400MK/SA the stove price becomes less critical. Another influencing factor is a household's ability and willingness to purchase higher value goods, an indicator reflected in 50% of households using batteries (Appendix 8). Few families stated their monthly income but those that did indicated 3000-4000MK, showing that cooking fuel is a significant part of total expenditure. The SBS is at a prototype stage and as such it is difficult to assess the final unit cost. Bluwave Ltd is aiming for USD10, or 1250MK, correlating with the views of stove users where a figure of around MK1000 was suggested. So in any direct comparison of initial investment levels the SBS will be worse than the ICS, scoring 1.

3.2.3 Lifecycle Costs

Users reported that the body of the improved charcoal stove tended to last for one year, due to the metal used being recycled and low grade. The ceramic liner/grate lasted for 6 months although this varied depending on quality and usage. The lifespan of the SBS has assumed to be 5 years and over this period the total expenditure on the two stoves is comparable (Table 5). As both the initial and operating costs are higher for the SBS it offers no lifecycle savings under the current market conditions. If the 10% fuel savings stated in section 3.2.1 can be brought about, then these will payback the cost of the SBS in 7-8 months. If the stove producer were to act as an energy service company (ESCO) and sell both stove and fuel as a 'package' then there is the potential to cross subsidise the stove by adding a small margin on the fuel price. As the stove costs were similar, the fuel savings marginal and the payback period relatively long the SBS is rated as similar to the ICS on lifecycle costs, scoring a 2.

Table 5. Stove costs over 5 years

	ICS stove/liner	**SBS**
Price [MK]	150/80	1250
Life span [Yrs]	1/0.5	5
5 Yr Cost [MK]	1150	1250

Prices taken from Wynne-Jones and McFadden [17, 33]

3.3 Accessible

3.3.1 Fuel Supply Chain

So as to cause no actual or perceived inconvenience to users, any ethanol supply network would have to reproduce the existing charcoal structure shown in the baseline fuel survey (Appendix 8). The SBS fuel would have to be made available in smaller quantities via door-to-door sellers or in larger quantities in markets or shops, an achievable task with a moderate impact on cost. When asked about purchasing ethanol most users indicated that they would like to buy in varying quantities of 1 to 5 litres from a local shop/market or a petrol station. The safety and quality implications of the handling and storage of relatively larges amount of ethanol by traders will need to be carefully considered, although many currently trade paraffin without any significant reported accident levels. Any problems with the dilution of fuel with water could be overcome with a tamper proof seal. As charcoal is made in rural areas away from the city it suffers from fluctuating transportation costs and supply problems in the rainy season. So an ethanol supply chain with year wide, stable prices would be an attraction to users. The SBS fuel processing facilities could be located near to the existing fuel blending depots to minimise transportation costs.

To cook food for the average family size of 4.5SA (Appendix 8) an improved SBS would have an ethanol consumption of around 4.4 L/week or 230L/year. With current annual sugarcane ethanol production at around 20 million litres (Box 1), of which 5 million litres is used for fuel blending and an assumed 20% going for export, there is sufficient capacity for 48,000 stoves. Whilst this quantity would represent a breakthrough in household energy it would still only meet a fraction of the country's urban energy needs. If a step change in production occurs (Box 2) and exports are stopped then there is capacity for over 110,000 stoves, but this seems unlikely for economic reasons. Although it would be possible to set up the supply network, given the requirement for alternative feedstocks and the likely limit of the current market on available volumes, it is marginal as to whether the fuel supply chain can be set up, so scoring 2.

3.3.2 Stove Supply Chain

In Mbayani the ICS was sold in local markets and had been made by artisans in the surrounding districts of Blantyre. This meant that quality varied but prices were kept low, aided by the use of recycled metal and local clay. The SBS would need to be sold from similar locations as well as from shops and supermarkets. As the performance of the SBS relies on some close tolerances between components the design and manufacture will have to balance performance with the cost of production and materials. This will necessitate mass production and at present Malawi does not appear to have this capacity, so initially stove manufacture will need to be outside the country, in a region where manufacturing costs are low to keep the stove affordable. This also correlates with the findings of a review of stove programmes where projects involving the mass production of stoves, or stove parts, seemed to be more successful [11]. As the stove will have to be imported costs could also be reduced by an exemption from import/export duties but the price will still be susceptible to changes in currency rates. Overall, it is likely that the stove can be made accessible to customers and so the score is 3.

Box 2: Changes to the Ethanol Market in Malawi

A reduced ethanol price and a larger production volume are key to the future success of the SBS. Lower operating costs can be achieved through the better integration of sugar and ethanol processing facilities, as well as the modernisation of the Dwangwa plant. Processing costs would be reduced by extra hydrous ethanol plant [18, 20] as a higher alcohol content is not required for the SBS fuel. Production efficiencies and volumes could be increased with greater on site storage, to better cope with the fluctuations in supply and demand [20]. Currently energy costs are high, due to the use of imported coal, with alternatives limited by the country's weak electricity grid and the use of most bagasse to power sugar processing, although efficiency improvements here would have obvious benefits. One interesting solution is the Bluwave boiler, a scaling up of the technology to an industrial application, with the potential to 'self power' ethanol production. The seasonal nature of sugarcane production means that the ethanol plants are dormant for over 4 months a year and the development of alternative feedstocks would increase both production volumes and efficiencies [20] as well as stabilise prices. Sweet Sorghum, a cereal, is one potential feedstock as it is well suited to the local conditions and can also be grown out of the sugarcane season [34, 35]. It also has the added advantage that whilst the stalks can be used for ethanol production the grain can be used as food, in what is a food insecure country. Other potential feedstocks include Cassava, a starch rich tuber, and Calatropis, a latex producing invader species. Another option is to produce ethanol from higher grade molasses, which would otherwise be used for sugar production, resulting in a step change in output [36, 37]. A flexible production strategy, where sugar/ethanol production and the petrol blending ratio are altered to suit market conditions would optimise the countries resources [36, 38]. This report has not included the possibility of expanding the area of land under sugarcane cultivation as the issues are complex with many environmental, financial and social constraints.

As the Government is a key stakeholder in both sugar and ethanol production, any changes to the market will require it's close involvement. Some positive actions would be to decouple the price of household ethanol from petrol and to open up the industry to more competition, including imports. All revenue raising activities should be removed from household ethanol until the industry has had time to mature. However, any changes to the current market will need to be carefully assessed as it plays an important role in the Malawian economy [1], with a rising worldwide ethanol demand making exports increasingly attractive. When this is combined with the difficulty Malawi faces with petrol imports, as well as the limited availability of capital in the country, the steps required to promote ethanol as a household fuel will be a difficult but not unachievable task.

4. CONCLUSIONS

4.1 Is the prototype SBS appropriate for use?

Potentially; compared to the ICS it was worse on safety, better on usability and the performance was similar. The SBS suffered from manufacturing problems and more work is required on fuel safety, stove flaring and emissions as well as performance at start and simmer.

	Worse	Similar	Better
Safety	**1**	2	3
Usability	1	2	**3**
Performance	1	**2**	3
Appropriate	1	**2**	3

4.2 Can the SBS be made more appropriate?

Yes; with some seemingly achievable improvements it can be made better than the ICS in the areas of safety, performance and usability. A redesign and better manufacturing would solve most current problems but a moderate increase to the fuel viscosity (gelling) is needed to achieve a better safety level.

	Worse	Similar	Better
Safety	1	2	**3**
Usability	1	2	**3**
Performance	1	2	**3**
Appropriate	1	2	**3**

4.3 Can the SBS be made affordable?

Potentially; the stove operating costs can be made similar, even marginally better, but the initial investment will always be higher. Consequently the lifecycle costs are similar. With the existing high ethanol price the fuel would be too expensive and some marked changes to the current market will be needed to make the stove affordable.

	Worse	Similar	Better
Operating Costs	1	**2**	3
Initial Investment	**1**	2	3
Lifecycle Costs	1	**2**	3
Affordable	1	**2**	3

4.4 Can the SBS be made accessible?

Yes/Potentially; it is likely that the stove can be manufactured and supplied to users but marginal as to whether the fuel supply chain can be established given the requirement for alternative feedstocks and the likely market limitation on available volumes.

	Unlikely	Marginal	Likely
Fuel Supply Chain	1	**2**	3
Stove Supply Chain	1	2	**3**
Accessible	1	**2**	**3**

5. RECOMMENDATIONS

The SBS requires further development and technical recommendations are given in Section 3.1.4. The most critical areas are the improvement of fuel safety and a better performance at full power, as well as simmer, to reduce both running costs and emissions. The SBS heater attachment should also be developed further. It is vital that research is undertaken to assess stove emissions, including the products of both the incomplete combustion and the dehydrogenation of ethanol, The development of the SBS has already cost Bluwave Ltd a considerable amount of money, so any future development work will need to be done in conjunction with an external 'smart' subsidy (e.g. World Bank, Shell Foundation).

As with Project Gaia and the Gel Fuel Stove, it is both government and industry support that is vital to the development of the fuel supply chain. Capital investment, tax breaks and the restructuring of the market are all needed to lower prices and increase available volumes of fuel ethanol. Alternative feedstocks will need to be developed to give year-round availability, increased volumes and stable prices. It is highly likely that, in addition to setting up a fuel processing plant, Bluwave Ltd will have to produce a proportion of the required ethanol themselves. This will all require considerable investment, potentially from sources such as Global Environment Facility or the Clean Development Mechanism. However, to apply for this funding a full analysis of GHG flows through both ethanol production and end use in Malawi will be required. Further economic analysis is required of the benefits of the scheme, including the economic savings from a reduced exposure to stove emissions. Once operational, the stove programme should be self-sustaining without excessive Government support [11].

Once the SBS has been developed to a level where its performance and reliability are no longer an issue a fuller pilot study should be carried out. Here it will be possible to assess the performance of the stove over a longer period with the ability to consider different market groups as well as the price elasticity of the stove and fuel. Whilst the various tests conducted did produce valid results, improvements can be made: recording power and efficiency throughout the WBT to give a truer picture of stove performance (requires heat resistant scales); operating the stoves for some time before testing to allow for any changes with use, conducting the CCT under the same conditions as actual stove use (outside in the case of this study); and asking field test users to record any charcoal left after cooking.

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APPENDIX 1: A MAP OF MALAWI

APPENDIX 2: THE STOVES UNDER TEST

Bluwave SuperBlu Stove (SBS) (A modified version of the stove manufacturers technical specification)

The SuperBlu Stove has been specially developed to burn ethanol in an economic and safe way. The stove first heats the ethanol to above its boiling point of 78ºC at which point the fuel vaporises. It is then passed over a copper catalyst at a temperature of 400ºC where the process of hydrogenation takes place and the ethanol reacts to form acetaldehyde and hydrogen gas. It is claimed that this process provides an enhanced combustion and lower emissions compared to other ethanol stoves.

The stove is started by pouring a small quantity of ethanol into the nozzle preheat reservoir and igniting it with either matches or the supplied piezo-electric starter stick. The combusting fuel draws air from under the flash plate causing a partial vacuum in the bottom of the burner cup and also in the fuel tank. This then causes fuel to be sucked, via the fuel feed pipe, from the tank into the burner cup where it is heated by the nozzle element. Once above 78ºC the fuel vaporises and gaseous ethanol rises up the capillary feed pipes towards the nozzle. The pilot tube ensures ignition and the burning ethanol, in the form of a low blue flame, heats the nozzle to approximately 400ºC at which point the stove becomes operational. The entire starting process takes under 5 minutes but is dependant on fuel levels in the tank.

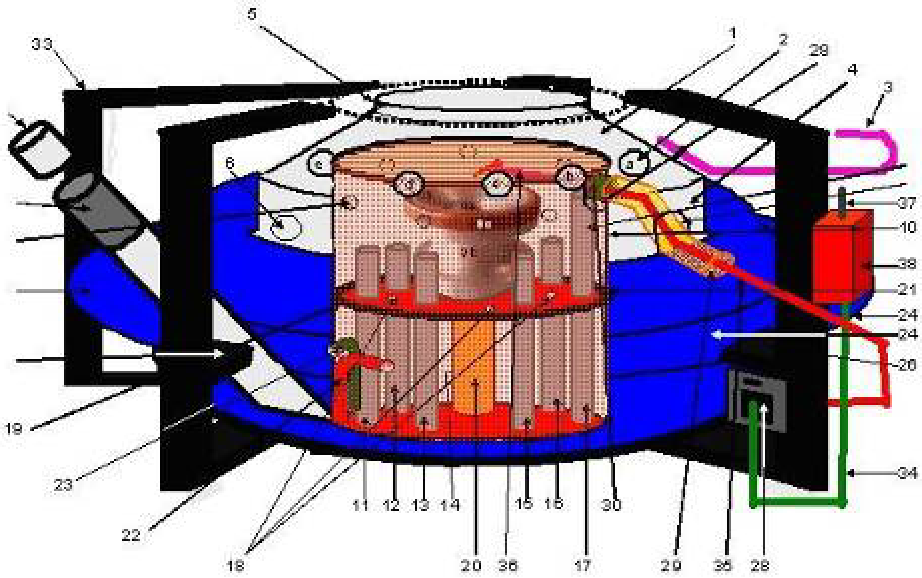
Once operational the ethanol gas passes around the nozzle tunnel, becomes superheated and undergoes hydrogenation. This process causes the developed blue flame to have a yellow outer section making it more visible to the user. The fuel feed and outlet pipes ensure that there is only a minimal level of fuel in the burner cup ensuring a controlled combustion and a high degree of safety if the stove is turned over. When operational the tank is kept under vacuum, enabling the fuel to be stored in liquid phase at high temperatures well above the ambient flashpoint temperature of 14ºC.

The stove is constructed of metal and has no consumable parts such as a wick. The manufacturer claims that an earlier, lower powered stove of slightly different design achieved a fuel consumption of 100ml/hr. Although not part of this research the stove can be turned into a heater with the addition of a ceramic cylinder on top of the pot ring. Global patents are in process for the Bluwave Technology.

The manufacturer can be contacted at:

Bluwave Limited, P.O. Box 80006, Maselema, Blantyre 8, Malawi, SE Africa.
Tel: 00 265 164 2287 / 2873
Fax: 00 265 164 2782
email: marko@bluwavemw.com

1	**Regulator**
3	**Regulator handle**
9	**Nozzle**
9a	**Preheat reservoir**
9b	**Vacuum tunnel**
9c	**Copper ring**
10	**Combustion cup**
11 to 16	**Capillary feed**
17	**Pilot pipe**
18	**Nozzle preheat holes**
20	**Element**
21	**Flash plate**
22	**Fuel inlet feed**
23	**Fuel outlet feed**
24	**Tank**
32	**Fuel tank inlet**
33	**Stove stand**



Manufacturers Schematic of the SuperBlu Stove

Note: This is an older model with a now defunct starting mechanism on the right hand side. Some items are not to scale.


Side View (regulator handle on left, windshield fitted)


Top View (fuel tank cap to the front, no windshield)


Stove ignition with a starter stick


Nozzle, Flash Plate and Capillary Feed Pipes


The SBS in use at the start of the field test


The SBS Flame

The Improved Ceramic Charcoal Stove (ICS)

The Improved Charcoal Stove (Malawi Ceramic Mbaula or Kenyan Ceramic Jiko) uses a clay grate/thermal liner to increase its efficiency over that of a basic charcoal stove. Its diameter is approximately 25 cm and weighs around 3.5kg. Charcoal is placed in the middle of the ceramic liner and lit with ignited paraffin, plastic or wood and the starting process takes around 10-15 minutes. Combustion air enters via an air door on the base of the stove. Local craftsmen make the stove out of recycled metals and local clay.


The Improved Charcoal Stove used for testing (air door open)


An ICS being started

D&S Gel Fuel Stove (GFS)

The Gel Fuel Stove is a simple can structure with a regulator that sits in a basic metal frame. Fuel is poured into the can though the middle of the regulator and lit with matches, quickly producing a developed blue flame of low carbon content. The stove is stopped by placing a lid over the regulator. The scheme is similar to several that have been developed in Southern Africa and D&S Gel Fuel Ltd are operating as a franchise of Greenheat South Africa who make Gelfuel for the commercial export market. D&S Gel Fuel Ltd can be contacted on gelfuel@africa-online.net or at P.O. Box 40530, Kanengo, Lilongwe 4, Malawi.


The Gel Fuel Stove and a bottle of Fuel


The GFS cooking Nsima

APPENDIX 3: THE FUELS UNDER TEST

To test for the energy in a fuel it can be combusted in a bomb calorimeter where the combustion products are then cooled back down to room temperature, with the energy used for cooling equating to the available energy in the fuel. When moisture free fuel undergoes complete combustion the hydrogen that was contained within the fuel reacts with oxygen to form water vapour that mixes in with the other combustion products. If the products are cooled and this water vapour is condensed to a liquid then the Higher Heating Value (HHV or the gross calorific value) is being measured. If the water is left in a gaseous phase then the Lower Heating Value is measured (LHV or net heating value). In a cook stove any water in the combustion products will escape as steam and will therefore not do any useful work, so to avoid calculating an efficiency that is too high the LHV is used. As the bomb calorimeter test returned a HHV the results will need some modification.

SBS Fuel

The fuel used in the SuperBlu stove is hydrous ethanol (96% ethanol, 4% water), which has a density of approximately 0.81 kg/L, together with denaturing agents and colouring. The average result from the bomb calorimeter was 25.9MJ/Kg, lower than the expected value of 27.7 MJ/Kg. Therefore the LHV was changed proportionately to give a value of 23.2 MJ/Kg

	HHV	**LHV**
100% Ethanol **(0.791 kg/L)**	23.4 MJ/L	21.2 MJ/L
	29.6 MJ/Kg	26.7 MJ/Kg
96% Ethanol **(0.810 kg/L)**	22.5 MJ/L	20.1 MJ/L
	27.7 MJ/Kg	24.8 MJ/Kg

Anhydrous ethanol (no water) has a melting point of –114.1ºC, a flash point of 14ºC (the minimum temperature at which there is a sufficient concentration of vapour to start a flame), a boiling point of 78.5ºC and an auto ignition temperature of 363ºC.

Charcoal Fuel

Charcoal is typically 80% fixed carbon and 20% volatiles, of which 3% is hydrogen. The energy from burning charcoal can be altered by the build up of ash and the removal of low energy volatiles after first ignition [21], so it is difficult to calculate the exact energy released from the fuel. The variable quality of the charcoal used during testing led to two samples of differing sizes being taken and they returned an HHV of 28.1 and 27.0 MJ/Kg for a large and small piece respectively (from approx. 20cm and 2cm diameter wood). The average value was 27.6 MJ/Kg and assuming 3% hydrogen and 10% moisture content an LHV of 26.7 MJ/Kg has been used in the performance calculations.

Gel Fuel

Gel Fuel is approximately 75% liquid ethanol mixed with water and thickening agents which give it a high viscosity, roughly equal to the consistency of mayonnaise, with a density of 0.71kg/L. Colouring and flavouring agents are added to improve safety. The test results gave an HHV of 19.6 MJ/kg and assuming the thickening agent used has the same hydrogen content as ethanol an LHV of 16.4 MJ/Kg was calculated.

The tests were conducted at the University of Loughborough Chemistry Laboratories and each fuel was tested three times.

APPENDIX 4: THE WATER BOILING TEST

Example Water Boiling Test Data Sheet

SBS	Test 1	
JR	05/11/2005	

Air temp (merc thermometer)	Start		29.0
	End		29.4
PHASE 1 - HIGH POWER (COLD START)			
Pot Empty	0.935		
Pot with 2L water	2.935		
Stove Empty	2.505	kg	
Stove with Fuel	2.740	kg	
Fuel in Stove	0.235	kg	
Starting Method	Lighter		
	Time	Temperature	
Stove Start	17:02		
Pot on Stove	17:03	26.6	
	17:07	shake	
	17:14	36.8	
	17:18	39.8	
	17:23	47.2	
	17:33	79.7	
Boiling	17:36	95.6	
Final stove mass	2.670	kg	
Final pan plus water mass	2.920	kg	

	Thermocouple	Alc Thermometer
Air temp		
Local boiling temperature	95.6	96.5
PHASE 2 - HIGH POWER (HOT START)		
Pot Empty	0.935	
Pot with 2L water	2.935	
Stove Empty	2.505	kg
Stove with Fuel	2.745	kg
Fuel in Stove	0.240	kg
Starting Method	already lit, wait to heat up	
	Time	Temperature
Pot on Stove	17:43	28.7
	17:48	49.6
Boiling	18:00	95.6
Final stove mass	2.680	kg
Final pan plus water mass	2.910	kg

	Thermocouple	Alc Thermometer
Air temp		
Local boiling temperature	95.6	96.5
PHASE 3 - LOW POWER (SIMMER)		
Pot Empty	0.935	
Pot with 2L water	2.940	
Stove Empty	2.505	kg
refuel Stove with Fuel	2.680	kg
Fuel in Stove	0.175	kg
Starting Method	already lit	
	Time	Temperature
Boiling	18:08	95.6
Boiling - stove mass	2.655	kg
Boiling - pan + water mass	2.865	kg
45 Minute Simmer End	18:53	92.5
Final stove mass	2.520	kg
Final pan plus water mass	2.440	kg

Water Boiling Test Set up

A piece of wood and some piping were used to hold the digital thermometer probe in place

Digital Thermometer

Top Tronic T500K
K type -50ºC to 1300ºC Chromel – Alumel
Accuracy (18-28ºC ambient) -50 to 1000ºC +/- 0.3% reading + 1ºC
Thermocouple K type probe accuracy 1.5% of reading

Electronic Scales

Avery Berkel DZ 342
Max 15kg, Min 0.1 kg
Temp range - 5 to 35ºC
Read to the nearest 5 grams

The Effects of a Pot Lid

To better reflect local conditions the WBT procedure was modified to include a pot lid in the high power phases. To check the effects of this change, and also to allow other interested parties to compare data, the experiment was repeated with the lid off. By removing the lid more heat escaped from the pot through the increased evaporation of water (6% of initial water rather than 1%) and the time taken to boil was therefore longer. Consequently the fuel consumed was greater and so the SFC increased near proportionally but with a slight reduction for the reduced volume of water at the end of the test. The presence of the lid made no statistically significant difference to the thermal efficiency as it is a measure of both the boiled and evaporated water. The firepower did change slightly but it is thought that this was due to error. With the lid on, the variance in the results increased but it is not known if this was due to an greater variance in evaporated water (due to the lid fit) or the larger impact of scale error when measuring the lower levels of evaporated water

Hot Start WBT (2 Litres of Water)		Lid on		Lid off		% diff mean	Sig@95%
		Mean	CoV	Mean	CoV		
Duration of phase	minutes	16.1	7.3%	23.9	0.6%	-48%	yes
Thermal Efficiency		43.0%	8.1%	43.2%	3.0%	0%	no
Temp corrected SFC	g fuel/kg Water	34.0	9.0%	48.2	4.8%	-42%	yes
Firepower	kW	1.4	2.2%	1.3	4.1%	7%	yes

APPENDIX 5: PERFORMANCE EQUATIONS

The equations below are adapted from the Bailis stove test procedure [23].

<u>Local Boiling Point Calculation</u> $\mathbf{T_b}$

Blantyre is at an altitude of 1064m and the local boiling point can be calculated by:

$$T_b = \left(100 - \frac{h}{300}\right)°C$$

$$= \left(100 - \frac{1064}{300}\right) = 96.5°C \qquad (1)$$

This result confirmed the findings of a test where a pot of water was brought to the boil and the maximum and minimum temperatures recorded were averaged and gave 96.5ºC.

<u>Thermal Efficiency</u> $\mathbf{h_c}$

This is a ratio of the work done by heating and evaporating water to the energy consumed by burning the fuel.

$$h_c = \frac{4.186 * (P_{ci} - P) * (T_{cf} - T_{ci}) + 2260 * (w_{cv})}{f_{cd} * LHV} \qquad (2)$$

In this calculation, the work done by heating and evaporating water is determined by adding two quantities:

- the product of the mass of water in the pot, (P_{ci} Initial pot and water weight, P Pot weight), the specific heat of water (4.186 J/gºC), and the change in water temperature (T_{cf} Final temperature, T_{ci} Start temperature)
- the product of the amount of water evaporated from the pot (w_{cv}) and the latent heat of evaporation of water (2260 J/g).

The denominator (bottom of the ratio) is determined by taking the product of fuel consumed during this phase of the test (f_{cd}) and the LHV.

<u>Specific Fuel Consumption (Temperature corrected)</u> $\mathbf{SC^T_c}$

Specific consumption can be defined for any number of cooking tasks and should be considered "the fuel required to produce a unit output" whether the output is boiled water or a meal. In the case of the WBT it is a measure of the amount of fuel required to produce one kilogram of boiling water (Note it is the water left in the pot at the end of the test (P_{cf} – P) that is used in the calculation). To enable a fairer comparison of stoves tested in different environmental conditions the specific fuel consumption is corrected to account for differences in initial water temperatures. The correction is a simple factor that "normalizes" the temperature change observed in test conditions to a "standard" temperature change of 75 ºC (from 25 to 100).

$$SC^T{}_c = \frac{f_{cd}}{P_{cf} - P} * \frac{75}{T_{cf} - T_{ci}} \qquad \text{[g water/kg fuel]} \qquad (3)$$

<u>Firepower</u> $\mathbf{FP_c}$

This is a ratio of the fuel energy consumed by the stove per unit time. It does not return the power output to the pot, rather the maximum available power output from the fuel (in Watts).

$$FP_c = \frac{f_{cd} * LHV}{60 * (t_{ci} - t_{cf})} \qquad \text{[W]} \qquad (4)$$

APPENDIX 6: THE CONTROLLED COOK TEST

Example Controlled Cook Test Data Sheet

Controlled Cooking Test Data Sheet

Date/Time	02-Nov-05	Altitude	1064	m	Water boiling temperature	96.5	deg C
Tester	JR				Ambient Temperature Start	30.5	deg C
Cook	PK				Ambient Temperature End	31.2	deg C
Type of Stove	Gel Fuel	Type of Fuel	Ethanol Gel Fuel		Start Time		
Inner Diameter	n/a	mm			11:24		
Wall thickness	n/a	mm	Stove Empty	1.270	End Time		
Weight of Stove	n/a	kg	Weight of Fuel: Stove, with Fuel	1.570	kg	12:51	
Type of grate	n/a						
			Stove End	1.405	kg		

Pot 1

Use	Fish	
Outer Diameter	170	mm
Height of Pot	80	mm
Capacity of pot	1.8	Litres
Weight of pot	0.270	kg
Method	**weight [g]**	**Time**
Start Stove		11:24
Water	580	
Dry Fish (Small)	150	
Pot on stove (with lid)		11:25
Fish boiled and pot removed		11:32
Drain Water		
Pot back on Stove (with lid)		11:42
Add Tomato/onion Sauce		11:42
Water	145	
Pot off stove		11:49
End Weight	0.920	kg

Pot 2

Use	Sauce	
Outer Diameter	178	mm
Height of Pot	85	mm
Capacity of pot	2.1	Litres
Weight of pot	0.290	kg
Method	**weight [g]**	**Time**
Sauce for Fish		
Vegtable oil	45	
Onions	100	
Pot on stove (with lid)		11:32
Tomatoes	250	
Salt	10	
Add tomatoes and salt		11:36
Pot off stove		11:42
Sauce for Rape		
Vegtable oil	60	
Onions	90	
Pot on stove (with lid)		11:57
Tomatoes	250	
Salt	20	
Add tomatoes and salt		12:01
Pot off stove		12:05
End Weight	n/a	kg

Pot 3

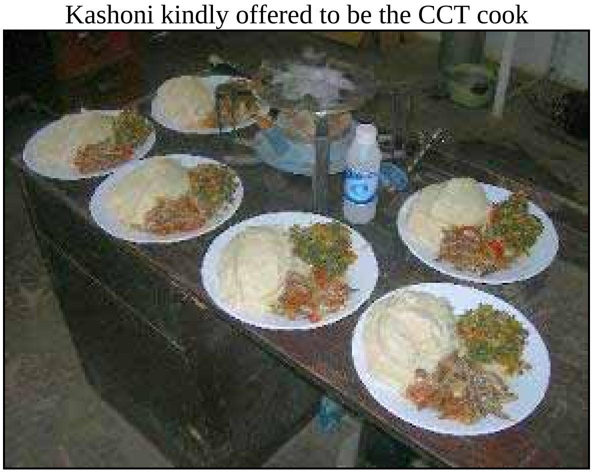
Use	Rape	
Outer Diameter	200	mm
Height of Pot	115	mm
Capacity of pot	3.6	Litres
Weight of pot	0.940	kg
Method	**weight [g]**	**Time**
Water	305	
Pot on stove (with lid)		11:49
Rape	555	
Pot off stove		11:57
Drain Water		
Pot back on Stove (with lid)		12:05
Add Tomato/onion Sauce		12:05
Pot off stove		12:10
End Weight	1.770	kg

Pot 4

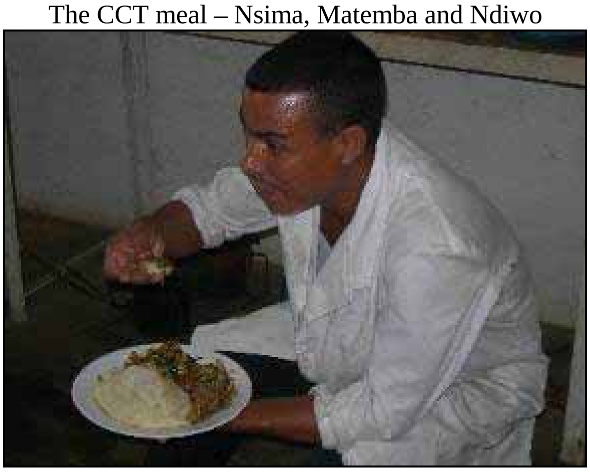
Use	Nsima	
Outer Diameter	225	mm
Height of Pot	120	mm
Capacity of pot	4.8	Litres
Weight of pot	1.185	kg
Method	**weight [g]**	**Time**
Water	3120	
Pot on stove (with lid)		12:10
Out of Fuel		12:20
Fuel added	230	
Relit		12:21
Water at 60 degrees		12:24
Oufa (maize flour)	305	
Boiling		12:38
Stir continuously		
Oufa (maize flour)	665	
Stop		12:51
End Weight	4.890	kg

Kashoni kindly offered to be the CCT cook

The CCT meal – Nsima, Matemba and Ndiwo



The test cooked 6 portions and there were 3 tests for each stove and three stoves to test (54 servings)



Many of which Luciano, the stove technician, reluctantly ate

APPENDIX 7: THE KITCHEN PERFORMANCE TEST

Possible factors for the differing fuel consumption ratios between test FCRs

User behaviour. Each stove user will have had a different set of habits and requirements for their stove and so a large variance will be present. User error would also have been a factor but it can be shown that a mis-recording of one unit of either fuel type will have lead to a change in SHFC comparable to the variance shown within each household's data sets (the error bars in Fig. 3).

Differing SBS performance. The SuperBlu Stoves used in this research were of varying quality and the impact this would have had on test results is difficult to assess. It is known that the stove performance dropped over the first 30 hours of use and this coincided with the cumulative cooking time during the KPT, and to a lesser extent the laboratory tests. This would have resulted in an increased ethanol consumption and subsequent rise in FCR. Unfortunately as the same stove was not used for both the WBT and CCT a direct comparison is not possible.

Differing ICS performance. The WBT recorded the ICS efficiency at the lower end of reported ranges in other studies and it is possible that the field test stoves were of a better performance. However as the stove was sourced from the Mbayani area and of typical design and manufacturing standards this is not thought very likely. The variability in charcoal quality will also have had some impact.

Charcoal consumption. The CCT recorded the exact amount of charcoal used during the test with any fuel remaining in the stove subtracted from the total. In the field test, when users had some charcoal left in the stove after cooking they would not have recorded the quantity, whether it was reused later or left to burn out. This is likely to have resulted in a reported charcoal usage slightly higher than actual and a subsequent decrease in FCR. In addition if users had cooked for a short period of time then, due to its inflexibility, the ICS would have consumed proportionately more fuel than in the CCT so decreasing the FCR.

Differing test conditions. The CCT was specific to only one type of meal and did not measure performance at simmer. Given that the SBS had a poor performance at low power then, if included in the CCT, this would have resulted in an increased FCR. However this would have further increased the gap between KPT and CCT indicating that users may not have closed the air door on the ICS, so reducing fuel consumption, instead using alternative methods listed in Section 3.1.2. As the CCT was conducted indoors the stoves would not have been exposed to the same conditions that were present in the KPT where most users cooked outdoors in semi-sheltered areas. The impact this would have had on the relative performance of the stoves is not known. Although ethanol was provided free to stove users it is not thought that this encouraged an increased consumption, especially given the lower FCR in the field test.

Fuel Use Survey Daily Questions (English Translation)

Household Energy Survey of 20 households in the Mbayani District of Blantyre, Malawi.
10th - 17th August 2005

Household ID		Family Name	
Day			

Please fill in the following sheet the best you can.

	Please give answers for one day only		
Type of stove(s) used and what was cooked [ceramic stove, three stone fire, electricity(hot plate),]	Stove	Food	
Today how much fuel did you use and how much did it cost. [number of charcoal containers, wood bundles, electricity/time]	Amount	Cost (K)	
How long did the cooking take?	Morning	Afternoon	Evening
How many people did you cook for? (Adults and children)	Morning	Afternoon	Evening
Additional comments, do you have anything interesting you want to add?			

Fuel Use Survey General Questions

Household Energy Survey of 20 households in the Mbayani District of Blantyre, Malawi.
10th - 17th August 2005

Household		Family Name	

Section 1 to 4 to be asked at by an enumerator
Copy of last page to be filled in by household members daily

1 General

1.1 Introduction

"Hello, my name is _________________ and I am here as part of the Bluwave ethanol stove research programme. Do you have the time to answer a short questionnaire about your cooking habits and the fuel you use? The answers you give will be treated in the strictest confidence and used for research purposes only. If you do not want to answer a particular question please let me know and I will move on to the next one."

1.2 General Information

Name of respondent(s)	
Gender of respondent(s)	
Position in household	

1.3 Household characteristics

Would you tell us about the size and membership of the family living in this house?

	Member	**Number**
Adults	Men	
	Woman	
Children (under 18)	Boys	
	Girls	
	Total	

2 Household Energy

2.1 What do you use fuel/energy for?
[Charcoal, fuelwood, kerosene, electric, other (please state)]

	Summer		Winter	
	Most used	Other Fuels	Most used	Other fuels
Cooking				
Lighting				
Space heating				
Water heating				

2.2 What else do you use fuel/energy for?
[I.e. appliances, entertainment, home industry]

____

2.3 Where do your family get fuel from?
[Fuel types: Charcoal, Woodfuel, Kerosene, Other (please state)]
How many minutes walk was it?
[Tick nearest time]
Why did you go there?
[Distance, price, near market]

	Fuel type	Distance (Minutes walked)				Why
		0-10	**10-30**	**30-60**	**60 +**	
Local seller (vending)						
Local seller (door to door)						
Local shop/market						
I buy and sell charcoal						
Other (please state)						

2.4 Over the year are there times when you experience difficulty in obtaining fuel. What do you do to mitigate the problem?

____

____

3 Stoves

3.1 How did you get the stove(s), how much did it cost, how did you pay for it, whose decision was it to buy it and who bought it?

Stove			
How did you get it?			
How much did it cost?			
How did you pay for it?			
Whose decision was it to buy it?			
Who bought it?			

3.2 What do you like and dislike about your current stove(s)?
[Rank 1-4, 1 is most liked/disliked]
[Ease of use, time spent attending, time to start, smoke, soot etc]

Stove _____________

Like	Rank 1	Dislike	Rank

Stove _____________

Like	Rank	Dislike	Rank

Stove _____________

Like	Rank	Dislike	Rank

3.2 Do different cooking practices cause you to use different stoves?
[Cooking nsima or beans, boiling or simmering, different pots]

Activity	Stove	Reason why

3.4 Do you have to repair/maintain your stove, how long does it last?

Stove	Need to repair or maintain?	How long does it last?

3.5 What would you expect from a new type of stove?

____

3.6 Do you think people become ill because of smoke?

____

3.7 Is there anything you do to reduce your household's exposure to smoke? [How]

____

SBS Survey General Questions

SuperBlu Ethanol Stove Survey
20 households in the Mbayani District of Blantyre, Malawi.
August 2005

Household		Family Name	

All sections to be asked at by the enumerator

1 General

1.1 Introduction

"Hello, my name is _________________ and I am here as part of the Bluwave ethanol stove research programme. Having now had the stove for over a week we would like to ask about your views on the stove. The answers you give will be treated in the strictest confidence and used for research purposes only. If you do not want to answer a particular question please let me know and I will move on to the next one."

1.2 General Information

Name of respondent(s)	
Gender of respondent(s)	
Position in household	

Safety

1.1 Did anyone hurt themselves on the stove? Yes / No

If yes what happened? ____

____

[Burn, Cut, Stove/Fuel]

1.2 Did you spill any fuel? Yes / No

If yes what happened? ____

____

[Filling tank, Filling Nozzle]

1.3 Were there any other **safety** related problems with the stove?

____

____

[Stove body too hot, fuel leakage, excessive flames, flames on side of tank etc]

User friendly

2.1 Did it take long for you to learn how to use the stove? Yes / No

What were the problems? ____

____

[Didn't know how to use it, afraid to use, wouldn't start, didn't warm, went off with fuel still in the tank (flame disappeared)]

(Once you were used to using the stove)

2.2 Did it start first time Yes / No

If No, How many times did it take to start? ____________________________

2.3 What was your preferred starting method? Matches / Lighter

Why? ____

2.4 Was it easy to control? Yes / No

If No, What was the problem? _______________________________________

2.5 Did it stop first time Yes / No

If No, What was the problem? _______________________________________

2.6 Did you change the way you cooked when using the stove? Y / N

How did you change? ____

Why did you change? ____

2.7 What did you like/dislike about the stove compared to what you normally use? (Tick like/dislike)

	Like	Comment	Dislike	Comment
Starting				
Starting/warm up time				
Starting/warm up outdoors				
Cooking Temperatures				
Overall cooking time				
Turning off				
Cleaning				
Stove body temperature				
Filling with fuel				
Fuel consumption				
Fuel quality				
Design				
Durability				
Stability				
Ability to use different sized pots				
Soot				
Smoke				
Smell				

5.6 What task was the stove good for?

____

____

5.7 What tasks **didn't** you use the stove for and why?

	Why?			
Cooking activity	Start/Warm up time	Cooking temperatures	Fuel consumption	Other (please state)

Fuel

6.1 Did you run out of fuel? Yes / No

What days was this on? ____

6.2 We are going to try and compare your fuel use from the first week (fuel survey) with what you used when you had the stove. Do you think this is valid in your case? Yes / No

Why? ____ [numbers cooked for, food cooked, special occasion, away from home]

Future

7.1 What changes would you like made to the stove design?

	Tick	Comment
Start		
Warm up		
Cooking temperatures		
Stopping		
Two pot capability		
Other (please state below)		

7.4 What would make you buy the stove? Please state the four most important items (rank 1 to 4, 1 highest)

	Rank
Modern design	
User friendly	
Cooking Temperatures	
Cooking Times	
Two pot capability	
Portable	
Reduces deforestation	
Health (does not make you cough/no smoke etc)	
Other (please state below)	

7.2 Suppose the stove has been developed to a final product and could last for six years, what price would you be willing to pay for it?

(Start with highest price first and work down, asking for reasons each time)

Cost	Yes/No	Reason
1200K		
600K		
200K		

7.3 If the fuel was widely available and gave 2 hours of cooking per 250ml bottle, how much would you be willing to pay for the fuel per bottle?
[Think about how much you spent on charcoal per day and how many bottles of ethanol you might use in one day]

(Start with highest price first and work down, asking for reasons each time)

Cost	Yes/No	Reason
25K		
20K		
15K		

7.5 Knowing approximately how much fuel you used in one day where would you want to buy the ethanol fuel from and what quantity would you buy it in?

	Buy from	Quantity (250ml bottles or in litres)
Local seller (vending)		
Local seller (door to door)		
Local shop/market		
Other (please state)		

7.6 In an average month what is your household income? Remember to include what you get from your small business, salary and gifts/remittances.

____

SBS Survey Daily Questions (English Translation)

Household ID		Family Name		Day	

Please fill in the following sheet the best you can. Please give answers for ONE DAY ONLY

ETHANOL ON THIS SIDE

	Morning	**Midday**	**Evening**
How much ethanol did you put in the stove today? How many times did you start it? (If you used other fuels please write overleaf)	Bottles Starts	Bottles Starts	Bottles Starts
What food did you cook with this fuel?			
How long did the cooking take?			
How many people did you cook for? (Adults and children)			
Did you spill any ethanol or use it for any other purpose? If so, how much?	Bottles		
Additional comments, do you have anything interesting you want to add?			

PLEASE TURN OVER

CHARCOAL, FIREWOOD AND ELECTRICITY ON THIS SIDE

	Morning		**Midday**		**Evening**	
	Amount	**Cost (K)**	**Amount**	**Cost (K)**	**Amount**	**Cost (K)**
Today how much charcoal, firewood or electricity did you use and how much did it cost? [charcoal containers, wood bundles, electricity/time]						
What food did you cook with this fuel?						
How long did the cooking take?						
How many people did you cook for? (Adults and children)						
Why did you choose not to use ethanol?						
Additional comments, do you have anything interesting you want to add?						

An area of Mbayani

Magi Matinga talking to the stove users (kneeling with her back to camera)

Sorting charcoal into plastic bags for sale

To get used to the stove participants cooked a meal

A sack of maize flour (Ufa) and a warming nsima pot

The final stages of making nsima

Lloyd getting ready to distribute the stoves

Magi serving drinks

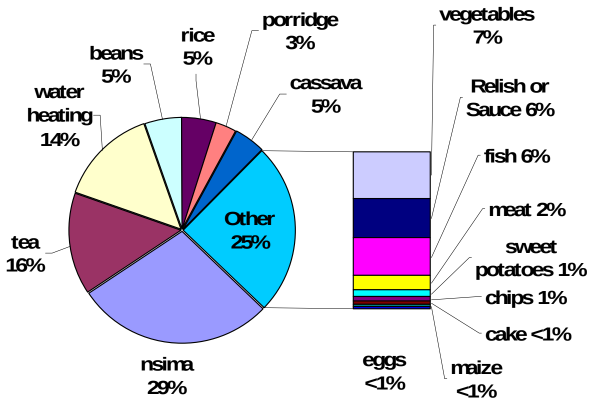
Lloyd taking feedback from stove users
(note the wood stockpiled for the rainy season)

Some of the participants (taken at the first meeting)
Chief Magassa and his wife are at either end of the photo

APPENDIX 8: BASELINE FUEL SURVEY

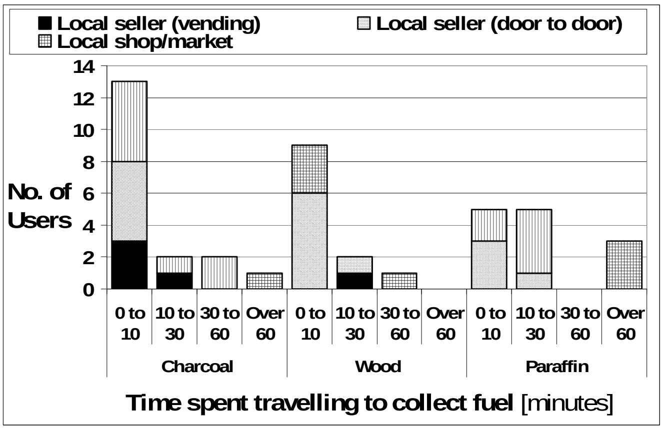
The results of the baseline fuel use survey showed that all households used charcoal as their main cooking fuel and when heating water 84% used charcoal and the remainder firewood. Seasonal space heating was also with charcoal and the main fuels used for lighting were paraffin 53%, candles 42% and electricity 5%. Over half of households also used batteries indicating the presence of higher value goods, often radios. All the users who took part in the survey owned an improved charcoal stove and 65% also used wood on a three stone fire to some extent. On average each household spent over 4 hours a day either cooking food or heating water for an average household of 4.5 Standard Adults or, as an approximate example, 2 men, 1 woman and three children.

To enable a more detailed assessment of stove use, households were asked to record the tasks their stoves were put to and the cumulative results (by incidences) are shown below. The three most common tasks were cooking nsima, making tea and heating water, all of which required high power. Nsima, the staple food in Malawi, is made by bringing maize flour (Ufa) to the boil in a pan of water with the lid on. Once boiling, the mixture is vigorously stirred to a near solid consistency and for a family sized quantity the whole process takes between 30-40 minutes. Low power, or simmer, was only required for approximately 20% of tasks such as cooking beans, rice, porridge, cassava and deep frying foods such as chips. Of these cooking beans is the most critical due to the long duration required.



Baseline Fuel Use Survey Cooking Tasks (By recorded incidence)

Although multiple fuel usage was not measured in the survey general comments from users included the fact that for economic reasons some used firewood to heat water whilst baking was mainly done on the lower heat attainable at the side of a three stone fire. Also of note was that the majority of tea and water heating was conducted in the morning where time was critical to the user. Of the families who took part in the field test the majority bought fuel from door to door sellers or shops/markets, stating price and convenience as the motivating factors. Most bought locally, from places less than 10 minutes away, but over half those buying paraffin (for lighting) were willing to travel further in order to buy larger volumes at a cheaper price. When asked about difficulties in purchasing fuel throughout the year the majority of people identified the rainy season as a time when fuel prices, especially charcoal, increase. Coping strategies include stockpiling fuel, switching to cheaper firewood or burning whatever is available.



Existing Fuel Supply Chain

APPENDIX 9: SUPERBLU STOVE - SAFETY AND FAULTS

In Depth Safety Test

In-Depth Stove Safety Tests

Stove ID: **Tester:** **Date:**

Equipment
Angle measurer, 1kg weight, String/Chord, 4L pan of water, Stopwatch, tape measure

Comments/Observations
User safety, Structural Integrity, Finish Quality etc

0) Check
Passed Basic Test
Comments/Observations on stove:

____

1) Stability Test
With the fuel tank empty tilt the stove forward until it topples, record angle of topple
Repeat for sideways stability
Place 4L pan of water on the stove and repeat the experiment
Check the stove starts ok and burns well on an uneven surface

	Angle/degrees	Comments/Observations
Front topple angle		
Side topple angle		
Front topple angle with 4L pan		
Side topple angle with 4L pan		
Burn on uneven surface (15 deg)		

2) Mass Test
Run the stove for 1 hour
Place a 10kg mass on the pan ring and leave running for 1 hour
Check for deformation

Comments/Observations	

3) Refuelling Test
Run stove for 1 hour
Open fuel cap whilst lit, record results
Replace cap and wait for flame to stabilise
Spill 30ml fuel on the stove nozzle whilst lit and record results
Turn stove off and spill 30ml of fuel on the stove, record results

Action	Comments/Observations
Open cap whilst running	
Spill 30ml fuel when lit	
Spill 30ml fuel on nozzle when out	
Spill 30ml fuel on tank casing when out	

4) Rough Use Test
Place protective metal sheet over pan ring, Drop 1kg weight from a height of 50cm
Place large spoon in pan and with downwards force run around base of pan

Action	Comments/Observations
Drop 1kg weight	
Stirring test	

5) Knock Test
Place lit stove on floor
Suspend 1kg weight on 50cm chord and raise to 45 degrees. Release weight to strike stove stand, note results

Comments/Observations	

6) Drop Test
Place lit stove on edge of 1m high bench. Push stove off and note results

Comments/Observations	

7) Destruction Test
Impact a fully fuelled ignited stove on the tank/nozzle assembly until destruction or major fuel leak

Comments/Observations	

With the fuel cap left off and the stove shaken a small steady flame appears at the fuel tank inlet

A blocked fuel return pipe causes the burner cup to overflow, spilling fuel which then ignites

Soot deposits on a pot base from a typical WBT phase

Stove with oversized nozzle preheat holes

Stove post mortem showing tank deposits and incorrect fuel pipe/tank geometry

Stove with solder failure between the burner cup and tank (the holes in the tank occurred during the removal of the regulator)

Oxide build up (?) inside the burner cup (the damage occurred during the removal of the components)

Stove tipping angle – note the continued operation of the stove and the stable flame

Just before the end of the destruction test – the stove was still working despite the application of a large metal bar.

APPENDIX 10: GEL FUEL STOVE RESULTS

Appropriate

The gel fuel stove was stable in use although pots tended to slip on the stand top. The burner cup reached 85ºC and was easily accessible posing a risk to the user. However the leg, which also doubled as a handle, reached only 35ºC and once cooking had finished the stove cooled rapidly. The gel fuel proved extremely safe as it burned in a very stable manner and its high viscosity minimised any danger from spillages [29]. Starting and stopping the stove was easy but its lower weight did make it more vulnerable to knocks. It was not possible to verify claims on stove emissions although it did give off virtually no soot during use.

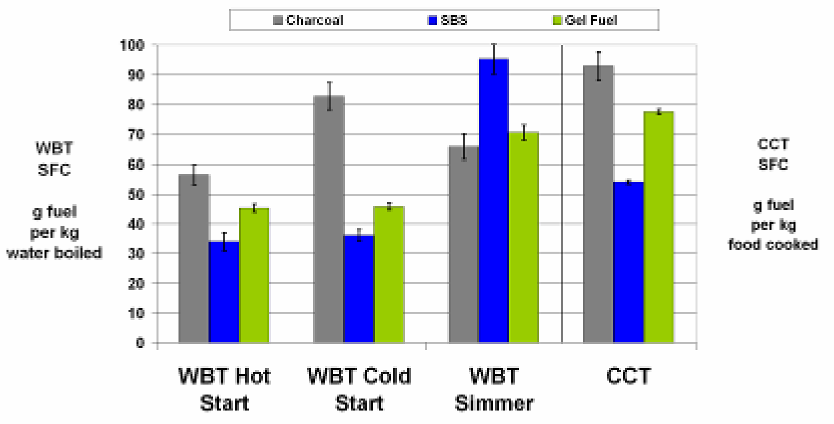
The GFS did not undergo a field test and so it was not possible to obtain the users views on the unit. However it was the opinion of both the CCT cook and the author that the stove was easy to use with a quick start time and a maximum power sufficient for the required tasks. The stove output at simmer was the lowest of the three stoves on test and the response to a change in regulator setting was instant. However at maximum power the high fuel consumption meant the stove had to be refuelled part way through the cook test, although this was also the case with the ICS and SBS. The stove and fuel also proved very portable.

The GFS gave a similar performance to the SBS with the hot start WBT results statistically inseparable. The stoves quick start capability showed with just over a three minute difference between the hot and cold start test durations and in the latter a time some 55% of the SBS equivalent. The better simmer performance was confirmed with a firepower of 0.6kW, the lowest of the three stoves. The efficiency at full power is in line with another survey [30] where a maximum efficiency of 40% was reported and a maximum and minimum power of 2.5 and 0.8KW respectively. These firepower values are higher than the authors' results with the difference most likely due to the higher stated fuel LHV of 22.3 MJ/Kg, compared to the 16.4 MJ/Kg used in this report. In the high power WBT the GFS had an approximate 30% higher specific fuel consumption ratio than the SBS and at simmer the GFS behaviour stands in marked contrast to the SBS, showing the problem the latter has at this power level.

Water Boiling and Controlled Cook Tests

WATER BOILING TEST		ICS		SBS		Significant Difference	GFS		GFS/ICS Significant Difference	GFS/SBS Significant Difference
2L of water in 3.3L pot		Mean	CoV	Mean	CoV	@ 95%	Mean	CoV	@ 95%	@ 95%
COLD START										
(including starting period), Lid on										
Thermal Efficiency		15%	4.3%	40%	4.8%	yes	44%	1.2%	yes	yes
Duration of Phase	minutes	32.8	8.4%	33.4	12.2%	no	18.6	2.6%	yes	yes
Temp corrected SFC	g/kg Water	83	5.5%	36.2	5.1%	-	45.9	2.4%	-	-
Power	kW	2.1	11.3%	0.8	12.4%	yes	1.3	2.7%	yes	yes
HOT START										
(excluding starting period), Lid on										
Thermal Efficiency		23%	6.8%	43%	8.1%	yes	45%	2.8%	yes	no
Duration of Phase	minutes	17.8	6.8%	16.1	7.3%	no	15.3	1.9%	yes	no
Temp corrected SFC	g/kg Water	57	5.7%	34.0	9.0%	-	45.4	3.0%	-	-
Power	kW	2.5	2.1%	1.4	2.2%	yes	1.4	1.8%	yes	no
SIMMER										
45 Minutes, Lid off										
Thermal Efficiency		41%	9.8%	32%	3.0%	yes	58%	1.9%	yes	yes
SFC	g/kg Water	66	6.5%	95.3	5.2%	-	70.5	3.5%	-	-
Power	kW	1.0	3.0%	1.2	4.1%	yes	0.6	2.7%	yes	yes
Cold/Hot Significant Difference@95%										
Thermal Efficiency		yes		no			no			
Duration of Phase		yes		yes			yes			
Temp corrected SFC		yes		no			no			
Power		yes		yes			yes			
Hot/Simmer Significant Diff@95%										
Power		yes		yes			yes			

CONTROLLED COOK TEST		ICS		SBS		Significant Difference	GFS		GFS/ICS Significant Difference	GFS/SBS Significant Difference
5.25kg Cooked Food		Mean	CoV	Mean	CoV	@ 95%	Mean	CoV	@ 95%	@ 95%
Duration	minutes	123.7	4.8%	107.3	2.9%	yes	90.0	3.3%	yes	yes
SFC	g/kg food cooked	93.0	5.2%	54.1	1.3%	-	77.5	1.2%	-	-



Specific Fuel Consumption Results

The more realistic CCT shows a difference in SFC between the two ethanol stoves of over 40%, with the FCR (in terms of ethanol fuel volume to charcoal mass) of the GFS and SBS at 1.17 and 0.72 respectively. However when considering the SFC in terms of the energy used, where the SBS fuel LHV was 1.4 times that of the GFS, the two stoves are no different and both used 1.3 MJ of fuel per Kg food cooked. When calculating operating costs for the SBS, field test results were used and as the GFS underwent no such tests another method is required. In section 3.1.3 it was assumed that the better performing SBS stoves returned a FCR of 0.37, some 51% of the CCT ratio quoted above. If it is assumed that the GFS would experience a similar change between CCT and KPT and the same margin is applied to it's CCT value (a slightly generous assumption given the likely impact of the varied SBS performance), then a final FCR of 0.60 L/Kg is derived. In terms of duration the GFS was the shortest of the three stoves due to its quick start and refuelling times. More generally the GFSs lower CoV's indicate a more repeatable performance, an advantage for the user. The safety and usability of the GFS were better than both the ICS and the current SBS. The stoves performance was similar to the others on test but its lower and more stable simmer power, as well as quicker start time, gave it a better rating. In terms of appropriateness the GFS was better than the two other stoves, showing the advantage of a gelled fuel.

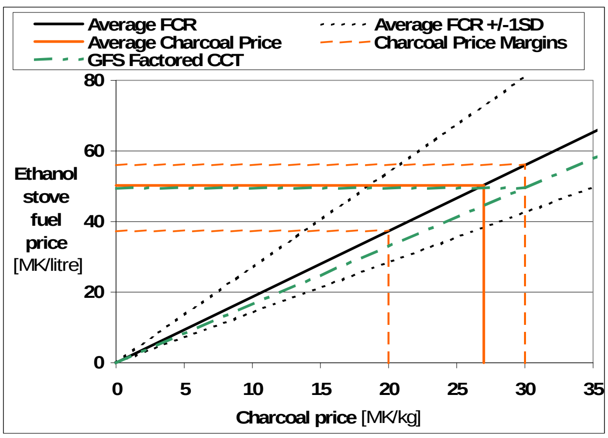
SBS Appropriateness

	Worse	Similar	Better
Safety	1	2	3
Usability	1	2	3
Performance	1	2	3
Appropriate	1	2	3

GFS in green and underscored, SBS in grey

Affordable

When the FCR of 0.60 L/Kg is assessed against the charcoal prices in the Mbayani area it is apparent that the gel fuel would have to be produced at a maximum of 50MK/L to be competitive with charcoal at 30MK/Kg.



Competitive Stove Fuel Price

However this is below the price of ethanol under current market conditions, reflecting the manufacturers current problems. Even if the market becomes more favourable to ethanol as a household fuel, and in the future production of the gel fuel can be achieved for 80MK/L, this would still not make the GFS competitive with charcoal as it's operating costs would be 1.6 times that of the ICS. Other authors have estimated this ratio at 1.5 to 2 [16, 30] and at the current market prices for ethanol and charcoal this ratio is over 2.6.

Ethanol Fuel Price

All Prices in MK/L	GFS 2005	SBS 2005	GFS FUTURE	SBS FUTURE
Ethanol Production				
Production Cost	23	23	18	18
Operating Cost	6	6	6	6
Net Margin	28	28	6	6
Ethanol Price (pre tax)	**57**	**57**	**30**	**30**
Stove Fuel Production				
Ethanol	48	57	25	30
Processing Cost	23	15	17	11
Operating Cost	23	23	17	17
Distribution Cost	12	12	9	9
Net Margin	12	12	12	12
Retail Price (pre tax)	**117**	**119**	**80**	**79**

2005 Ethanol Production: Production cost is taken from Liwimbi [18] and is in line with current world prices [16]. Final ethanol price is from Liwimbi and Wynne-Jones [17]. GFS 2005: Data is from both Wynne-Jones and the authors' inference. The reduction in ethanol price is due to 1L of ethanol making 1.2L of gel fuel. Processing and operating margins set at 20% of retail price. Distribution margin and Net margin set at 10% of retail price. Overall retail to ethanol price ratio of 2 is as in Utria [16]. SBS 2005: Processing cost is 2/3 of GFS 2005 due to a simpler process. Future Ethanol Production: Production cost is 20% lower then 2005 due to industry improvements. Ethanol producers net margin set at 20% of ethanol price. SBS and GFS Future: Processing, operating and distribution margins reduced by 25% from 2005 levels due to new, larger processing facilities with a larger capacity.

In more upmarket supermarkets the GFS (including stand) sold for 800MK but in local markets would probably sell for less, although no data was available. No lifecycle costs have been calculated as both fuel and stove costs were greater than for the ICS. Both the operating costs and initial investment for the GFS were worse than for the ICS, and subsequently the lifecycle costs. So in terms of affordability the GFS cannot compete with the ICS, reflecting the manufacturers current problems.

SBS Affordability

	Worse	Similar	Better
Operating Costs	1	2	3
Initial Investment	1	2	3
Lifecycle Costs	1	2	3
Affordable	1	2	3

GFS in green and underscored, SBS in grey

Accessible

The D&S Gel Fuel Company already has a factory near Lilongwe that produces around 1000L/day and a stove and fuel distribution network in supermarkets. The author didn't observe any GFS in the Mbayani markets although a supply chain could easily be set up. The company is also planning on bringing out a higher cost model to better suit market demands. The rising ethanol price has made the fuel non-competitive and has led to a halt in gel fuel production. Customers have subsequently complained [17] and this will have had a negative impact on people's perceptions of what is a technically good stove. Given that the stove is already produced and that the fuel processing factory was operational, the GFS shows that it is possible to set up an ethanol household fuel scheme. However as stated for the SBS it is the existing ethanol market that poses the main risk to the scheme, as experienced by the D&S Gel Fuel Company. The GFS scores identically to the SBS.

SBS Accessibility

	Unlikely	Marginal	Likely
Fuel Supply Chain	1	2	3
Stove Supply Chain	1	2	3
Accessible	1	2	3

GFS in green and underscored, SBS in grey

Overall

The GFS proved very appropriate for use. The performance was entirely suited to the standard meal cooked in the CCT and the gelled fuel ensured a very safe operation. The stove and fuel are accessible to users but it was the high operating costs, even given a reduced ethanol price, which made the stove non competitive with the ICS.

However it is stressed that these results are based on modified controlled cook test data and not from a field test as was the case with the SuperBlu Stove. More developed versions of the GFS are available which are similar in appearance to modern paraffin stoves, with a metal stove body covering the stove burner so further improving safety and usability.

Gel Fuel Stoves on a supermarket shelf
(Shoprite, Blantyre)