

Biochar Stoves: an innovation studies perspective



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8th April 2011

Supported by- IDRC-CRDI and AIT

Contents

1. Basic Project Information.....	3
Project narrative	3
Partners.....	4
Acknowledgements	5
2. The Research Problem.....	5
Box 1: Cooking Stoves: Key Issues and Problems.....	6
What is biochar?.....	15
Carbon storage	15
Soil improvement.....	16
Fuel.....	17
3. Objectives.....	21
Participative Distributed Innovation Processes (PDIPs).....	21
Function of stove	23
Barriers to uptake	23
Criteria for an improved design.....	24
4. Project activities and Research Methodology	27
4.1. Project location.....	27
Cambodia	27
India.....	27
What improved stoves are available in India?.....	27
What improved stoves are available in Cambodia?	28
4.2 Stove designs.....	28
4.3 Stove fabrication.....	29
4.4 The Anila Stove	29
4.5. The EverythingNice Stove (EN).....	30
4.6. The Sampada Stove.....	31
4.7. Anderson’s (Champion) TLUD	31
4.8. Stove Testing Methods.....	32
4.9. Household Baseline study.....	33
5. Project outputs.....	34
5.1. Controlled stove testing.....	34
5.2. Biochar production	39
5.3. User feedback of stoves’ use	39
Results.....	39
5.4. Use of Biochar.....	48
5.5. Results of Household Survey & Analysis	49
5.6. Women’s Discussion Groups	59
5.7. Summary of Additional Data from Workshops and Meetings	63
6. Project Outcomes	63
6.1. Online resources and Webinars	63
6.2. Workshops	64
Stove donations.....	64
7. Overall Assessment and Recommendations	65
References	70

1. Basic Project Information

Project narrative

The project began with a presentation of the proposal and project plan at the official meeting 'Launching Event and Inception Workshop' with AIT and IDRC-CRDI in Bangkok 7-10 December 2009. The project is led by the University of Edinburgh. The PI is Dr Simon Shackley and the in situ researcher Sarah Carter. Sarah designed and undertook the field work, and developed the partnerships that allowed the project to be implemented in both Cambodia and India. Simon created the theoretical framework and has written the interpretative and conceptual parts of the report. Implementation of project activities began in January 2010, and fieldwork was completed in December 2010. The production of the report was undertaken in January to April 2011, and the official termination of the project was March 12th 2011. Fieldwork was undertaken in Cambodia between January - August 2010, and then from October - December 2010. Fieldwork was completed in India from August - October 2010. The timeline for important events is shown in Table 1.

Table 1: Timeline of Key Project Activities and Events

Date	Location	Activity
18.11.2009		Project accepted
7-10.12.2009	Bangkok, Thailand	Launching Event and Inception Workshop Held by Asian Institute of Technology
18.01.2010		Project blog launch http://biocharinnovation.wordpress.com/
25.03.2010	Malaka, Malaysia	Biochar Malaysia Workshop. Presentation. Organised by University of Kuala Lumpur
18.06.2010		Launch of UKBRC Hedon webpage http://hedon.info/Biochar
07.07.2010 - 12.10.2010	Siem Reap, Cambodia	Household stove testing (9 HHs)
07.08.2010 - 26.09.2010	Siem Reap, Cambodia	Household baseline questionnaire campaign (101 questionnaires)
25.08.2010 - 05.10.2010	Phaltan, India	Household stove testing (8 HHs)
28.08.2010 - 04.10.2010	Phaltan, India	Household baseline questionnaire campaign (100 questionnaires)
16-17.09.2010	Phaltan, India	Workshop held: Biochar: Production & Use 34 attendees
29.09.2010	Phaltan, India	Women's workshop discussion group 23 attendees
24-29.10.2010		E discussion: Biochar; the Potential in Asia Pacific? Moderator and participant http://biocharm.wordpress.com/eworkshop/
22-23.11.2010	Siem Reap, Cambodia	Workshop held: Biochar: Production & Use 29 attendees
03.12.2010	Siem Reap, Cambodia	Women's workshop discussion group 20 attendees

Partners



The University of Edinburgh is one of the world's top 22 universities, and the School of GeoSciences is a leading multidisciplinary group, which has over 100 academic and research specialists, over 1100 undergraduate and 250 postgraduate students, and has some of the best geo-scientific infrastructure in the UK (www.ed.ac.uk).



UKBRC

The UK Biochar Research Centre is an alliance that connects research organizations with significant biochar research activity in the UK. The UKBRC aims to serve as a source of robust data and informed objective analysis on this subject to all stakeholders (www.biochar.org.uk).

The UKBRC has also worked on the BIOCHARM project (Biochar for Carbon Reduction, Soil Management & Sustainable Agriculture) a project focusing on multi-country (Cambodia, India and Philippines) field trials of biochar application to agricultural soils <http://biocharm.wordpress.com>



Appropriate Rural Technology Institute (ARTI), India was an informal partner for this project, providing logistical and technical support. ARTI is a renowned NGO in the field of biomass energy, improved cooking stoves and sustainable agriculture. Two time winner of the prestigious Ashden Awards, ARTI is one of the pioneers in the area of R&D on biochar production and use in India (www.arti-india.org).

This project received support under the programme, 'Enabling Bio-innovations for Poverty Alleviation in Asia Project', funded through **IDRC-CRDI** (www.bioinnovationpolicies.ait.asia), and managed by the **Asian Institute of Technology**, Bangkok, Thailand.

Acknowledgements

We would like to thank AIT's staff for guidance during the project. We also thank the UKBRC at the University of Edinburgh for the contribution of CAD 12,540 of in-kind resources. We are especially grateful to ARTI, in particular Dr. Priyadarshini Karve and also Dr. Anand & Meera Karve and the whole team from the Phaltan office. Thanks for logistical support go to the NGO, ConCERT in Cambodia - in particular Michael Horton. Many thanks go to the translators and enumerators Vichida, Bunny and Makara Tan in Cambodia, and Imtiyaz Shaikh in India. Finally, we thank AIT and IDRC-CRDI for supporting the project, both financially and through provision of advice, without which the research would not have been possible.

2. The Research Problem

The main aim of the project was to investigate the extent to which biochar-producing stoves represent a bio-innovation which could help in improving quality of life amongst lower income households. In order to do that, an in-depth study was carried out in some selected communities to assess their response to new stove designs and to understand responses with respect to technical aspects, socio-economic issues including cooking cultures, agricultural information and wealth status.

For several decades, designers have sought to improve cooking stoves, generally to provide a stove with increased efficiency or more commonly now, reduced emissions. This project is focused on those improved cook stoves (ICSs) which have the ability to produce biochar. While more energy efficient stoves have been developed since the 1970s, their uptake has been disappointingly slow and patchy (see Box 1 for an overview of the issues) In the past several years, the significance of cleaner stoves has risen-up the policy agenda, with the publication of important documents such as *The Research Roadmap: Improved Cook Stove Development and Deployment for Climate Change Mitigation and Women's and Children's Health* [1]. This roadmap emerged from a workshop held at the Asian Institute of Technology (AIT) in November 2009 and sponsored by the US State Department and the Association of South East Asian Nations (ASEAN). The Roadmap recognizes that cook stoves are of global significance – at least 500 million unimproved stoves are in regular use causing serious health impacts arising from the inhalation of particles known as the products of incomplete combustion (PICs). The global warming potential of the PICs has become increasingly recognized, e.g. with the publication of the UNEP-WMO integrated assessment of black carbon in 2011 [2, 3]. According to the report, tackling both black carbon [4] from all sources (of which cook stoves are just one) and tropospheric ozone would have “immediate and multiple” benefits, including reducing global mean temperature by 0.2 to 0.7°C (compared to what they would have been in 2050) and saving between 0.7 million and 4.6 million lives through improved air quality. Atmospheric scientist Dr. Veerabhadran Ramanathan has estimated the positive atmospheric forcing due to black carbon to be c. 0.9 Wm^{-2} (with a range 0.4 to 1.2 Wm^{-2}) [3]. The climatic impacts of BC are, however, still very uncertain. While BC absorbs incoming solar radiation, other organic carbon with which BC is typically emitted, tends to reflect solar radiation, having a cooling effect. The particles can also form sites for water condensation. Warming of the atmospheric layer where

pollutants occur also cools the earth's surface, reducing convection and rainfall. The overall effect of these complex processes and interactions is not fully understood.

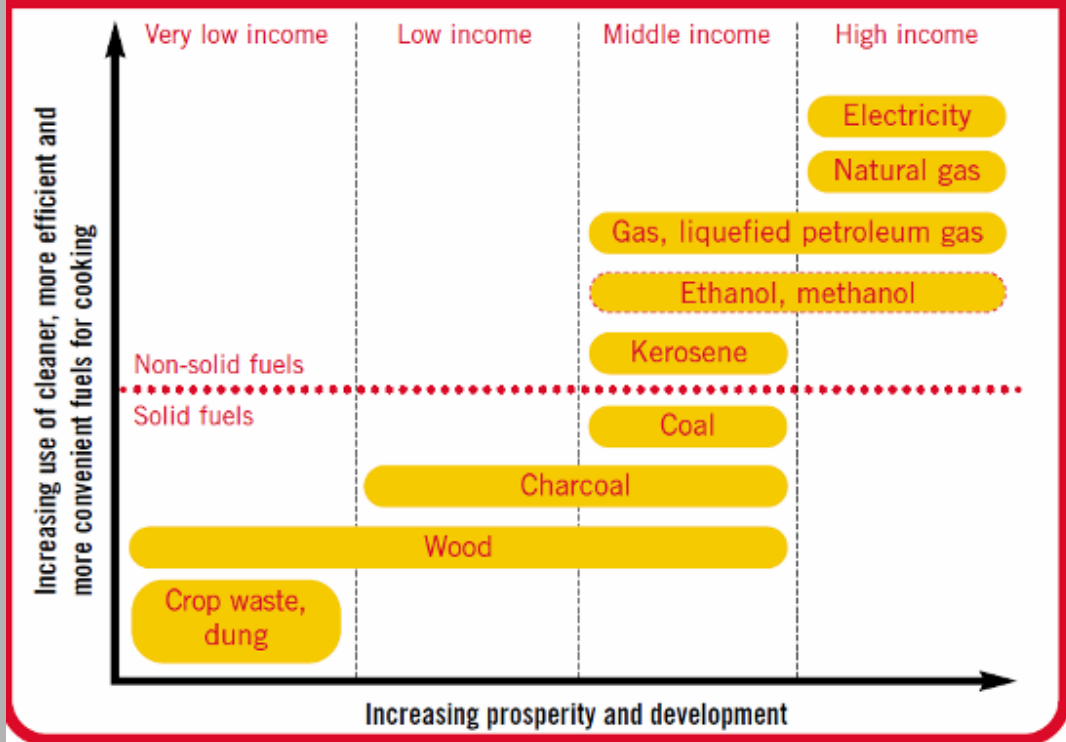
Box 1: Cooking Stoves: Key Issues and Problems

A major cause of poor health in low-income communities, and especially amongst women, is indoor air pollution (IAP) arising from inhaling smoke from cooking fires. Over a third of humanity - 2.4 billion people - burn biomass (wood and non-woody materials such as dung and agri-residues) to supply their domestic energy requirements (mostly cooking and heating) [5]. Smoke is “the gaseous products of burning materials especially of organic origin made visible by the presence of small particles of carbon” and steam is “a vapor arising from a heated substance” ([Merriam-Webster](#)). In relation to cook stoves, emission measurements frequently include smoke, carbon monoxide and sulphur dioxide. These can be measured by a smoke density meter (i.e optical sensor) and flue gas analyser (electrochemical or similar). Other potentially harmful substances, including PM2.5 (particles less than 2.5 micrometres), PMs 3.5 and 10, are also commonly measured by specialist devices (e.g. electron microscopes). Other emissions from burning can include GHGs (methane, carbon monoxide, carbon dioxide, nitrous oxides (NO/NO₂)), volatile organic compounds (VOCs) and sulphates. There is not necessarily a linear relationship between efficiency (i.e. thermal efficiency or fuel efficiency) and harmful emissions. Analysis of emissions should be undertaken over the whole cooking cycle, and under realistic cooking conditions, as emissions can change over the duration of the burn. The different chemical properties of fuels need to be taken into account (resin / rubber for example will produce high and noxious emissions). Once pots are used in trials, the condensation of smoke and steam can produce more visible emissions, although the actual emissions may not be changing.

Technologies for accurately assessing stove emissions have been improving in recent years as a consequence of the “recent affordability of appropriate sensors, signal-conditioning electronics, and automated data acquisition systems” (page 16, [1]). A good examples is the PEMS system designed by the organization Aprovecho and consisting of an optical PM sensor and CO and CO₂ sensors in a small case with an interface to a laptop for displaying and analyzing data. The PEMS is designed to be used in the laboratory in combination with a collection hood which has a suction fan and an air flow sensor. It markets at around \$10K and more than 20 units have been sold [1]. Garrett et al. suggest that cost-effective devices for measurement of particle size, count and total mass could be considered in future RD&D [1].

The health impacts of smoke from stove are extensive. While hard to quantify with accuracy, in work for the WHO, Professor Kirk Smith and colleagues have estimated that 1.6 million premature deaths occur as a consequence of IAP and smoke, including 0.9 million children under five years old (see also references in [6]). Jan notes that: “Millions more face other problems such as chronic respiratory diseases, asthma, breathing difficulties and wheezing, reduced lung functions, stinging eyes, sinus problems, and low-birth-weight babies” (page 4, [6]). This amounts to 3% of global burden of diseases. Indian-based NGO, ARTI, report that annually over 500,000 women and children in India die prematurely due to diseases linked with long term exposure to IAP [7]. Women (and children) are the hardest hit by indoor air pollution, since they spend more time by the fire, exposed to smoke – typically three to seven hours per day for the rural poor. Women who cook on traditional biomass stoves are up to four times more likely to suffer from chronic obstructive pulmonary disease, such as chronic bronchitis, than women who cook using clean fuels [5]. The energy ladder below shows the link between poverty and use of low quality fuels, leading to IAP and related health issues. The orthodoxy is that as people become wealthier, they move up the energy ladder and take advantage of superior, cleaner fuels.

Figure 2: The energy ladder: household energy and development inextricably linked



Source: WHO: Fuel for Life - Household Energy and Health.
<http://www.who.int/indoorair/publications/fflsection1.pdf>

Since they are mostly responsible for providing food, and procuring energy for cooking food to feed the family, women tend to be most affected by not only IAP but also limited fuel availability, hence gain from cleaner and more energy efficient stoves. Efficient stoves burn less fuel per unit delivered heat than traditional stoves, reducing time spent collecting fuel and freeing-up time for other household tasks and for undertaking paid work to help supplement family incomes. Women are responsible for gathering of fuel wood, which results in back problems from carrying heavy loads, and girls are removed from school to assist with these household tasks [5]. Where fuel is purchased, more efficient stoves would reduce household expenditure for cooking tasks.

A useful way of combining the cost-effectiveness of measures to reduce greenhouse gas forcing and to ameliorate health impacts is illuminated in Figure 1. The analysis indicates that improved cook stoves are more effective in improving health and reducing positive climate forcing than options such as nuclear, wind, hybrid vehicles and solar energy. While transition from coal to LPG stoves in China makes good sense from a health perspective, it is less effective in terms of reducing radiative forcing. From coal to biomass gasification stoves is a very good investment from the perspective of both health amelioration and reduced radiative forcing.

Based upon field research in Mexico, Johnston et al. [8] estimate that the carbon abatement cost from improved stove introduction is \$5 – 8 tCO₂⁻¹ (60% adoption rate, including community and monitoring & verification costs) - a very competitive abatement cost and similar to the values in Figure 1. The double-dividend of health and climate benefits arising from improved stoves appears viable, holding out the prospects for financial support via credits for carbon dioxide (equivalent) reduction. As Simon et al. put it: “There is indeed tremendous potential for both localized ‘intensive’ benefits and also global ‘extensive’ advantages emanating from scaled up carbon-financed ICS (improved cookstove) programs” (page 20, [9]). Johnson et al. [8] discuss and review the potential problems with validating ICS for the purposes of carbon markets, such as variability in: fraction of fuel used which is from non-renewable biomass (since CO₂ emissions from renewable biomass cannot be included), context of use, type of application, the baseline emissions and fuel consumption (i.e. of the open-fire stove). Simon et al. additionally discuss other potential problems including: whether to include non-CO₂ gases or not, leakage (i.e. impacts of change in resource use upon resource extraction by others or elsewhere), and longevity of carbon finance and climate policy [9]. They also note that mutual ‘support’ between health and climate benefits could become an impediment: e.g. the “distribution economies of scale and technology standardization may be ill equipped to satisfy diverse household requirements, leading to the allocation of inappropriate stoves and to continued levels of indoor air pollution” (page 18, [9]). Distribution of stoves which are not suitable for household practices could result in their abandonment or decreased use, hence reducing net greenhouse gas abatement. On balance, however, Simon et al.’s review appears to be cautiously optimistic that the mutual support will be beneficial and that financing through the carbon markets is credible.

A lot of effort has been devoted in the past several decades to developing improved stoves and several types, which reduce fuel use by 40 to 50% with equivalent reduction in associated emissions, are now in production at > 100,000 units per year [1]. Figure 2 compares a number of stove designs in terms of the quantity of black and other organic carbon emitted (converted into CO₂ equivalents) for a given cooking task. The biomass gasification, charcoal and fan-assisted stoves stand out as far superior to more conventional designs.

Charcoal stoves clearly require production of charcoal, which unfortunately has a high carbon emission factor when current charcoal-making technologies are utilized (estimated at 1.9 tCO₂e (equivalent) t⁻¹ woody feedstock, higher than the carbon emission factor for wood combustion of 1.65 tCO₂ t⁻¹) (calculated from data in [10]). Hence, overall, charcoal production and use releases 60% more CO₂e than would arise from the combustion of the same quantity of wood. Note, however, that the source data on which this calculation is based is of a poor quality and a more rigorous programme of empirical measurements of emissions from different charcoal production technologies is required. Fan-assisted stoves require an electricity source, e.g. from batteries, the grid or, potentially, through the use of thermo-electric (TE) devices which convert some of the heat generated by the stove into electricity [1], though TE devices require considerable further development and cost reduction.

Biomass micro-gasification, i.e. in which part of the biomass is converted to a clean ‘synthesis gas’ and burnt, and a solid charcoal residue is produced, emerges as one of the key contending options for improved stove designs. Micro-gasification for cooking purposes has been extensively reviewed recently by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH [11]. A small selection of the stoves

reviewed by GIZ is shown in Figures 3 and 4. Data showing the performance of a number of the top-lit updraft (TLUD) micro-gasification stoves is shown in Figure 5. The two indicators are emissions of carbon monoxide (CO) (red lines) and particulate matter (PM) (blue lines) and threshold levels which have been proposed are show on the left-hand side (20g CO and 1500mg PM for the 5 litre water boiling test (5-l-WBT)). The TLUD stoves clearly have major benefits over traditional stoves and are generally below the threshold levels. Where charcoal produced is not burnt, emissions are lower.

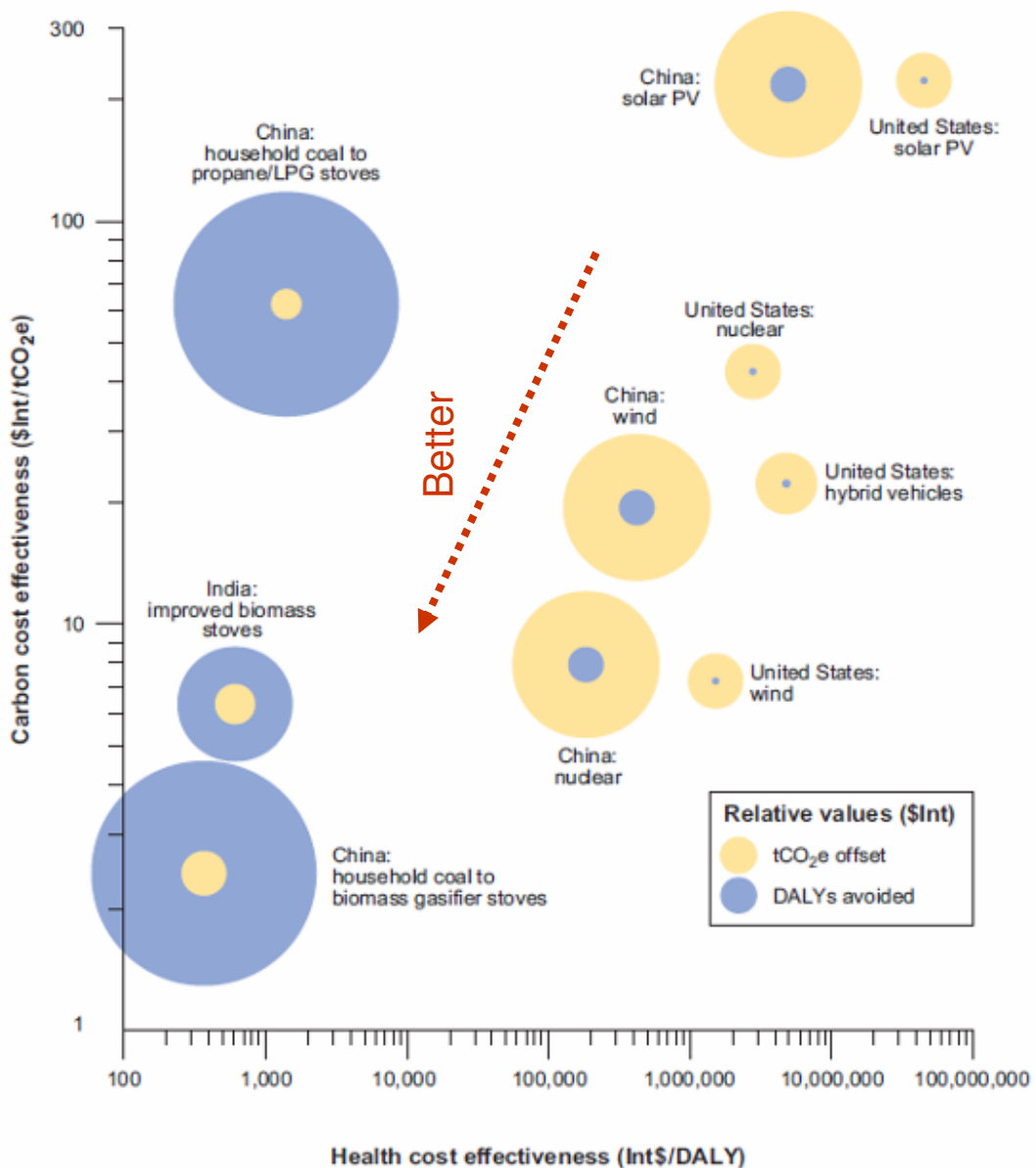


Figure 1: Comparison of the health and climate mitigation cost-effectiveness of household, transport, and power sector interventions. Area of circles denotes the total social benefit in international dollars from the combined value of carbon offsets (valued at 10\$/tCO₂e) and averted DALYs (\$7,450/DALY is representative of valuing each DALY

at the average world GDP (PPP) per capita). (DALY stands for disability-adjusted life year, and is a way of measuring disease burden, expressed as the number of years lost due to ill-health, disability or early death. The more cost-effective the interventions are, the closer to the graph's origin. (source: figure 2, [12])

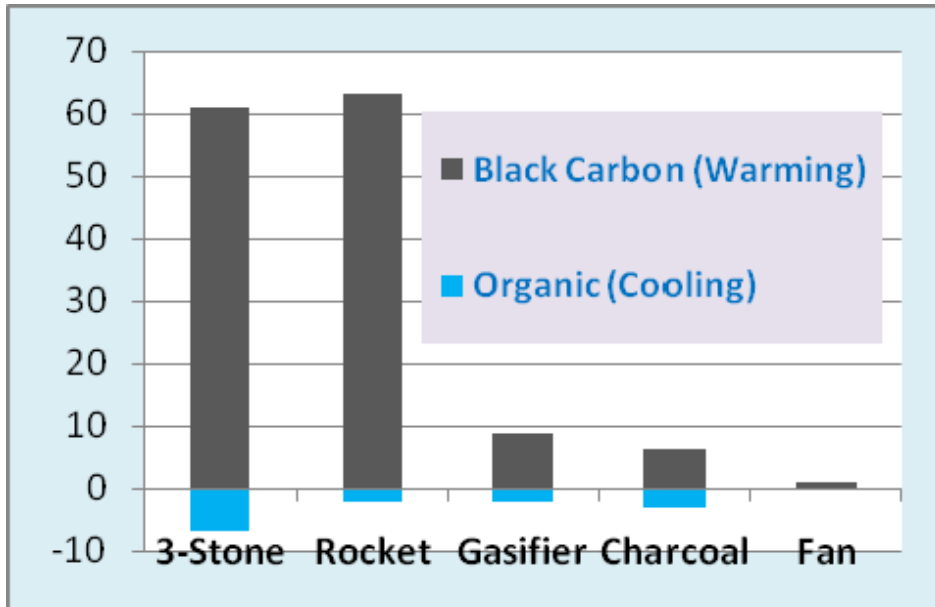


Figure 2. Grams of CO₂ equivalent per liter of water boiled and simmered for 30 minutes for five different stoves. The black carbon (soot) warms the atmosphere and the organic carbon has an atmospheric cooling effect. The fan stove also reduced the time to reach boiling. This graph is adapted from a report on measurements made at the Aprovecho Research Center 2007. The conclusions have been confirmed and expanded in a series of tests performed by the US Environmental Protection Agency in 2009. It should be noted that this figure does not include production of carbon monoxide (CO) emissions which are very significant for the charcoal stove and ignores the emissions from the production of the charcoal. (source, figure 2 [1]).



Figure 3: Four micro-gasification stoves reviewed by GIZ, source: [11]

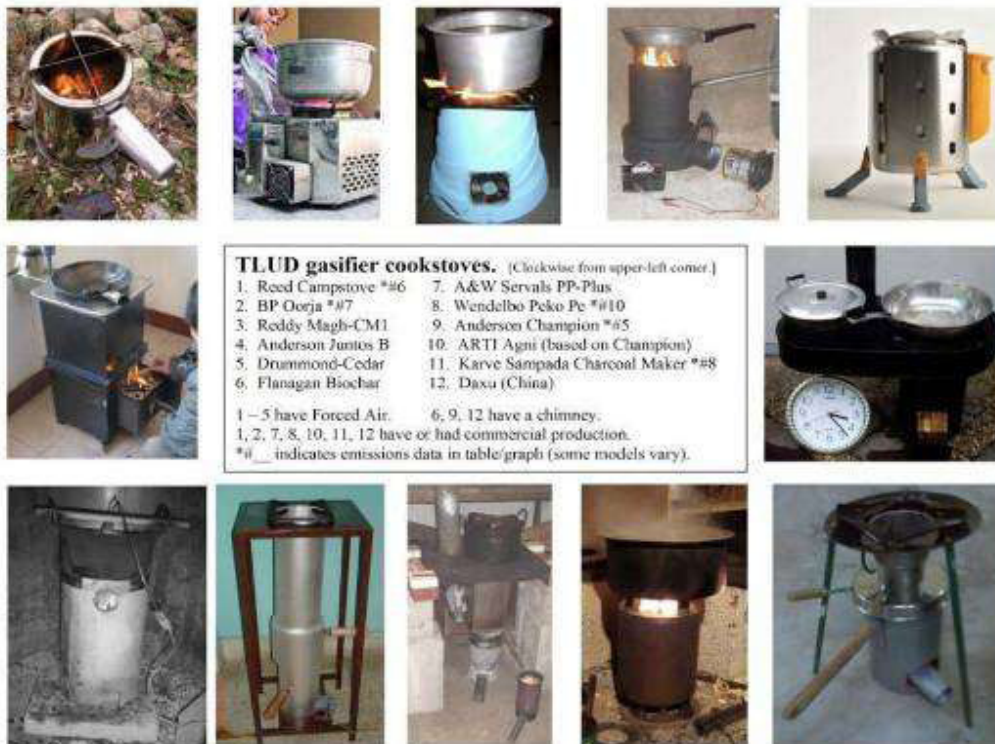


Figure 4: A range of top-lit updraft (TLUD) stoves, source [11]

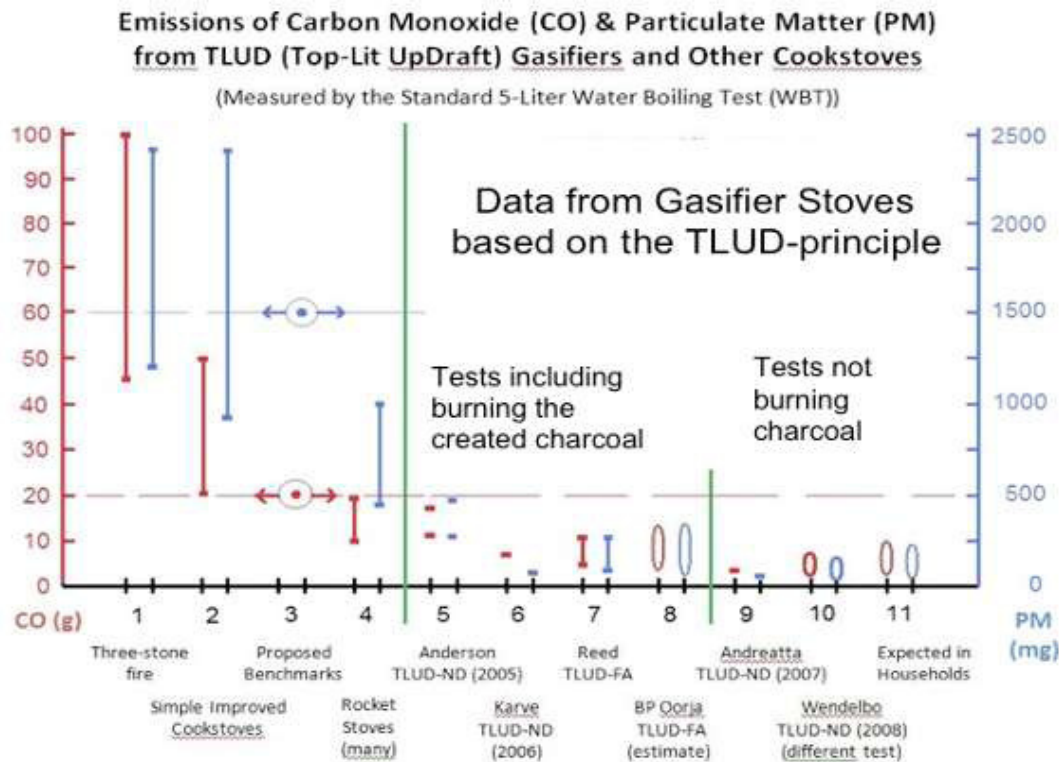


Figure 5: Comparison of the performance of a variety of stoves with respect to: carbon monoxide emissions and particulate matter (PM) *Graph Compiled by P. Anderson (2009), Legend: FA= fan assisted, ND=natural draft.* CO emissions are shown in red, PM in blue: vertical lines indicate ranges of measured data. Source data from Aprovecho Research Centre (Comparing Cook Stoves), other tests by the indicated persons and own estimates. All gasifiers listed are top-lit-up-draft versions. (source [11]).

The fuel consumption of gasification stoves is currently difficult to compare to that of conventional stoves because they are batch-loaded. In the conventional 5 litre water-boiling test, once boiling the water is kept simmering for 45 minutes. This is easy to do for a conventional stove where additional feedstock can be inserted into the fire as required, but not so easy to accomplish in the case of an enclosed gasification unit [11]. Some estimates of fuel consumption use have been presented in reports and results are summarized in Table 2, but we should highlight that the numbers have not yet been verified in the peer-reviewed literature. Fuel reductions from using gasification stoves in the order of 30 – 50% appear to be credible, though it is not entirely clear what is the baseline case being compared to.

Table 2: Some preliminary data on the fuel consumption of gasification stoves

Name of stove	Developer / designer	Estimated fuel consumption or reduction compared to traditional stove or open fire	Source
PekoPe	Paal Wendelbo	768g wood pellets for 5-l-WBT	[11]
Oorja™	FirstEnergy	c.30% reduction	[1]
Philips natural draft woodstove	Philips	c. 50% reduction	[1]
Vesto™	New Dawn Engineering	c. 35% reduction	
BioLite™		42%	[1]

Another important point arises from the work of Johnson et al. [13] who undertake a comparison of GHG emissions associated with the standard WBTs with those from typical stove use in the case of the improved stove the ‘Patsari’ in a rural community in Mexico. Reduction in emissions from installation of the ‘Patsari’ were quantified in both simulated kitchens and in field conditions in eight homes with open fire stoves and 13 homes with ‘Patsari’ stoves. “The results demonstrate that nominal combustion efficiencies (NCEs) of open fire cookstoves were significantly lower ($p < 0.001$) in rural homes during daily cooking activities (89.7 +/- 2.0%) compared to WBTs in simulated kitchens (94.2 +/- 0.5%), which results in almost a doubling of the products on incomplete combustion (PICs) emitted” (page 1206, 2008). In other words, the standard WBT for comparison does not appear to simulate the actual cooking operation very well, leading to an underestimate of the emissions arising from open fires. Furthermore, Johnson et al. found that: “NCEs for the improved ‘Patasari’ stove were significantly higher ($p < 0.01$) in rural homes during daily cooking activities (92.3 +/- 1.3%) compared to during WBTs in simulated kitchens (87.2 +/- 4.3%), as WBTs do not reflect cooking activities in rural homes” (ibid.). This important empirical evidence suggests that use of the WBT is not representative of actual cooking tasks, at least in this field situation in Mexico, and results in an underestimation of the greenhouse gas reduction benefits of replacing an open fire stove with an ICS. There are some potential disadvantages arising from the use of gasification stoves and these are summarized in Box 1.

Box 1: Summary of Benefits and Disadvantages of Gasification Stoves (after [11] with own additions)

Strengths:

- Clean and complete burning of a broad variety of solid biomass
- Currently lowest emissions of natural draft cook-stoves
- High fuel efficiency due to complete combustion
- Can use a wide range of local biomass including residues that can otherwise not be burned cleanly in other stoves
- Less tending of fire with batch-loading
- Ready for use immediately after lighting

Weaknesses:

- Regulation of firepower (turn-down ratio) can be difficult

- Difficulties to extinguish gas-generation at the end of the cooking process before all fuel is consumed
- Inflexibility of cooking times with batch feeding device that cannot be refuelled during operation
- Require fire-starting material to initiate pyrolysis in the gas-generator
- The stove can be too high to fit-in with usual cooking practices (e.g. where the custom is to sit or squat on the floor)

Opportunities:

- Gasifier units can be attached to existing stove structures to broaden the range of usable fuels, giving users the choice to use what is available at the moment
- Can create charcoal as by-product of cooking
- Enable carbon-negative cooking if char is saved and used as biochar
- More efficient stoves might enhance the quality life, e.g. through providing 'spare' fuel for water heating

Risks

- If the flame of the combustion unit extinguishes and the gas-generator keeps on producing woodgas, thick smoke leaves the unit unburned. How people learn to avoid this risk needs to be assessed, and to see how different this is from the same phenomenon in a regular smoky smoldering open fire without flame
- People may continue to collect the same amount of wood for stoves as they did prior to using the gasification unit, so savings will not materialize, and either cooking itself will become less efficient, or else the extra fuel will be used for some other purposes
- Poor people selling firewood to institutional buyers (e.g. schools) will lose out as demand decreases (though again a 'rebound effect' might occur whereby a new or enhanced service or utility is exploited, hence demand could remain the same).

Biochar Stoves

A modified use or design of micro-gasification stoves can also be used to produce 'biochar', which is a potentially valuable soil amendment as well as a long-term carbon store. In this project, we explore the opportunities and barriers associated with such biochar stoves and examine the role of innovation in their further development. There are two different ways in which biochar can be produced in stoves.

- a) In the chamber of a gasification stove through removal of the char before it combusts and turns to ash, or alternatively through water-quenching of the char to prevent combustion. (Technically these are 'autothermal' stoves, in which the fuel is directly pyrolysed with a flaming pyrolysis [11]).
- b) In stoves which have two fuel containers. The outer fuel container is packed with biomass and is heated by the combustion or gasification reactions taking place within the inner fuel container. The heat converts the biomass in the outer container into char. An example is the Anila micro-gasification stove. Some of the key processes occurring in a stove are described in Box 2.

Box 2: What processes occur in cook stoves to produce biochar?

Gasification stoves involve two processes. First, solid biofuel is pyrolysed into a mixture of hydrocarbon-containing gases and charcoal. Second, the gases are burnt with a clean (smokeless) flame. When the stove is used to make charcoal, the operation of the stove is stopped at this stage and the charcoal is removed as a by-product. If the charcoal is left in the stove, it will usually burn releasing more heat and leaving ash. A primary air flow is required for pyrolysis, while a secondary air flow is introduced into the hot gas above the fuel in order to assist the gas burn [7].

Organic matter used as fuel in stoves is converted thermally into syngas, solid residue (including biochar and ash) and liquid (including tars). Similar processes occur in large-scale gasifiers, and are designed to maximise the gas production which can be captured and then used for electricity or heat generation. However these conditions are generally created in stoves using simple technology to maximise heat production for cooking. Depending on the type of stove, a mixture of processes will occur at any one time during use of the stove. Pyrolysis, gasification and incineration will occur to varying degrees and at different stages in the burn, and in different places within the stove.

Pyrolysis: Pyrolysis is chemical decomposition at high temperatures. The word comes from the Greek-derived 'pyro' fire, and lysis 'decomposition'. Unlike for combustion, oxygen or any other reagents are not required. Thermal cracking of organic matter occurs in the absence of air. Industrial processes can be divided into fast and slow pyrolysis. Slow pyrolysis involves a slow heating rate and a peak temperature that is generally between 400 – 600°C. Carbonisation occurs together with production of syn-gas and liquids.

Gasification: During the gasification stage, a small amount of air is required but not enough to complete the burn. In gasification cook stoves, it is the syngas which is burned to produce the heat. The gas consists of carbon monoxide, methane, carbon dioxide and others, depending on process conditions.

Incineration: This is the process of full combustion in an oxygenated environment. The char produced by pyrolysis in a micro-gasification stove will usually be incinerated to ash.

What is biochar?

First coined by Peter Read, biochar refers to charcoals which are prepared for carbon storage while potentially allowing soil improvement [14, 15]. A more technical definition is that biochar is a "porous carbonaceous solid produced by thermochemical conversion of organic materials in an oxygen depleted atmosphere which has physiochemical properties suitable for the safe and long-term storage of carbon in the environment and, potentially, soil improvement" page 9, [16].

Carbon storage

Plants take-up carbon dioxide from the atmosphere during photosynthesis and a proportion of this can be fixed in biochar and stored long-term in soil [17]. Biochar

persists in the soil because it is resistant to microbial degradation [18]. A review of the literature suggests a Mean Residence Time (MRT) of somewhere in the order of 1000 to 1500 years [19, 20]. Other studies suggest that biochar can persist in soil for 5000 years plus [18]. Such long-term carbon storage begs the question of whether carbon credits are potentially available from improved cook stoves that produce biochar for storage in soil.

Soil improvement

Biochar modifies the physical, chemical and biological properties of soil [16, 21]. It can improve water retention, enhance the infiltration of water into soils and reduce tensile strength (enhancing the 'workability' of the soil). Biochar provides some nutrients to soil, including phosphorus, potassium, magnesium and other micro-nutrients (reflecting the composition of the original feedstock). While approximately 50% of the nitrogen in the feedstock is retained in the biochar, it appears to be locked-up in the chemical configuration of the biochar and therefore largely not available to soil microorganisms or plants. Biochar also contains labile carbon which will be utilized by soil microorganisms, potentially increasing the demand for nitrogen, so care has to be taken that biochar addition does not create a problem of nitrogen deficiency in the soil. Biochar appears to enhance the Cation Exchange Capacity (CEC) of soil over time, possibly through slow oxidation of the biochar surfaces. These properties can all potentially lead to benefits in agricultural soils and a large number of field trials have been undertaken in the tropics and sub-tropics which demonstrate yield improvements. The results of a review by Verheijen et al. [22] of biochar crop trials is presented in Figure 6.

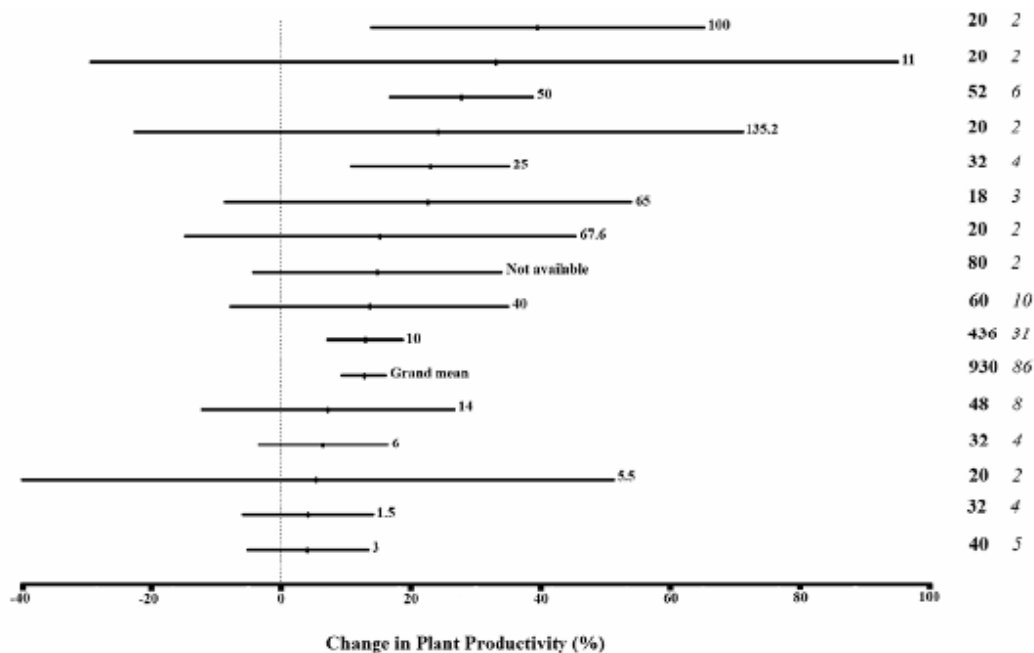


Figure 6: The percentage change in crop productivity upon application of biochar at different rates, from a range of feedstocks along with varying fertiliser co-amendments. Points represent mean and bars represent 95% confidence intervals. Numbers next to bars denote biochar application rates (t ha⁻¹). Numbers in the two columns on the right show number of total 'replicates' upon which the statistical analysis is based (**bold**) and

the number of 'experimental treatments' which have been grouped for each analysis (italics) (from Verheijen et al. [22])

The sample means indicate a small, but positive, effect on crop productivity with a grand mean of c. 10%. While there is some apparent trend of increased biochar additions resulting in higher yields, this is not statistically significant at the $P = 0.05$ level as can be seen from the overlapping error bars at the 95% confidence interval. Biochar additions at rates of 10, 25, 50 and 100 t ha^{-1} led to statistically significant increases in crop yields compared to a control with no addition, though other studies using 40 and 65 t ha^{-1} did not show any statistically significant yield increase. Figure 6 illustrates that there is a wide variance in the response to biochar addition, e.g. at the 5.5, 11 and 135.2 t ha^{-1} application rates. Verheijen et al. speculate that the reasons for this are variability in the biochar, crop and soil types. They also note that the means for each application rate are positive and that no single biochar application rate had a statistically significant negative effect on crop productivity. The studies they examined do not cover a wide-range of latitudes and are heavily skewed towards (sub-) tropical conditions.

Fuel

Only if char is added to soils do we call it biochar. Where char is used as a fuel we call it charcoal. These definitions help to distinguish biochar from charcoal and avoid problems over allocation of carbon abatement. The fact that char can be used either as a fuel or as a soil amendment is potentially important as it represents flexibility and indicates multiple-uses / users. Such flexibility has been shown to be important in accounting for successful technological innovation [23].



Figure 7: Charcoal briquettes, ARTI India (Picture by Harry Thompson)

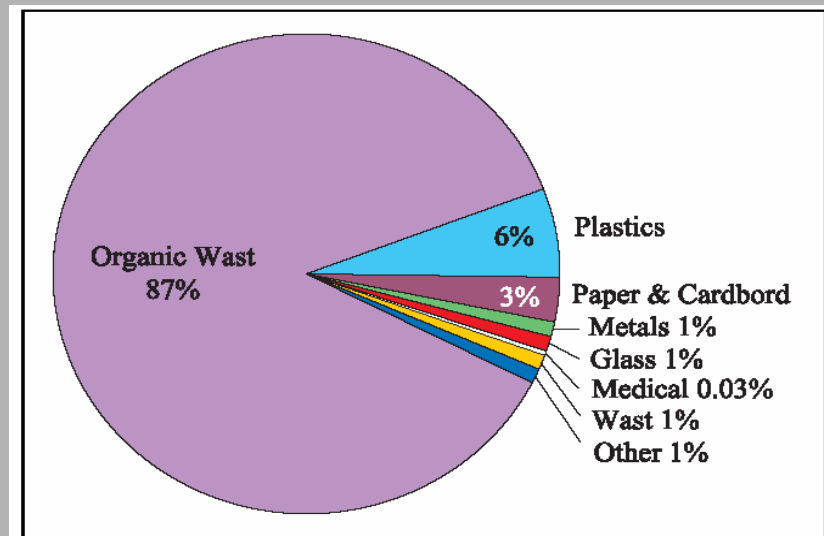
Charcoal produced in a gasification or pyrolytic stove has superior fuel qualities to the dried biomass from which it is produced. Charcoal is a more energy dense material than its feedstock, e.g. the calorific value of charcoal is typically 25 to 28 MJ kg^{-1} while that of

wood c. 16 – 18 MJ kg⁻¹ and straws, husks, etc. often less. Charcoal has a low moisture content and is a more homogeneous fuel than biomass [24]. Charcoal is easy to light and burns without a high flame; it produces very little smoke due to removal of most of the more volatile organic matter during pyrolysis. Biochar produced from different parts of the same tree can differ with respect to ash content [24]. The grindability of char was found to vary, that produced from wood being the highest. Ability to grind the material is important in processing, for example into pellets or fuel briquettes. Charcoal is typically soaked in water and then mixed with a binder (commonly clay or a starchy material, for example rice mill waste). An extruder can then be used to produce the briquettes. In India, char briquettes are being marketed successfully by ARTI (see Figure 7) and in Cambodia, such char is being produced commercially. Several companies and NGOs are specializing in the production of such 'green charcoal' from agri-residues as an alternative to wood charcoal (Box 3).

Box 3: GERES Green Charcoal, Cambodia

Fuel consumption in Cambodia:

- 80% of the population use biomass as their main source of energy to meet their daily needs
- The total wood demand is estimated at 2,300,000 tons* per year
- The total charcoal demand is estimated at 240,000 tons* per year, equivalent to 1,500,000 tons of wood. Every year, the equivalent of 39,000 soccer fields of forest is cut to make charcoal.



Source. CSARO, 1999 in Interconsult/ADB/MPP

The types of waste produced in Cambodia are shown in the pie-chart above.

The next step is scale-up to produce charcoal as the main product from organic waste streams:

- Heat used for other purposes like biomass dryer
- Organic waste (coconut waste, char from garment factories, mixed organic waste, sugar cane waste and rice husk - some has to be purchased but the majority is available free) transformed into sustainable fuel
- Charring yield: 20%

- Energy efficiency: 75%

Overview of production process:



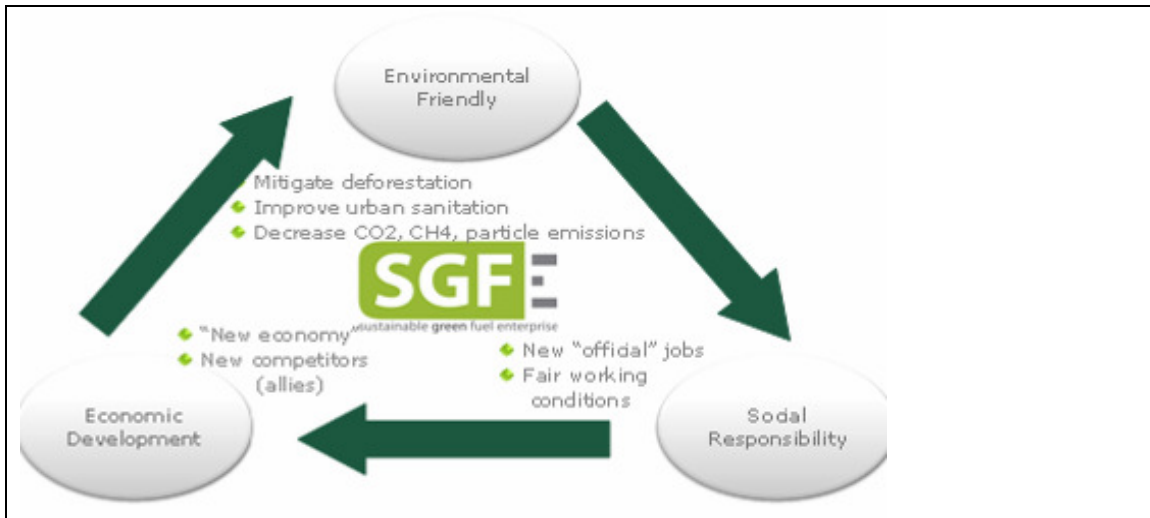
100% renewable product - better composition than wood charcoal

- Longer burning time, higher calorific value
- No sparks, no dust, no smell, less smoke
- Manageable and clean to use
- Standard product: reliable and consistent quality

ENVIRONMENTALY FRIENDLY

Sustainable Green Fuel Enterprises

- About 20 full time jobs, recruited from the poor communities of Stung Meanchey
- Socially fair working conditions
- Initial production capacity of 700 kg/day
- 1kg of char-briquettes saves 6.5 kg of wood (4.5 tons/day in total)



An already demonstrated mechanism for obtaining carbon credits in the Voluntary Carbon Market (VCM) is through avoided deforestation arising from the fuel savings from more efficient use of wood in cook stoves (see Box 4). Another example is the NGO and company Pro-Natura which has developed a slow-pyrolysis kiln for producing charcoal from agricultural residues such as husks, shells and straws (Box 4). Carbon credits were obtained for the charcoal from the VCM on the basis that such fuel production represents avoided deforestation.

Box 4: Case study of Carbon offsets in the Voluntary Carbon Market through Charcoal Production

1. Case study One: GERES Cambodia Fuel Wood Saving Project

GERES (Groupe Energies Renouvelables, Environnement et Solidarités) successfully accessed carbon finance for a stove development and distribution project. The New Lao stove, an improved charcoal stove, was distributed into Cambodia as part of the Cambodia Fuel Wood Saving Project (CFWSP). This stove saves 22% of wood compared with traditional stoves, and since the project was initiated in 2002, over 20,000 stoves have been distributed. Carbon credits in the Voluntary Carbon Market (VCM) are calculated from the fuelwood savings, and buyers include the Agence Française de Développement (AFD). In 2008, the AFD purchased 60,000 t CO₂. From 2003 – 2009, 769 000 tCO₂e have been saved through the project. More information is available from [25].

2. Case-study Two: Pro-Natura Green Charcoal

Pro-Natura produces 'green charcoal' from agri-residues in its 'Pyro-7' kilns producing up to 900 tonnes per year with a char yield of 33% [26]. At 3 to 4 tonnes per day production, the green charcoal can provide the energy needs of c. 20,000 people. Pro-Natura has estimated the CO₂ equivalent emissions reduction from green charcoal to be 11.6 kgCO₂e per kg charcoal [26]. This is calculated as the consequence of avoided deforestation (7.7kgCO₂ kg⁻¹ charcoal), avoided methane (from charcoal production, all vapours having been combusted) (2.7 kgCO₂ kg⁻¹ charcoal) and avoided burning of unused biomass (0.18 kgCO₂ kg⁻¹ charcoal), against which project-based emissions of 0.12 kgCO₂ kg⁻¹ charcoal have to be included. Expressed per unit biomass, the net carbon equivalent abatement is just under 4 kgCO₂e per kg biomass, giving this a very high carbon abatement efficiency (e.g. most biochar systems appear to abate from 0.8 to 1.4 tCO₂e t⁻¹ feedstock) [27].

3. Objectives

The aim of this project is to conduct a stakeholder-based critical analysis of the potential for biochar gasifier stoves to provide benefits to poor households hence to contribute to poverty alleviation and socio-economic development. The project has undertaken original field research as well as several workshops to build-up knowledge and understanding of the biochar stove as a possible bio-innovation. The main objectives of the research are to:

- establish and facilitate a process of dialogue and stakeholder engagement regarding the potential role of biochar produced from stoves;
- devise prototype guidelines, protocols and standards for how biochar can, where appropriate, be encouraged and how its deployment can be properly managed, and;
- advance conceptual understanding of participative, distributed innovation processes (PDIPs).

In order to engage with stakeholders effectively and meaningfully, it was necessary to obtain independent information on the performance of different biochar-producing stove designs. In neither of the project areas did the residents have much of a choice of stoves to use; therefore it was difficult to evaluate performance with respect to existing use. We therefore had some different biochar-producing stove types manufactured and set up standard controlled and user-tests (e.g. WBTs). While we noted above the limitations of such standardized tests pointed out by Johnson et al. [13], we did not have the resources to use more credible field conditions for testing. Furthermore, such alternative field testing methods have not yet been standardized, so making comparisons problematic.

Participative Distributed Innovation Processes (PDIPs)

A key starting point for the study arises from innovation studies which, over the past several decades, has highlighted that innovation is a distributed process involving inventors, innovators, users and distributors; and that, consequently, tradition, perception, inertia, practice, routine and behaviour all play key roles in understanding the response to, uptake of and popularity of new technologies. This led to the view that the users' perception of stoves would depend not only upon objective measures of mitigation of indoor air pollution (IAP) or resource use efficiency, but also upon their perception of new designs, the fit with existing cooking practice, preference and habits and with other cultural factors. Furthermore, in offering-up a 'solution', a community has to agree with the identification and definition of a corresponding 'problem' to which the proposed innovation is an answer. Garrett et al highlight that no 'one stove size fits all' and promote the concept of a 'cook stove user space' [1]. They advise that more understanding of different user communities is necessary and that stove design needs to respond to the cooking requirements of each of these user communities. This work attempts to contribute to such an effort.

Within the discipline of 'innovation studies' an important distinction is made between the 'inventor' and the 'innovator'. The inventor comes up with the novel design, technology or idea; the innovator is the one who makes that invention commercially viable (or successfully promotes the technology such that it is widely adopted). An invention can be made by a single individual, whereas innovation involves a number of individuals and usually organizations.

Innovation is rarely a linear process in which a technology is developed and launched on to an unsuspecting public (the 'supply-push' model). On the other hand, innovation tends not to be the direct result of the public (or sub-set of) demanding a specific technology (the 'demand-pull' model). A more realistic depiction is that innovation is the co-product of supply-push and demand-pull. In this version, some users get involved in quite detailed ways in the innovation process, as do distributors, sellers, marketers, consultants, advisors, enthusiasts and so on. For this reason, and because innovation rarely has a discrete endpoint, the co-production model has also been described as 'distributed innovation processes'. Another framework of use here is the concept of 'instituted economic processes' and 'embeddeness', whereby innovation is a process which takes place within a social context and in relation to institutions and social practices, a perspective often associated with Karl Polanyi [28, 29].

The motivations for innovation are many but can include the attempt to address a perceived 'social problem'. In such cases, there is often a deliberate effort to engage the potential users of the technology or new design using one of the repertoire of methods which have been tested by firms and social scientists. This includes questionnaires, focus groups, in-depth discussion groups, market-mapping, participant-observation and consensus conferences. Clearly, the more interaction the designer / developer has with the target community a technology is intended for, the more the design is likely to reflect current preferences and perceived needs. In many cases, though, applications of new technology cannot be fully predicted in advance. An example is the popularity of SMS text messaging on mobile phones, which mobile phone operating companies did not originally predict to be so popular and one of the key functions of mobile telephony. Hence, there is frequently an element of uncertainty and surprise associated with innovation as new technologies, designs, practices and ideas become more widely disseminated.

In practice, innovation has often failed to reflect and balance the needs of suppliers and users. In some cases, technologists and designers have been guilty of pushing their ideas too hard and capturing the attention of potential funders and marketers, resulting in products and services which do not sufficiently reflect user needs. In other cases, mediators between inventors and users, such as finance houses, NGOs, government agencies, and companies with a dominant market position, play the critical role in shaping innovation. Development agency GTZ notes that:

"Which design gets promoted by project developers – often this is based less on need and more on which technological innovation the funders want to fund. They may perceive a design which an organization wants to promote unsuitable, due to their own constraints on what they can fund, they may think the design is 'before its time', or for another reason." ([30]).

In order to improve stove design, the needs of the user have to be assessed. Women are likely to be the main users of stoves, and can be consulted regarding design

innovation by accessing women’s groups and by user testing in households. Where questions specific to women are being discussed, it is beneficial if the enumerators are women to encourage discussion and to allow opinions to be voiced freely. A new technology is more likely to empower women where women are given some control in the development of the technologies and are involved at all stages of the process. Since cooking is an activity that is closely-related to cultural practice and tradition, women should be directly involved in developing solutions which suit their preferences and circumstances [5] .

Function of stove

A designer may design a stove with a particular cooking task in mind. Different tasks require different levels and durations of heat and also the ability to vary the flame intensity throughout the cooking process. Cooking is not the only use of a stove. This means that not all stoves may be suitable for all activities or even all cooking tasks. Some of the different uses of stoves in Cambodia and India are shown in Table 3; for some tasks specific stoves are employed, e.g. making palm sugar in Cambodia.

Table 3: Uses of stoves in Cambodia and India

<ul style="list-style-type: none"> • Cooking meals for family • Light / heat 	<ul style="list-style-type: none"> • Boiling water (non-food household use i.e. bathwater) • Brewing drink to sell 	<ul style="list-style-type: none"> • Boiling water to drink • Making animal feed
<ul style="list-style-type: none"> • Income generation cooking (food e.g. palm sugar to sell) 	<ul style="list-style-type: none"> • Other for income generation (e.g. textiles) 	<ul style="list-style-type: none"> • Curing tobacco

Barriers to uptake

Just because a stove is deemed to be ‘improved’ by a designer, does not mean that it will be regarded as such and adopted by target groups. In the literature there are many examples of projects to introduce improved stoves, but where stoves were not adopted at all or were adopted but rarely used. Reasons given for lack of success in projects have included poor project management and also poor design of the stove for the intended purpose. Below are some potential reasons for failure of uptake, relating to the features of the stove, and also the management of the project (mainly from [31]).

Stove

- Where the cost of the stove is high, this represents a risky option for low income users.
- The functionality may also be undesirable to users, for example where stoves are designed to reduce smoke, which traditionally would be useful to reduce the incidence of insects and for space heating.
- Lack of awareness of the local energy ladder and the tendency to move along it.
- People cook in the open, so benefits of smoke reduction are not so appreciated.
- The stove is difficult to light or use (often an unfamiliar stove is rejected because it requires learning to cook in a new way).

- The use of fuel specifications which are not available or easy to get (size and type of fuel).

Project Management

- Subsidies or free distribution of stoves are thought to give a lack of ownership of the stove, and can lead to less intensive or no use. Where stoves are given away, there is also the danger that they will be sold-on and a rule of thumb is that the minimum distribution price is double the salvage value.
- Lack of consultation, inappropriate timing, lack of permissions (from governmental and village leaders) and lack of involvement of the main stove users (usually women) means that people may not be predisposed to accept the technology.

Jan undertook a survey of users of 100 randomly selected households in two villages of rural northwest Pakistan and found that education and household income are the most significant factors determining a household's willingness to adopted an improved biomass stove [6]. However, Jan asked the household head, usually a man, rather than the cook, usually a woman, and there may be differences in perception that are related to gender.

Criteria for an improved design

The original motivation for improved cook stove design was to increase efficiency, and, more recently, there has also been a stronger focus on reduction of emissions by an improved design. This is reflected in the development of tests for improved stoves, which typically measure efficiency (wood consumption, thermal efficiency etc.) as is measured in the 5 litre water-boiling test and also in emissions testing. There is sometimes a focus on the ability of a stove to perform its function – to cook food or boil water, and this is partly measured in the development of the Kitchen Performance and Controlled Cooking Tests. The suitability of a stove to perform different cooking and other functions is likely to be important for users in their selection of a stove, as well as cost of the unit. A list of established stove design criteria is presented in Box 5.

Box 5: Stove design criteria

General:

Safety
 Smoke reduction
 Cleanliness / hygiene
 Fuel reduction
 Durability (spare parts availability and ease maintenance)
 Portability
 Familiarity
 Time saving in total
 Prestige / socio-cultural

Stove production considerations:

Accessibility
 Affordability
 Consumer driven technology
 Link with NGO's
 Level / appropriateness of technology
 Production possible by local tinsmith

Production possible by mechanical workshop
Welding required
Mass-production applicable
Access to templates and plans
Flexibility in raw materials required

Cooking considerations:

Filling with fuel, and feeding during burn
Ash / biochar emptying
Burn time (time of flame for cooking)
Time suitable for simmering
Time of burn unattended (for heating)
Ability to boil and keep hot large amounts (10L or more) of water
Speed of cooking (heat consistency)
Cooking cultures
Ease of ignition
Management of fire
Good taste of food
Can use a variety of feedstocks
Ability to vary flame / temperature

Biochar production:

Biochar production quantity / quality
Farming methods and requirements
Market creation for biochar or other potential end use of biochar

References:

Robert T Bachmann presentation – Workshop: Biochar Malaysia. University of Kuala Lumpur. 25 March 2010.
Paal Wendelbo's ideas for stove design: <http://www.bioenergylists.org/content/criteria-selecting-g>
[32]

One case study where the designer interacted with target communities to provide a 'fit for purpose' stove is the development of the Sampada and Sarai cooker at ARTI (Box 6). The demand by users of charcoal, a popular fuel higher up the energy ladder than biomass, was recognized by ARTI during the stove design process. However, as the case study illuminates, the production of charcoal has not yet been a driver in the uptake of the Sampada stove. The case study highlights the need for in-depth and sequential user-feedback and inputs and the need for the stove designers to be responsive to the user feedback. It also shows the importance of fitting the design to the need, e.g. in respect of shape, flexibility, portability, functionality, etc. The aesthetics of appearance and packaging are also important factors, helping to make a product more popular amongst consumers and merchandisers. It is not only consumers with larger expendable incomes who are swayed by design and appearance.

Box 6: Development of Sampada and Sarai Stoves in India

The Sampada is a gasification stove developed by ARTI and its sister company Samuchit which is composed of an inner and outer chamber and a pot raiser lid and is lit from the top. The Sampada can be used for producing charcoal as a by-product which can then be used in the Sarai cooker: The Sarai is "...an assembly, which is capable of cooking a meal for a family of five using just 100g of char briquettes (or char produced using the Sampada stove). A housewife, using a traditional wood-burning cookstove, would have to use about 3kg wood

for cooking the same amount of food.” In ARTI’s view, it makes sense to combine use of the Sampada and Sarai stoves, the former being used to produce charcoal that is then used in the latter. The Sampada gasifier stove has negligible emissions after the first ten minutes, operates for about 30-40 minutes per batch of 1 to 1.5 kg fuel (depending on fuel type), and produces about 200-300 gm of charcoal as a by-product, which can be used as biochar or as a fuel.

The following account is taken from the case-study by the stove’s designers, Dr Priya Karve and Dr A.D. Karve ([7]). The development of the Sampada involved recruiting users and self-help groups to provide feedback on the stoves and modifications. The users covered a range of economic groups and geographical areas.

The stoves were provided and used for one month prior to feedback being sought from 10-20% of the user group. Information from users of the prototypes covered the following five topics: fuel saving (compared to other stoves used); ease of lighting and use; cooking needs addressed (or not) by the stove; appropriateness of the price of the stove given its benefits; and suggestions for improvement.

The first design was a fixed version, but this was not popular and was withdrawn early on and a portable version developed instead. However, the first portable stove was quite small and users of the c. 300 stoves fabricated found that it was only suitable for small tasks such as making tea and snacks. A larger model was consequently developed and the metal was changed from mild steel to galvanised iron sheet to limit costs. User feedback indicated that the stove was a bit unstable when large pots were used and when food was being stirred; this led to the use of stronger leg supports.



Further, the users felt that the stove could look more attractive and that this would justify the cost of c. Rs. 800. The outer chamber was consequently fabricated from stainless steel, such that the stove has an attractive appearance. The stove is also packaged in a box which seems to improve its attractiveness to merchandisers and buyers alike. The following feedback was obtained from the user groups who tested the stoves.

1. Users are unwilling to spend more than Rs. 800 – 1000 on a wood-burning stove.
2. The stoves appeared to be more popular in peri-urban and urban areas than in rural areas. In rural areas, there appears to be less acceptance of a modification to traditional stoves, e.g. in which the fuel is fed from the top and where the method for lighting and maintaining the stove is different.
3. The designers believe that: ‘the main feature of the gasifier stove is its ability to produce charcoal, a high value product’ ([7]). However, ‘very few customers .. seem to grasp and value this feature’. The designers go on to remark that they are not sure whether this is because of a lack of awareness of the stove’s functionality, or whether it is simply not a valued function.
4. The gasifier stoves demand fuel that is cut up into small pieces compared to traditional stoves and this puts some users off. However, those users with more disposable income (generally in peri-urban areas) indicated that they would be willing to purchase fuel cut to the requisite size.

The Sampada is cost effective, paying for itself through reduced fuel purchases in two months, after which savings of Rs. 20 per day are possible (where fuel wood is purchased). The benefits of reduced smoke, cooking time, etc., are additional. However, very few of the test users were using the Sampada as their primary stove. Instead, the stove has tended to be used as a secondary device, for heating hot water (e.g. for bathing) or for cooking part of a meal. The reluctance to use the Sampada as the primary stove appears to result, not only from the need for fuel processing, but also from the difficulty in controlling the flame strength (turn-down/up ratio), either increasing or decreasing the heat rate. Such control is valued during cooking. A further disadvantage is that it is not really possible to add additional fuel to the stove during the cooking process if this is required. These aspects make the stove somewhat inflexible when compared to the liquid or gas fuel alternatives (LPG, CNG, etc.). Cooking many Indian dishes requires relatively high heat at the start followed by a much lower heating rate; yet the gasifier stoves will take some time to produce the maximum heat rate, after which they continue at that rate till the biofuel is fully utilized. This fuel burn characteristic means that the Sampada stove is well suited to boiling water, however, and this can be an important application for the stove.

Refs: Dr Priya Karve and Dr A.D.Karve, 'Gasifier Stoves using Biomass as Fuel', unpublished report, ARTI, January 2009, Pune, India. [7]
Rural Technologies Developed by ARTI', Appropriate Rural Technology Institute (ARTI), June 2008. [33]
http://www.samuchit.com/index.php?option=com_content&view=article&id=1&Itemid=3#sara

4. Project activities and Research Methodology

4.1. Project location

Cambodia

The Human Development Index (HDI) for Cambodia is 0.494, which gives the country a rank of 124th out of 169 countries for which data is available (2010 figure). Life expectancy is 62.2 and under 5 mortality is 69/1000 live births. On the other hand, after years of strife and hardship, Cambodia is currently undergoing fast economic development.

India

India has a HDI index of 0.519, which is 119 out of 169 countries (2010 figure). Health issues are among the key social problems identified in India, and life expectancy is 64.4 and under 5 mortality is 90/1000 live births. The state of Maharashtra, where the research took place, is currently undergoing rapid economic development, with a growth rate of c. 9% per annum.

What improved stoves are available in India?

Many improved gasification stoves have been designed, and are available, in India. ARTI has introduced gasification stoves - the Sampada and the Ageni stove - mainly in Maharashtra and adjacent states. Over 100 of the Sampada have been sold in semi-rural communities (as of 2009), through the company Samuchit Enviro-Tech Pvt Ltd. At

present there is little deployment in more remote locations. Several other gasification stoves were also developed in India, notably the Magh series available from Dr Sai Bhaskar Reddy, the Navagni, the Oorja and the Philips natural draft woodstove. According to HEDON's stove database (January 2010), 13 gasifier stove types have been deployed in India. The Anila stove, which chars biomass placed in an outer fuel container, is an alternative design from the perspective of biochar production.

What improved stoves are available in Cambodia?

In Cambodia, there are, according to HEDON's stove database, just three improved stoves which have been deployed. GERES has previously worked on the development of a TLUD design to assess its potential (see Box 7).

Box 7: GERES: TLUD development, Cambodia

T-LUD: Top-Lit Up Draft Technology introduced into Cambodia. First developed by Paul S. Anderson, adapted and introduced by GERES Cambodia in 2006.

Main advantage:

- More efficient: 40% compared to the traditional stove
- Clean cooking: very low emission of CO and PM
- Reduce deforestation
- Charcoal as a by-product

Introduced as a pilot project with 22 families during 3 months.

Lessons learned:

- TLUD production: need to standardize in order to be efficient, safe and reliable - more work required on the design
- Fuel production: traditionally used wood is too big for the burner, and small residues were not standardized; therefore there is a need for local production of standardized sustainable fuel at a low cost –
- Distribution network: easy access for user - difficult to ensure for remote households, and expensive set-up requirements

The project was not extended during that time, since GERES did not see the potential for the stove to be used as a household cook stove. However the stoves were introduced into a programme for the production of charcoal briquettes.

Source: Presentation by David Beritault, Geres at the Biochar: Production & Use workshop, Cambodia 22-23.11.2010. Presentation available: <http://biocharinnovation.wordpress.com/workshop-cambodia/>.

4.2 Stove designs

For this project a few stove designs were selected, representing the types of technology which were, or could be, easily fabricated using locally available materials and production methods and which could, potentially, produce biochar. The designs for many gasification stoves are freely available on the internet so where a suitable unit could not be found, they could be fabricated. (Many stove designers have not sought to patent or copyright their designs). Three well known gasification stove designs in which all the fuel is placed in the central cylinder, and subject to flaming pyrolysis, were selected. In

addition, we selected one stove (Anila), in which biomass to be charred is situated in the outer fuel container.

4.3 Stove fabrication

Where available, stoves for this project were purchased, and otherwise they were fabricated for the project. Since no gasification stoves are commercially available in Cambodia, the stoves (TLUD, EverythingNice and Anila) were made from sheet Iron (1.2mm thick) at the [Iron Workshop](#), Siem Reap, Cambodia. The Sampada used in India was produced by [Samuchit Enviro Tech Pvt Ltd](#), India. Although manufacturing of the Anila is apparently occurring in India, attempts to contact the producers were unsuccessful so the Anila used in India was produced by an artisan using 22 gauge galvanised steel. Measurements from the following selected stoves in Cambodia are reported in Table 4. More information on each of the stoves used is presented next.

Table 4: Dimensions of the stoves manufactured in Cambodia for the study

Name	Designer	Weight (kg)	Inner chamber height (cm)	Inner chamber diameter (cm)	Inner chamber volume (sq cm)	Outer chamber height (cm)	Outer chamber diameter (cm)	Outer chamber volume (sq cm)
Anila	Professor R. V. Ravikumar	5.4	37	15	5949	37	28	16244
TLUD	Anderson	4.1	29	16	5125	30	19	3381
Everything Nice	WorldStove	3.5	21	16	3711	33	19	5645
Sampada	Karve	3.5	25	20	7540	33	24	7389

4.4 The Anila Stove

The stove was designed by Professor RV Ravikumar, of the University of Mysore in India. Over 2500 units have been manufactured in India to date. This stove is a TLUD with a double chamber design, which produces char through external heating of biomass (i.e. unlike the more usual flaming pyrolysis): hence the charring process can be better controlled and combustion of the char avoided. The inner chamber is filled with wood or another feedstock which is burned, and the outer chamber, which is a limited oxygen environment, is filled with the feedstock to be charred (for example rice straw). Pyrolytic gases from the outer fuel chamber flow into the inner chamber and are combusted.

This stove has been deployed in Tamil Nadu in India, where (it has been reported) up to 70% of agricultural residues are discarded or burned (the remaining 30% are used as fodder). The stove can use this resource to produce an agricultural product for soil improvement. At present this is occurring in small-scale pilot projects in the region. During the manufacture of the Anila stove, it was decided to make a few design modifications as described in Box 7. More information on the Anila stove can be obtained from the following sites.

Folke Gunther on the Anila stove (including designs):
<http://africaclimate.org/2009/01/06/carbon-cycle-and-anila-stove/>

Is biochar produced by the Anila Stove likely to be a useful soil additive? (UKBRC Working Paper 4):

<http://www.geos.ed.ac.uk/sccs/biochar/documents/WP4.pdf>

A discussion group for those interested in the distribution of the Anila stove in Kenya: <http://groups.google.com/group/anilakenya>

Pictures which show how to use the stove, and how it works are available from Max Turunen:

<http://koti.mbnet.fi/maxt/tempstuff/anilaproject/anila%20using%20slides/>

<http://koti.mbnet.fi/maxt/tempstuff/anilaproject/air/>

Information about the project in Tamil Nadu and a cartoon for its use:

www.bioenergylists.org/stovesdoc/ravikumar/Biochar_Anila.pdf

Contact for Anila stove:

C.S.Ramaswamy for Mr.U.N.Ravikumar:

C.S.Ramaswamy B.E.(Mech)

Proprietor,

Sumuki Associates,

no.965/2,

J.L.B.Road,

Lakshmipuram,

Mysore-570 004

India

Box 8: Changing the design of the Anila stove.

Together with the ARTI team, we were able to make some suggestions, to refine the stove design during the fabrication process. These were:

- Adding a mud seal along the join of the main unit to the base plate, which stopped the escape of gases from the char production. The seal was simply some mud which is smeared around the join.
- Addition of a 'pot raiser'. The stove was observed to become smoky once the pot was added on top, so a pot raiser was added to the unit, which reduced the amount of smoke which was generated.
- Making the holes in the inner chamber smaller (alternatively the number of holes in the unit could have been reduced). This reduced the height of the flame to make it more manageable.

4.5. The EverythingNice Stove (EN)

This stove is part of the World Stove selection of stoves. The EverythingNice stove is an example of a 'refugee design' which is intended to be appropriate for disaster relief. The stove is, therefore, simple to make, uses as little raw material as possible and can be made with tins (old oil / paint cans for example) for the chambers, thus using waste resources. However, it can be made entirely from sheet metal if tins are not readily available; this will also potentially increase the lifespan of the stove, since many tin cans

are not as heat resistant as sheet metal alternatives. Further information on the EN and other World Stoves is available from the sources below.

Designs for the everything nice stove: http://worldstove.com/wp-content/uploads/2009/11/EverythingNice_Stove_Instructions.pdf.

Trials of the Everything Nice stove:

http://www.bioenergylists.org/EverythingNice_WorldStove

A sheet steel version:

<http://www.bioenergylists.org/sheet-steel-EverythingNice-stove>

Everything nice stove lighting:

<http://www.bioenergylists.org/content/lighting-everything->

Versions of the Everything Nice stove

<http://worldstove.com/album/your-versions-of-the-everythingnice-stove/>

4.6. The Sampada Stove

The Sampada is the smaller of the two gasification stoves designed by ARTI and is short enough that it allows the cook to sit cross legged to cook, fitting in with common practice in many countries. The outer chamber is stainless steel, while the inner chamber is made of mild steel. Over 500 units have been sold to date at around 30 USD each (<http://www.samuchit.com/>).

This stove, though a gasifier design similar to the Anderson TLUD and EN stoves, also used in this project, is not strictly speaking a top-lit stove, and works best if a small amount of wood is put in the bottom of the stove and lit, which heats up the stove. When further fuel wood is added gasification proceeds quickly. It was observed that this stove can easily accommodate larger pieces of wood than the TLUD and EN stoves (which have smaller burning chambers).

Information and purchase details of this stove can be found on the Samuchit website:

http://www.samuchit.com/index.php?option=com_content&view=article&id=1&Itemid=3#sampada%20stove

4.7. Anderson's (Champion) TLUD

The TLUD (Top-Lit Up-Draft) gasifier was originally designed independently by Tom Reed in the USA and Paal Wendelbo, who designed it for use in Africa in 1988. Since then, the design has been adapted and distributed around the world, with important contributions from Dr Paul Anderson. A prototype of the design amended by Anderson has been produced and tested in Cambodia. A model was also adapted by ARTI in India. The design plans that we used were for the Champion model, which won a clean emissions competition at a stove camp in 2005. Anderson has also developed a 'refugee' and 'artisan' version to suit different target audiences.

The Champion is a double chamber system, which is lit from the top. A chimney can be added and the air flows in via a tube at the bottom. More complex versions have a fan to force air into the system. Feedstock is gasified and burns with a smokeless flame. Waste biomass including wood shavings, corn stubble, coconut husks, reeds and sugar cane

bagasse have been tested. Charcoal is produced which can be burned in the unit, or saved to be burned at a later date.

More information and a design booklet is available online:

<http://www.bioenergylists.org/andersontludconstruction>

4.8. Stove Testing Methods

Standard tests were used to evaluate the performance of the stoves with respect to water boiling, efficiency, fuel use rate, fire power and so on. (e.g. <http://www.hedon.info/WaterBoilingTest>) [34]. Stoves were distributed to households in selected areas for testing. A questionnaire was developed to gather information from this exercise using elements from the household survey (see sections 4.9 and 5.5). The questionnaire was designed to collect a mixture of quantitative and qualitative data from the households related to their opinions on using the test stove. Information on their disposable income, family structure, etc., was collected to gather background data to their responses. In each case the respondents were asked questions about their experience of using the test stove and the same questions were asked about their baseline stove as a comparison. In both Cambodia and India, the baseline stove was either a traditional wood burning or charcoal burning stove (which was mainly used for wood burning rather than charcoal). (It is quite common for people who own a charcoal-burning stove to use it for burning wood instead).

A total of 17 households were selected and the following testing schedule was followed, which allowed each family to test each stove for 3 weeks. In Cambodia three types of stoves were tested between July and October 2010, and in India, 2 types during August and October 2010. In addition, information about baseline stoves and other livelihood characteristics were gathered (see sections 4.9 and 5.5).

Table 5: Design for stove testing in households

	Number of families	Anila	EverythingNice	Sampada	TLUD
Cambodia	9	3 weeks	3 weeks	Not tested	3 weeks
India	8	3 weeks	Not tested	3 weeks	Not tested

The stove was demonstrated to a family member who would be responsible for cooking with the stove and answering the questionnaire (see Box 9). Users were selected for whom use of the test stove would be relatively easy compared to their normal stove, i.e. they were used to cooking on a biomass stove. After the family had used one of the stove types for 3 weeks, the questions relating to that test were answered before the next stove was introduced. For the duration of the trial, the users trialed the test stove in addition to using the stoves which they would normally use (as determined by the participating household).

Box 9: Guidelines for stove testers

Initial introduction to stove covered the following points about the stove, which is:

- a prototype, therefore still has room for improvement, and is not yet available
- designed to reduce fuel use
- designed to burn smokelessly
- designed to produce biochar

The demonstration then covered:

- set up and safety of system*
- fuel choice and preparation
- fuel for char production (where necessary)
- how to light (ignition)
- how to keep alight (operation during burn)
- determination of which stage the system is in to conclude burn (combustion / gasification / end of gasification for those which produce wood charcoal)

And discussion also covered an introduction to:

- global warming, and the contribution from biomass burning
- forest loss, and use of resources
- biochar and it's potential uses

4.9. Household Baseline study

Information on the household characteristics of four target communities, two in Cambodia and two in India, was acquired and analysed, in order to assess whether benefits might occur with the introduction of improved stoves. A household (HH) questionnaire was developed with the aim of covering topics related to household wealth and socio-economic status, cooking cultures and also agriculture related questions. The livelihood assets in the Sustainable Livelihoods Framework (Box 10) were covered in the questionnaire - human, natural, social, physical and financial capital.

Box 10: The Sustainable Livelihoods Framework

The SL Framework is a participatory discursive technique designed to increase the effectiveness of development assistance. It can also help in the analysis and understanding of local livelihoods as well as in the assessment of the effectiveness of existing projects to reduce poverty. This framework is based on the following livelihoods assets which affect the poor: human capital, natural capital, social capital, physical capital and financial capital.

Source:http://www.livelihoods.org/info/guidance_shets_pdfs/section1.pdf

The questions were developed using themes from the Poverty Environment Network (PEN) Village Survey 1 (Box 11) as well as incorporating some elements from the stove testing questionnaire which was developed for the household user feedback of the stoves.

Box 11: PEN: The Poverty Environment Network

PEN is an international network and research project on poverty, environment and forest resources. Launched in 2004 by CIFOR, it provides tools for collecting household data.

CIGAR PEN prototype questionnaire in English, version 4.4 (Sept. 2008) (accessed 15th January 2009) <http://www.cifor.cgiar.org/pen/ref/tools/prototype.htm>

In each of the two countries, two communities were selected which would represent broadly differing socio-economic status. The areas chosen were known to the research team, and local knowledge, in addition to informal appraisal visit from the researcher, confirmed their suitability.

Within those communities, the questionnaire was administered to a randomly selected group - 50 households in each area (villages 1 and 2 in Cambodia and villages 1 and 2 in India). The enumerators began in what was deemed the centre of the community, and went out in a North, South, East and West direction visiting every third house in each direction. Alternatively, where the village was spread along a road or river, the sampling was altered to ensure a good coverage of the village area. The questionnaire was deployed in Cambodia from 07.08.2010 - 26.09.2010 and in India from 28.08.2010 - 04.10.2010.

5. Project outputs

5.1. Controlled stove testing

Each test was undertaken with the same amount of oven dried fuel (1000g) from the same plant species (*Casuarina equisetifolia*) and prepared to a standard size (approximately 3cm x 3cm x 10cm). The test methods were taken from the Water Boiling Test part 1: Cold start test (version 4.1.2) and calculations followed the Water Boiling Test Data Collection Sheet 4.1.2 (2010) [34]. The test comprised heating 2.5 litres of water from ambient temperature to boiling in three replicates, mean values being reported. A known (sufficient) quantity of fuel is added and then extinguished once the water is brought to the boil. The remaining fuel is weighed-out and subtracted from the initial fuel mass added.

Data collected included ambient air temperature and initial water temperature, time to reach boiling point, amount of char and ash produced and the amount of water at the end of the test. The performance measures calculated are: temperature-corrected time to boiling (minutes), burn rate (grammes per minute), thermal efficiency (%), temperature-corrected specific fuel consumption (grammes per litre) and firepower (Watts). Two sets of results are reported in the table below for the Anila stove, the first (Anila1) includes the contribution of the feedstock (in the outer chamber) which, when undergoing thermal degradation, produces pyrolytic gases which enter the combustion (inner) chamber. Anila1 does not, however, include the weight of the biomass fuel in the outer chamber or of the char produced there (only the biomass and char in the inner fuel chamber). (The biomass fuel is being somewhat under-counted, therefore, since energy from pyrolytic vapours arising from the biomass is being utilized in the stove). The

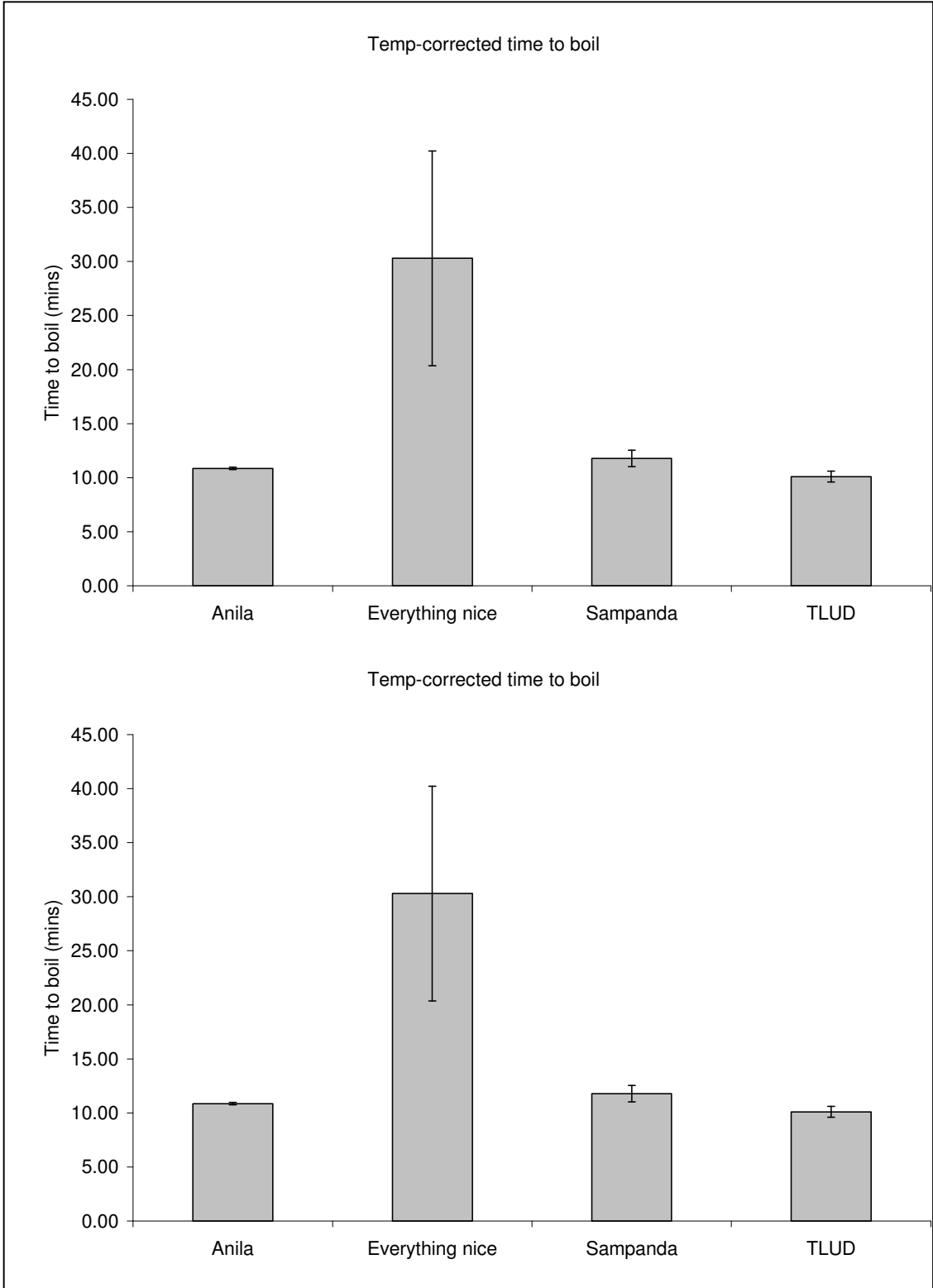
second results (Anila2) take account of the initial and end weight of the biomass and char which is added to both the inner and outer fuel containers.

Roth notes that our test of the Anderson TLUD stove: is “not representative for a proper operation of the stove” since, “the photos show excessive flames, which is probably due to too much air while in use and excessive gaps between the 10 cm length stick-wood fuel” page 56 [11]. This is a reasonable point and more testing is certainly required. Our experience was that the airflow is not that easily regulated which may have resulted in the stronger than desired flame. Our tests used fuel that was readily available in Cambodia at the time and context of the trial. This appears to have been too large for optimal operation of the Anderson stove. Whom is to determine whether a stove is operated under the proper conditions or not? If the stove designer prescribes the conditions of use too precisely, the real-world context of use of the potential user may be effectively precluded.

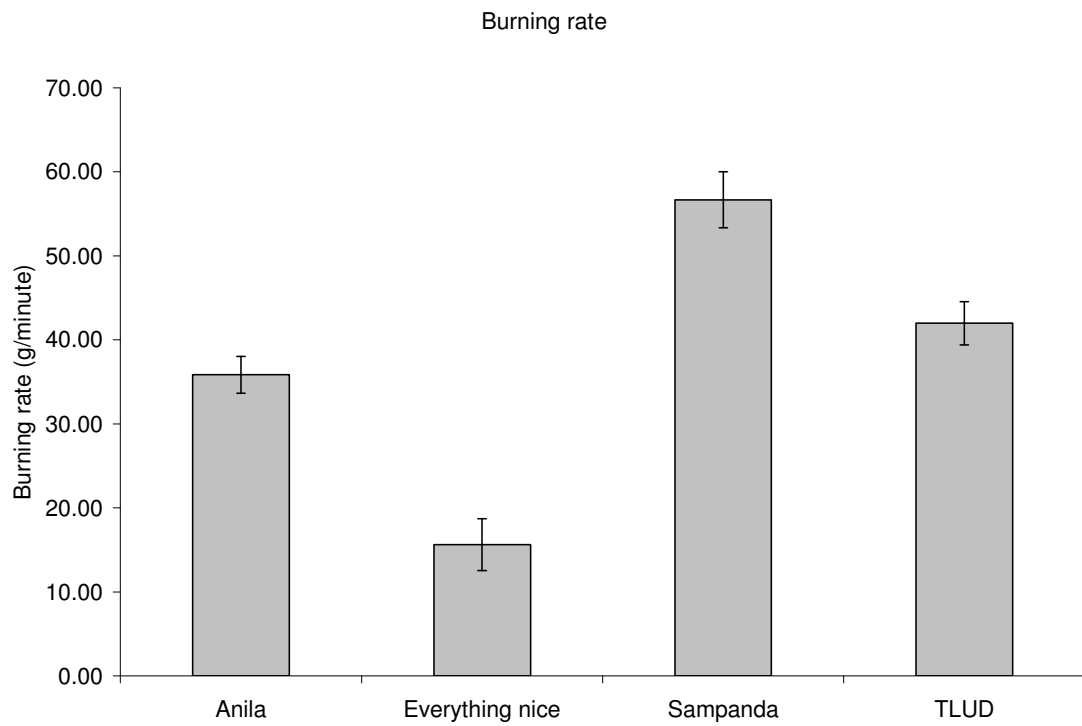
Table 6: Results from controlled testing of the gasification stoves using part 1 of the Water Boiling Test

	Temp-corrected time to boil	Burning rate	Thermal efficiency	Temp-corrected specific fuel consumption	Firepower
	Mins	g/min	%	g/litre	Watts
Anila1	10.86	35.83	0.14	162.62	11627.92
EverythingNice	30.29	15.63	0.19	177.18	5071.01
Sampada	11.77	56.67	0.12	305.71	18388.33
TLUD	10.10	41.98	0.12	171.16	13623.34
Anila2	10.86	105.83	0.05	480.18	34342.92

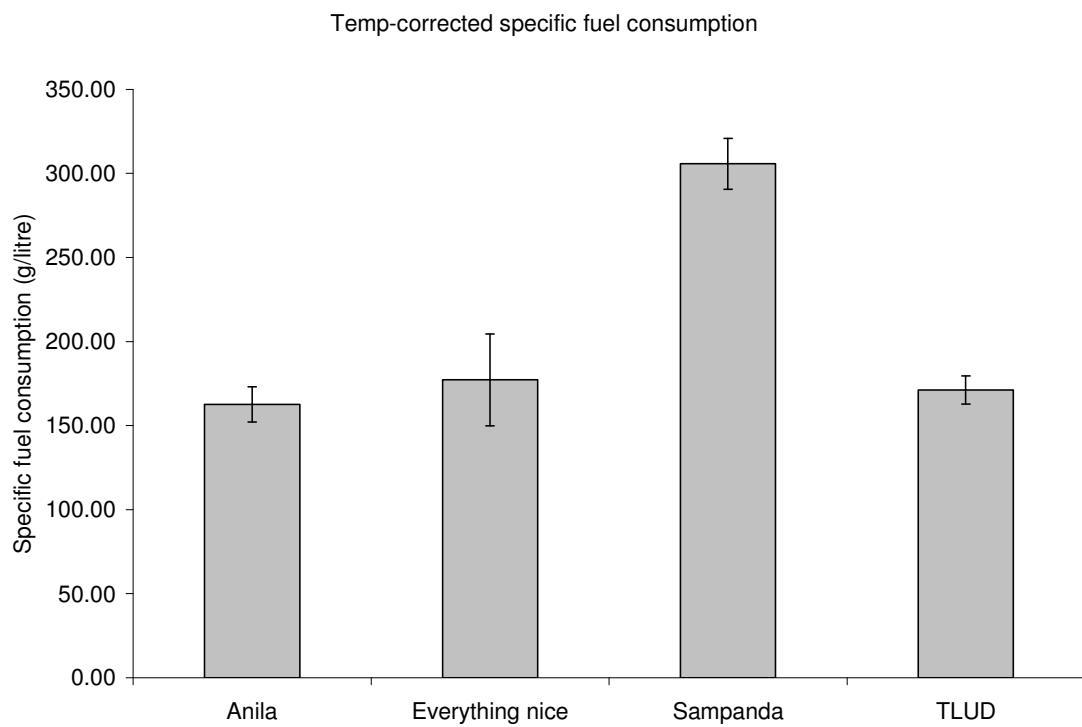
The EN stove takes longer to boil water, with time to boil similar for the other stoves tested; the EN, on the other hand, has the highest thermal efficiency, the Anila2 having the lowest thermal efficiency. The highest firepower is seen in the Anila2, followed by the Sampada. The graphs below show the results, including standard error bars derived from analysis of variance (Figure 8). The EN appears to be the most variable taking between 49, 15 and 26 minutes to boil (temperature corrected figures).



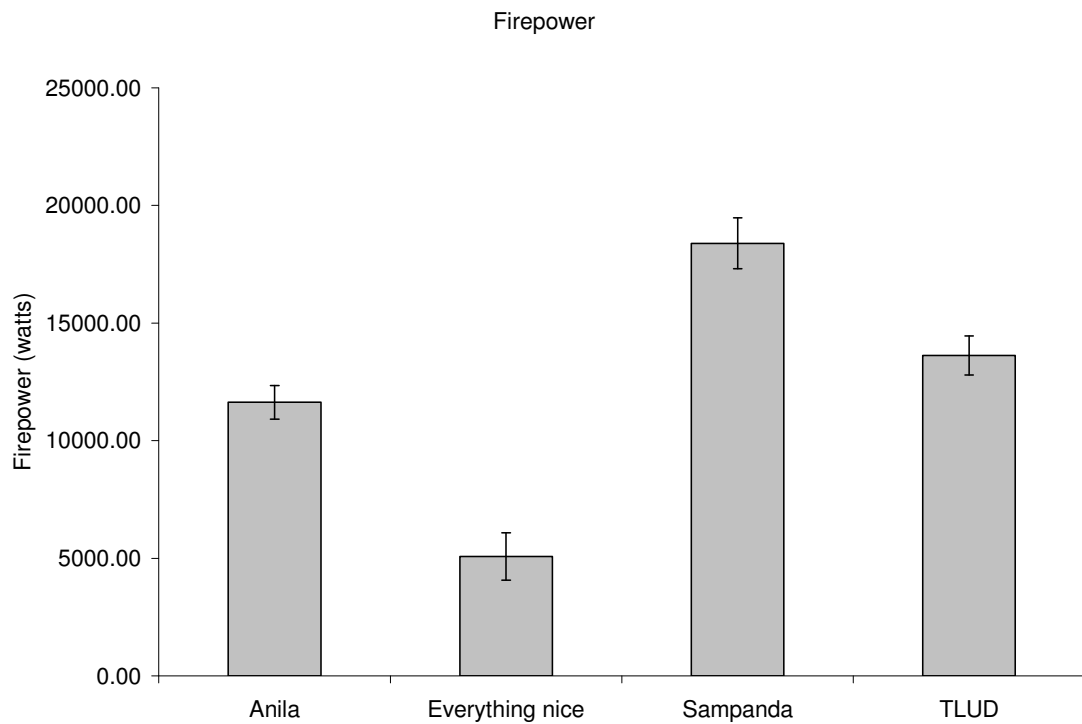
b)



c)



d)



e)

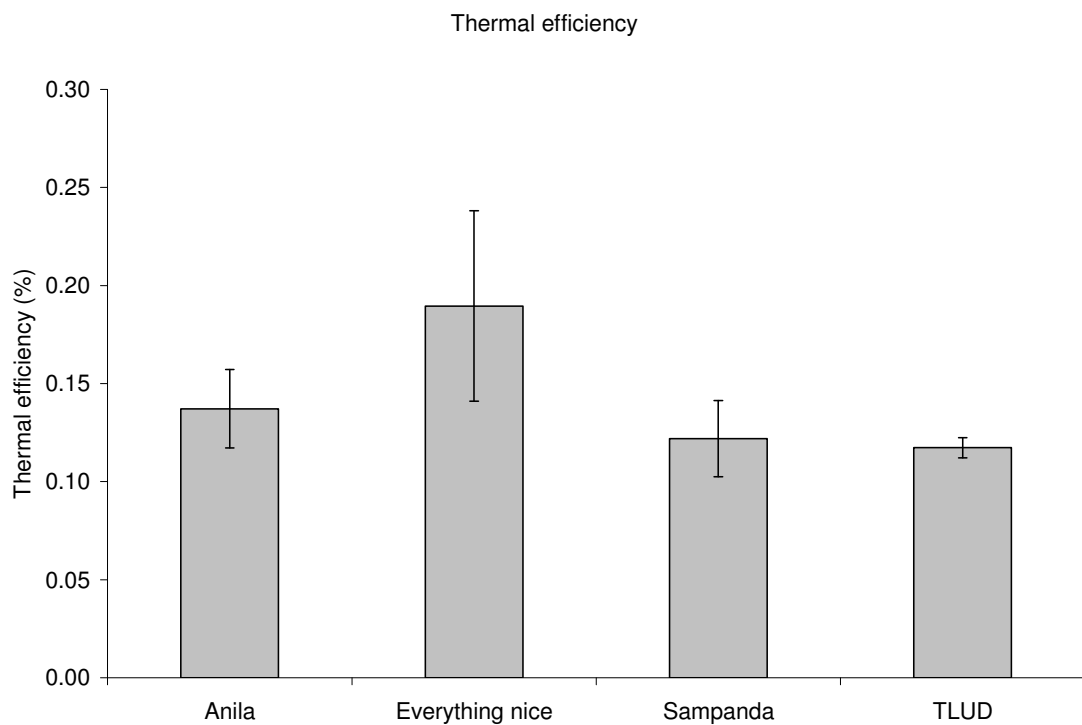


Figure 8: Results from the Water Boiling Test on the Anila, EverythingNice, Sampada and Anderson's Champion TLUD for **a)** Temperature corrected time to boil **b)** Burning rate **c)** Specific fuel consumption **d)** Fire power and **e)** Thermal efficiency

5.2. Biochar production

In previous research, biochar from the Anila stove was found to be of a consistent nature in terms of its pH and conductivity. The yield of biochar was enough for a yearly application rate of 0.5t/ha which might be suitable for users with small areas of land – typically poor, subsistence farmers [35].

Tests were carried out with a variety of different feedstocks in all of the test stoves, to assess the ease of producing biochar. To maximize biochar production, the stove has to be extinguished at the correct time: too early, and the wood has not fully charred, and too late and the char will have combusted and ashed. Looking for subtle changes in the flame, and carefully watching the feedstock, is required to detect the correct time for removing the char from the stove. Each stove was operated 5 times, and the biochar amount harvested varied from 0g to a maximum of c. 200g from 900g of feedstock (0 to 22%). (The biochar yield was occasionally zero due to difficulties in judging when to extinguish the flame or smoldering char). With practice the yield increased, although a problem arose from the biochar sometimes catching alight when removed, resulting in losses after harvesting from the stove. Leaving the stove to cool then emptying it led to reduced losses from burning or smoldering biochar (especially with small grade biomass used in the Anila stove). Biochar can be extinguished using water, although getting the stove wet during this process led to some corrosion of the metal.

5.3. User feedback of stoves' use

Results

Stove and fuel use

Cooking tends to be on traditional stoves and three stone fires in the villages around Phaltan, Maharashtra, India. These are commonly shielded stoves made from unfired clay, have a low efficiency, produce a lot of smoke and soot and have a life time of just a couple of years (pers comm. ARTI 2010). More movement up the energy ladder was observed in India within the project areas than in Cambodia, with use of kerosene and, more commonly, LPG stoves observed. Many communities still rely on energy from biomass however.

In Cambodia, simple fired-clay wood burning stove, and versions of metal and cement charcoal burning stoves were observed, in addition to the shielded concrete stove, and the shielded mud stove. The traditional stoves cost around 3 USD and in most areas around Siem Reap, wood and residues are commonly used fuels. Pictures and more information on baseline stoves are available on the website (<http://biocharinnovation.wordpress.com/07-stove-designs/traditional-stoves/>). The distribution of baseline stove types used by the respondents is shown in Figure 9. It can be seen that the primary stove tends to be a simple wood or charcoal stove design; while LPG and gas stoves are also owned by respondents, they are not typically used as the primary stove, presumably because of the higher fuel costs associated with their operation. The energy ladder concept is overly simplistic in that stove users do not always abandon biomass stoves on acquiring stoves with superior fuels; many users prefer to retain a range of stoves to increase fuel diversity and limit fuel costs [36].

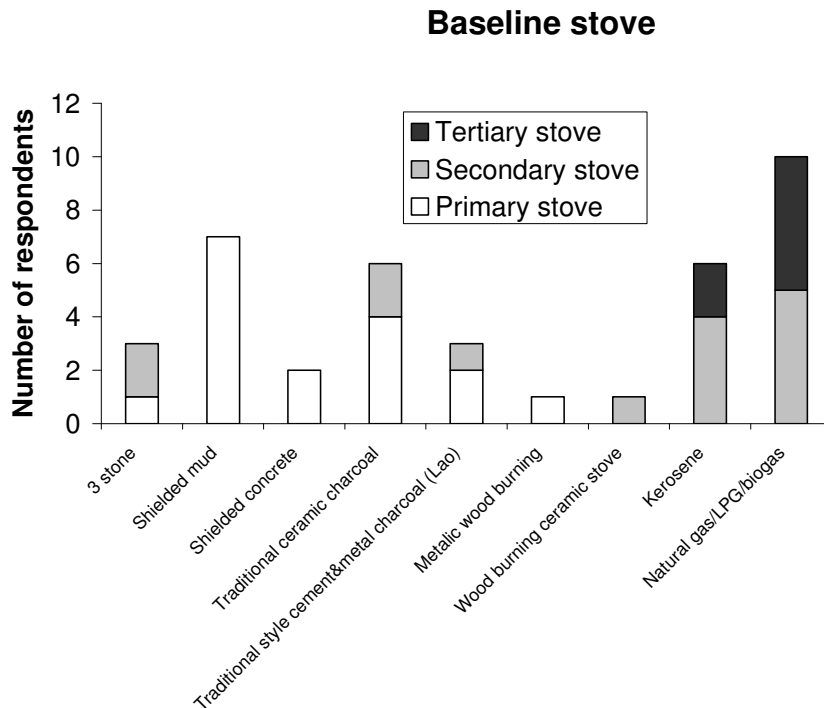


Figure 9: The distribution of baseline stoves for the users testing gasification stoves.

In Cambodia and India the primary use of the stove was cooking meals for the family, the secondary use in India being heating water for bathing, and in Cambodia the secondary use was boiling water to drink. One family in India stated the tertiary use as boiling water to drink.

All families had had their baseline stoves for 3 years and over, the average being 16 years ($n = 11$). The average cost of the stoves was 1.66 USD, ranging from 0 to 4.25 ($n = 13$). Families were mostly motivated to replace stoves only once they had broken, although two families stated that they got a new type of stove in order to get an improved version and one which would reduce wood consumption.

Participants spent between 0 and 11 USD per month on fuel, and the average monthly spend on fuel was 4.04 USD. Two participants did not spend anything on fuel. The fuels which the participants used routinely were mainly wood, although households typically used other sources of fuel in addition (Figure 10). Discussions confirmed that the cost of fuels - particularly charcoal, kerosene and LPG - made them more commonly second choices for users. The household did not, therefore, need to make any special arrangements for acquisition of fuel during the trial.

Fuel use

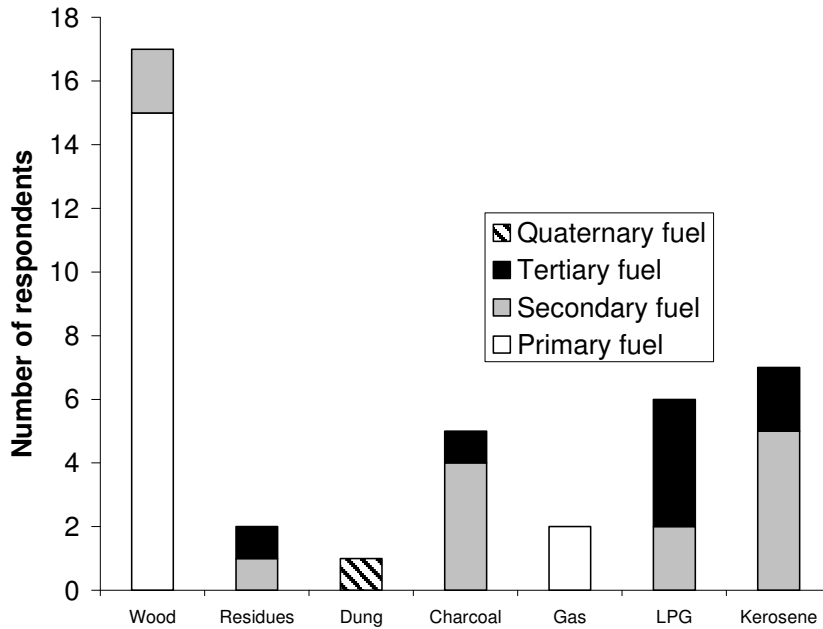


Figure 10: The fuel types used by those testing gasification stoves

Since all participants used wood, they were asked if they bought or gathered it. Most wood was gathered, and only 12% bought all their wood fuel (n=17) (figure 11).

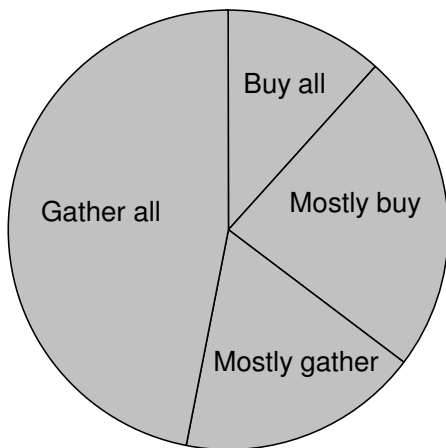


Figure 11: The source (buying and / or gathering) of biomass fuel for users testing gasification stoves

The respondents revealed that, in comparison to the situation 5 years ago, they spent more time (69%) or the same amount of time (31%) collecting wood (n=13), and that the availability was reduced (75%), or the same (25%), compared to 5 years ago (n=12).

Respondents were asked about the qualities (both positive and negative) of their baseline stove (the primary stove), following which they were questioned about each of the test stoves. Positive comments about a property or attribute of a stove are recorded above the zero point on the y axis and negative properties are recorded below it. Perceptions of baseline stoves varied widely, no doubt in part because the stoves themselves are different (Figure 12); generally the perception of the baseline stove is positive however. There was a wide variation in perceptions of safety, though it was still rated positively by more respondents than negatively. Where open three-stone fires are being used, it is possible for the user's clothes to catch-on fire while cooking. More positively rated features include speed of cooking, the taste of food, the ability of the stove to cook the staple food (rice in Cambodia, and roti in India), as well as ease of lighting and the ability to vary the flame and add extra fuel into the stove.

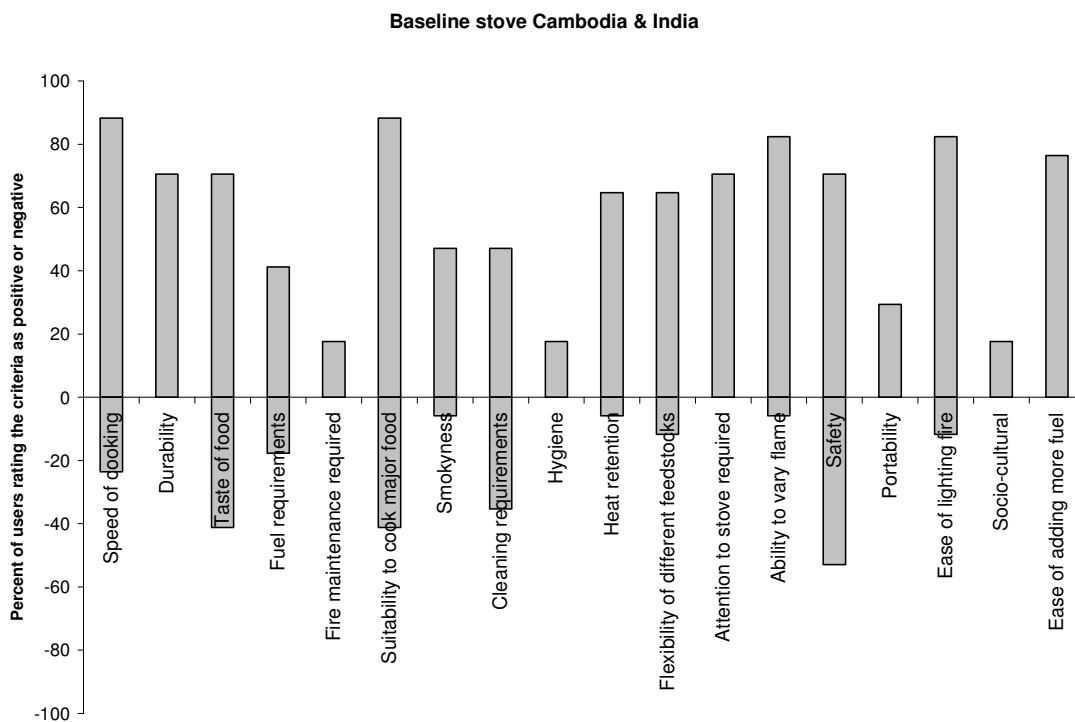
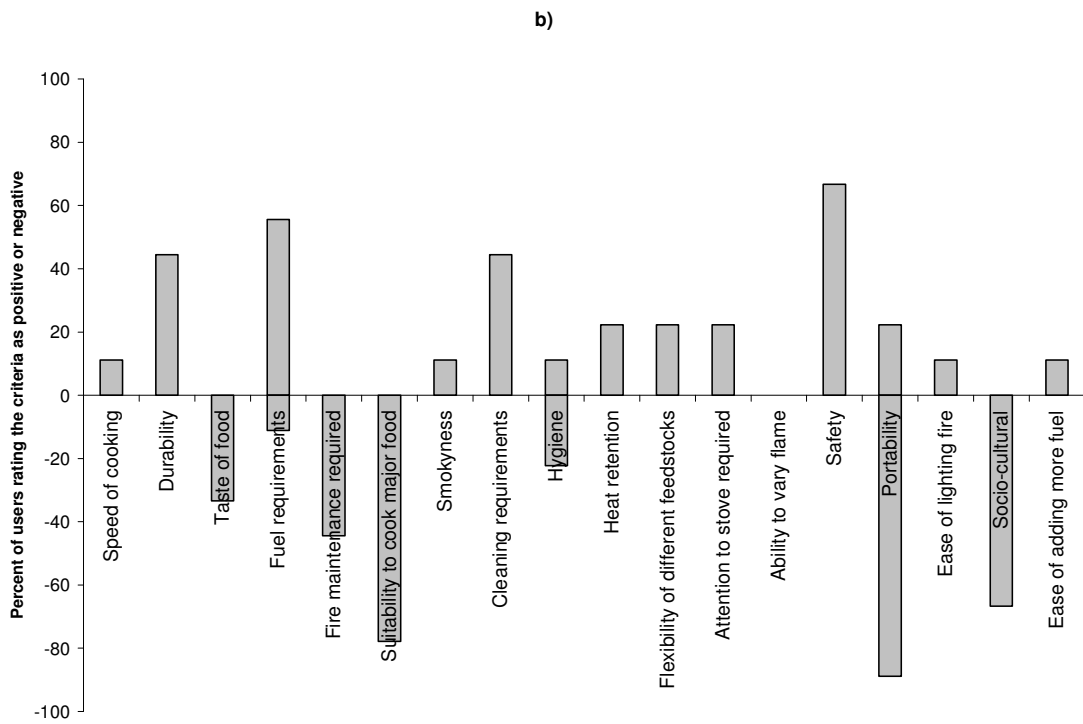
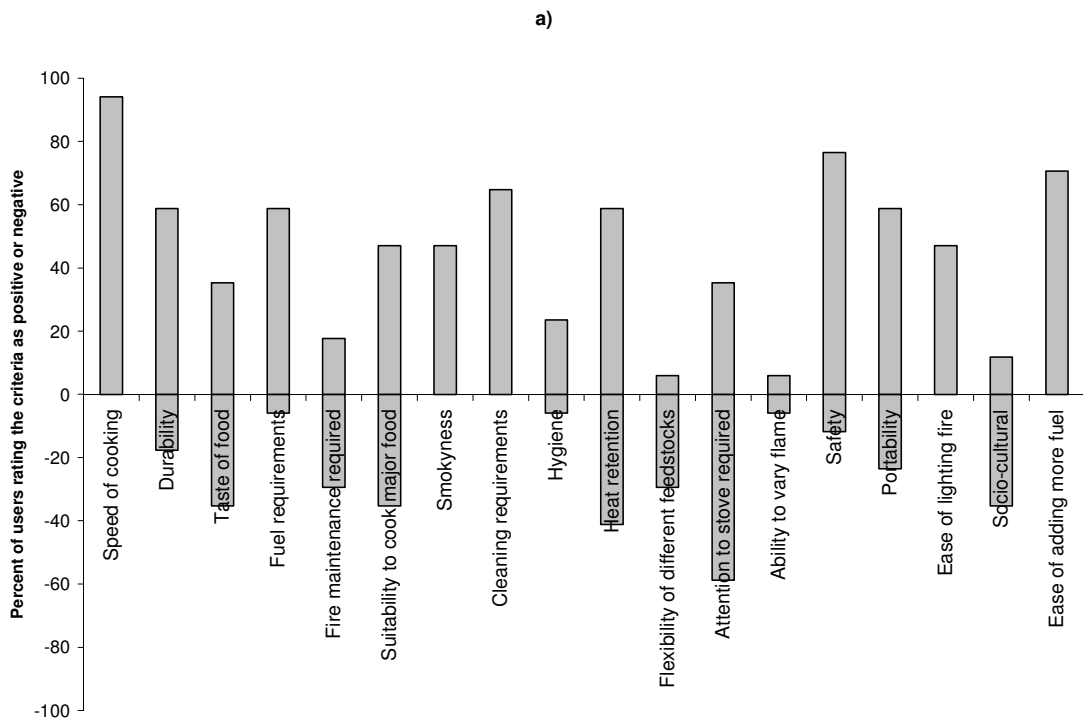


Figure 12: The gasification stove testers perception (negative and positive attributes) of their baseline stove.

User perceptions of the Anila, Champion TLUD, Sampada and EN stoves are illustrated in Figure 13. The questionnaire responses in India relating to the Sampada stove were more thorough than the responses to the stoves tested in Cambodia, which could be due to differences in enumerators, as well as in the sample and sampling procedures.



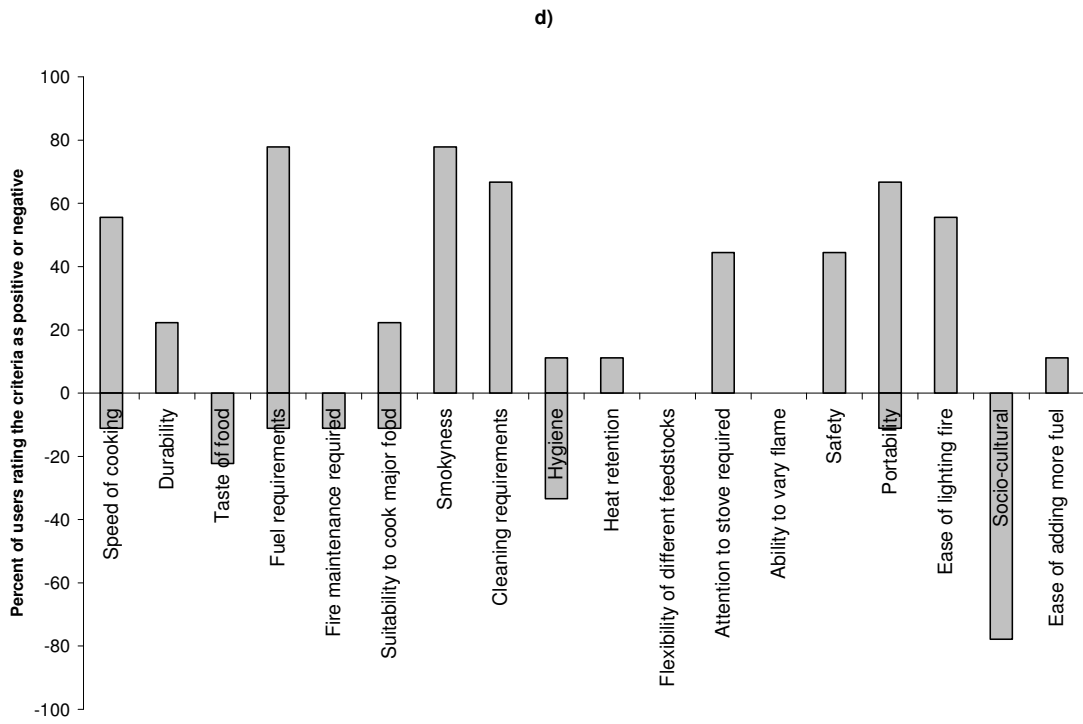
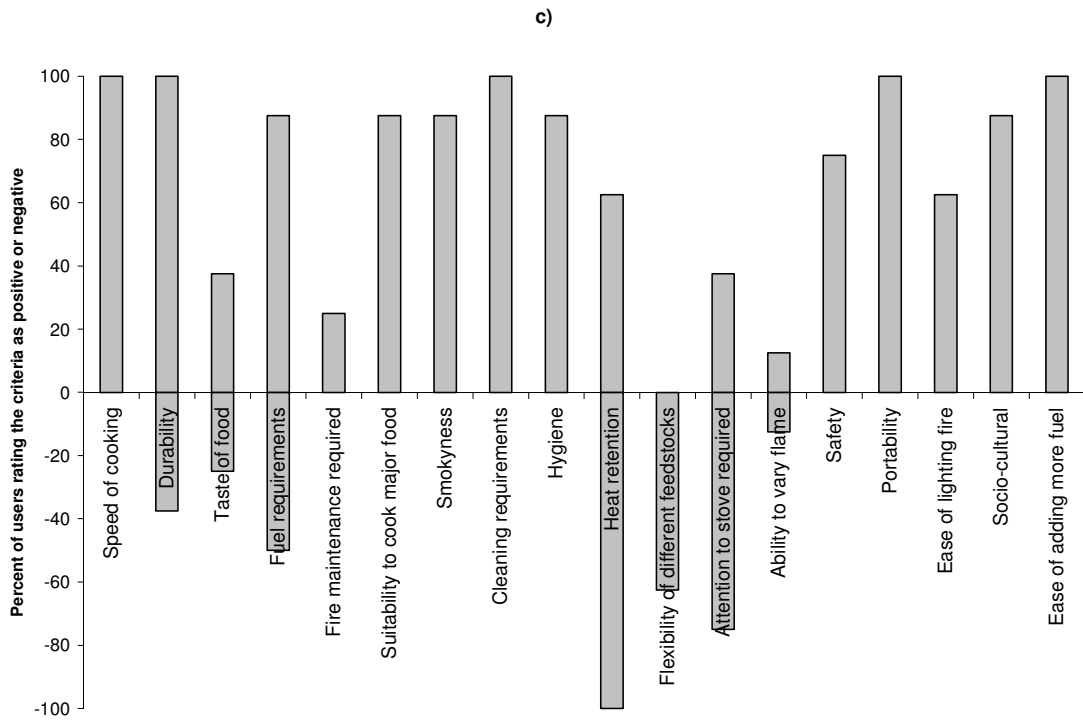


Fig. 13: The perception of stove attributes (positive and negative) for the users in Cambodia and India testing the following stoves: a) Anila, b) EverythingNice, c) Sampada and d) Champion TLUD.

The conditions of the stove testing undertaken by the 17 families who participated varied in some important respects. These differences include:

- Lighting methods varied, including use of resin, coconut fibre, part of a rubber tyre and dried furniture varnish.
- Some volunteers using stoves had damp wood, and this proved difficult to light and stay lit.
- A variety of wood types were used, from foraged wood to processed woods – including old furniture, and some worked better than others in the stove.
- Some of the families were very large, so cooking was being undertaken with larger pots and larger food volumes.
- Differences in the location of the kitchen (in a kitchen shelter, inside a building, in a courtyard, open garden area or raised-up on a shelf) all lead to different wind levels, and this variation influenced how well the stove performed. (All participants were requested to use the stove in well-ventilated areas)



Fig.14 a) Biochar production in TLUD stove in Cambodia; b) Sampada stove distribution in India and c) Stove testing in India

All the stoves had a higher rating by the testers for safety in comparison to the baseline stove (the improved stoves being more enclosed). The EverythingNice (EN) stove was reported to be more difficult to light than the other stoves and could be the reason why this stove was not so well tested as the others. (The EN stove was only tested a total of 62 times by the users, in comparison to the TLUD's 111 times). The EN stove tended to score less highly than the other three stoves, especially with respect to these criteria: suitability to cook major food, portability and fit with socio-cultural context. It should be remembered, though, that the EN stove design we used is intended for assembly and use by refugees hence a direct comparison with stoves designed and built for everyday use is perhaps not appropriate.

The Sampada stove appears to be rated most highly over all the criteria of all four improved stoves, with strong positive scores for speed of cooking, durability, fuel requirement, suitability for cooking major foods, smokiness, cleaning requirements, hygiene, heat retention, safety, portability, fit with socio-cultural context and ease of adding more fuel. Compared to the baseline stove, the Sampada does especially well on

the criteria of fuel requirements, smokiness, socio-cultural fit and cleaning requirements. However, there are also some features of the Sampada that are ranked more negatively than for the Champion TLUD, Anila or baseline stoves, including fuel requirement, heat retention, flexibility for feedstock and the required level of attention.

The Anila stove has a reasonably positive assessment, though with some negative attributes identified (such as need to maintain the fire, suitability for cooking major foods, level of attention required and fit with socio-cultural context). The Champion TLUD stove was also regarded reasonably positively. Interestingly, the Champion stove tended to have fewer identified negative aspects than the other stoves, with the exception of fit with socio-cultural context.

All four of the improved stoves perform better with respect to fuel requirements than the baseline primary stove according to the respondents, hence they are all meeting one of their key objectives. The Sampada and Champion TLUD perform well with respect to smokiness compared to the primary stove in the view of the users. Curiously, the Anila, and (even more strikingly) the EN stoves, do not appear to be regarded as superior with respect to smokiness compared to the users' primary stove. This might be a consequence of the way that the stoves were operated rather than any inherent design limitation. (It may also be a consequence of the way that the primary stoves are used to limit smokiness, though detailed observation and ethnographic research would be needed to explore this idea).

Eye-balling across Figures 12 and 13 suggests that the baseline stoves do surprisingly well in a comparison with the improved stoves across the set of evaluation criteria. Only the Sampada would seem to be clearly superior to the baseline, and even for that stove there are some more pronounced negative dimensions than for the baseline. It is not easy to draw clear conclusions from these findings, however, since an incumbent stove design will have certain appeal to many users from the mere fact of its familiarity and the users' knowledge of how to get the most out of it. Such implicit or tacit knowledge [37] would probably take longer to acquire than the 3 weeks we allocated for each stove. It is quite difficult to interpret the variability in response because the perceptions of individual users of each stove have not been related to their evaluation of their own primary stove. It is also unclear whether the user would have been evaluating the performance of their test stove relative to their usual stove or undertaking a comparison between the test stoves. It was not possible for the researcher to be present in person during the many operations of the stoves in households; hence the users may have been using fuels or operating the stoves in ways which were unintended by the designer. Finally, we have aggregated the results here across different households and two countries. In follow-on work, we will disaggregate the data and explore whether significant differences emerge between countries and households. More specific feedback about the stoves included the following points:

- in some cases, the height of the stoves was inconvenient, e.g. for Indian women who prefer to sit on the ground to cook (the Anila is the tallest of the test stoves);
- there was no easy way to add more wood into the stoves while the pot is on, since the gap between the pot and the stove restricts the size of wood which it is possible to add in;
- this 'batch' approach compares unfavourably with the 'continuous' fuel feed of other conventional and improved stoves since the user does not know precisely how much fuel is required prior to the cooking process and can end up using too

- little or too much fuel, the first introducing inconvenience and time delay and the second ending up waste fuel (and increasing biomass extraction and wasting time in collecting fuel);
- gasification stoves require reasonably small and uniform pieces of biomass, hence limit the use of certain feedstocks such as larger sticks, reducing overall fuel use flexibility;
 - the ability to alter the intensity of the flame was limited, so reducing the flexibility that cooks value;
 - it was difficult to remove the ash / charcoal from the stove without turning the stove over, so a way of emptying the stove could be made (which is achieved in some stove designs by having a trap-door arrangement, [11]);
 - those with large families struggled to cook effectively with large pots on these particular stoves;
 - the two lids of the Champion TLUD made it more difficult to handle, so these could be joined together;
 - the EN stove needed a draft and a grate – alternatively, larger holes in the fuel chamber would help to keep the stoves lit.

When asked whether they would use and buy the test stove, and what they would be prepared to pay for it, the responses in Table 7 were given. This broadly confirms the results in Figure 13. The most popular stove was the Anila, but it was also unpopular amongst nearly 50% of the respondents. The Sampada and Champion TLUD were not quite so popular, but had fewer detractors. For those that would buy the stoves, the price they suggested they would be willing to pay for the stove ranged from 2.22 USD and 25 USD, with the averages given in Table 7. The results of the stove tests undertaken for this project (see Figure 8) are broadly consistent with the user perceptions, but do not permit a clear discrimination between stoves with the exception of the EN (which performs less well). The fuel requirements of the Sampada were noted as a disadvantage by some respondents, with more negative perceptions of this variable than for the Anila and TLUD Champion stoves. This may be a consequence of the high fire power and fuel burn rate of the Sampada compared to the other improved stoves, as illustrated in Figure 8.

Table 7: Feedback from the stove testers on their desire to use and buy the test stove

	Number of respondents		Ave price \$	Number of respondents	
	Yes, use it	Yes, buy it		No, not use it	No, would not buy it
Anila	14	9	5.6	3	8
EverythingNice	1	1	5	8	8
Sampada	8	5	5.9	0	3
TLUD	6	6	7.5	3	3

The cost of the Sampada stove is around 25-30 USD (Rs. 1200), which is significantly higher than the willingness to pay on the part of the test families. Since the EN stove can be made from reclaimed materials, it is thought to be possible to build this stove within the budget which the users suggested (5 USD).

In summary, while the stoves tested do appear to meet some of the objectives of an improved stove (reduced fuel consumption, reduced smoke production), the users also noted some limitations in their functionality compared to their conventional primary

stove. Better flame modulation, fuel flexibility and ease of fuel addition can all make women's cooking tasks much easier on a daily basis and the 'improved' gasification cook-stoves turn out not to be as adequate as conventional stoves in these regards.

5.4. Use of Biochar

Because the stoves were only with the households for a short time, there was not much training on the potential uses of char from the stoves. However users did report making char from 26 of the stove testing periods (n=37) and the use of the char is shown in Figure 15.

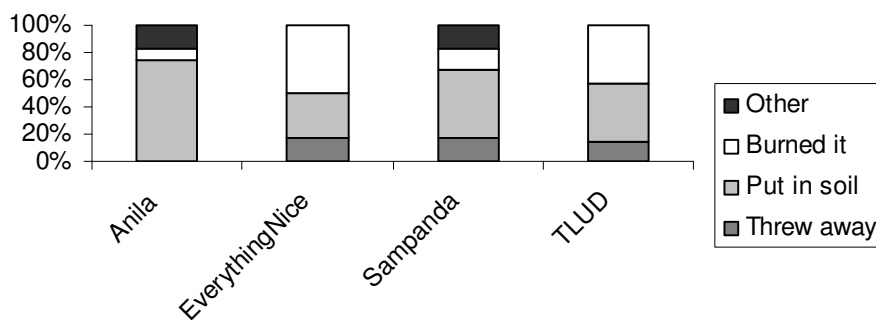


Figure 15: Use of the biochar as a percentage of the stove testers who produced biochar in the test stove.

The graph shows that the users mainly put the biochar into the soil - some on vegetable growing areas while others mentioned adding the biochar to tree growing areas. Many users reported use of biochar from the Anila stove which transpired, on further investigation, to be the burnt material from the inner chamber (which was more ash), rather than the char from the outer chamber. Many Anila stove users chose, in any case, not to put any biomass into the outer chamber for a number of reasons:

- the Anila stove was more likely to be smoky when used for biochar production;
- agri-residues are not always readily available and gathering additional residues can be difficult (one user had readily available rice straw, although even this was not 'waste' since was used as cattle fodder);
- not everyone wanted to invest the time and effort to collect additional residues because they could not see the benefits of producing biochar and regarded addition of biomass into the outer fuel container to be wasteful.

In some cases where charcoal was produced, families preferred to let it burn in the stove, while others removed the char for use in a charcoal stove. The 'other' option (Figure 15) included respondents selling the char for use in a solid-fuel iron and also in a knife sharpening tool.

5.5. Results of Household Survey & Analysis

Socio-economic status

The respondents were mainly the head of the household (HH) in India and the main cook in Cambodia (n=201). Because the head of the HH is often not the same person as the main cook, those making decisions about fuel use and buying the stove are not necessarily the one who cooks, and is responsible for providing fuel. The HH head usually decides which stove to buy though they usually do not do the cooking or collect fire wood. This would affect any stove implementation project, since the benefits which would be seen by the cook of an improved stove may not be appreciated by the stove purchaser.

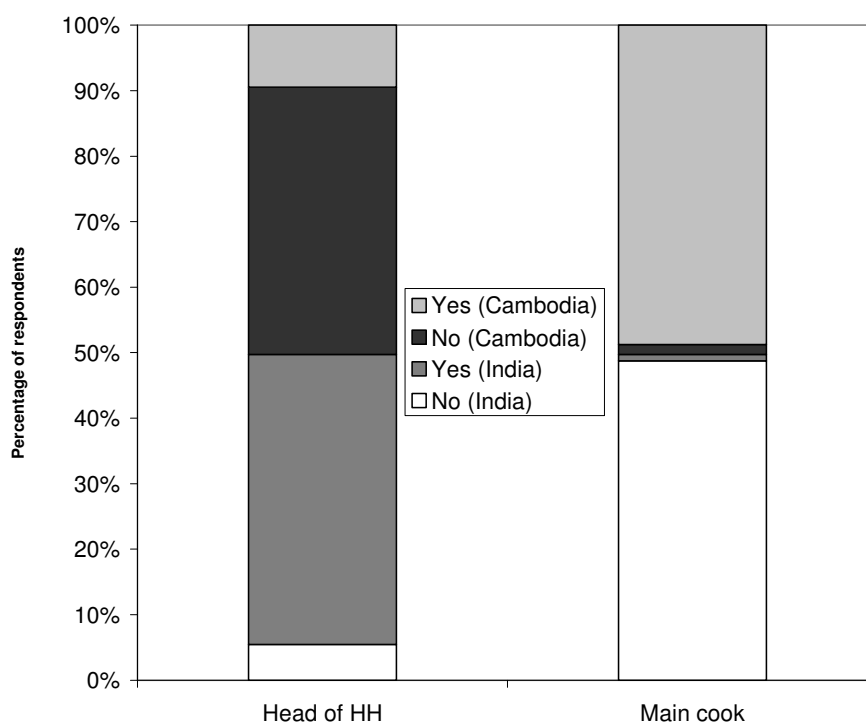


Fig 16: Percentage of respondents who are head of the household (yes or no) and cook (yes or no) both in Cambodia and India.

The mean number of family members in a household is 4.8 (n=201), 5 for Cambodia (n=101) and 4.6 for India (n=100). On average this is 1.6 male adults per family for Cambodia (n=100) and 2 male adults per family for India (n=99). This suggests some migration of male adults away from the villages or independent living by males in Cambodia. This may impact the availability of labour in the household for farming and also fuel gathering as well as creating differing cultural conditions and rural/urban development issues.

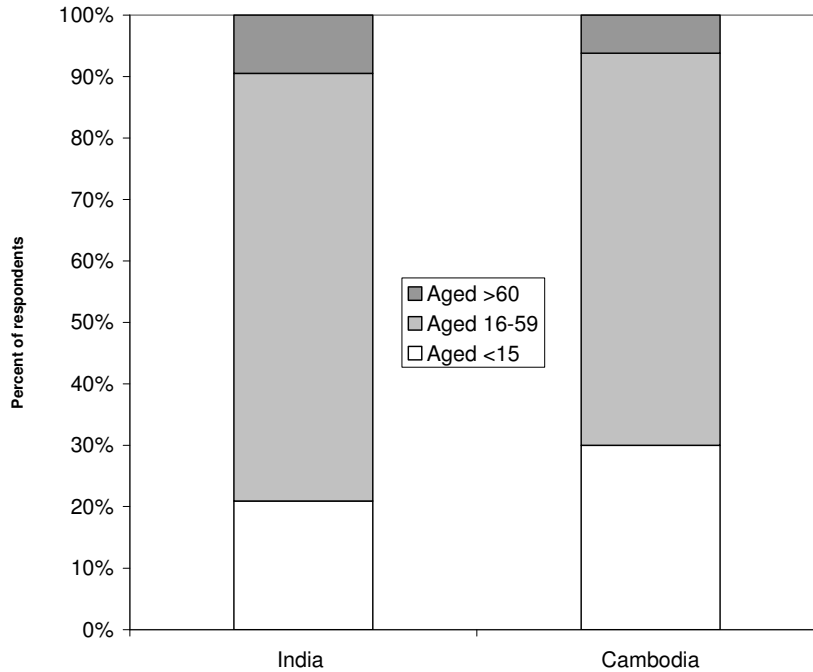


Fig 17: Percentage of respondents who are aged <15, 16-59 and >60 Cambodia and India.

The demographic graph (Figure 17) shows the ages of the family members (n=201), and a higher dependency rate can be seen in Cambodia, due to a higher percentage of children even though there are less elderly relatives. The lower average death rate as well as the effect of the Khmer Rouge regime may be responsible for the lower percentage of elderly family members in Cambodia.

Literacy

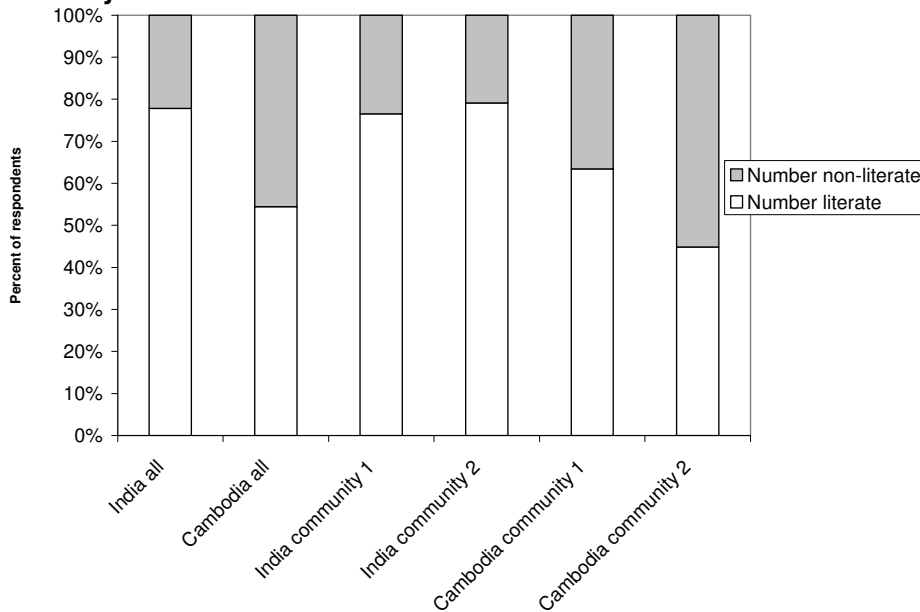


Fig 18: Percentage of respondents from India and Cambodia also in the sub-groups 1 and 2 in both Cambodia and India who are literate.

Literacy levels in India are much higher than in Cambodia, at around 78%, and in Cambodia 54%. Literacy levels fall below 50% in the second surveyed area.

Education

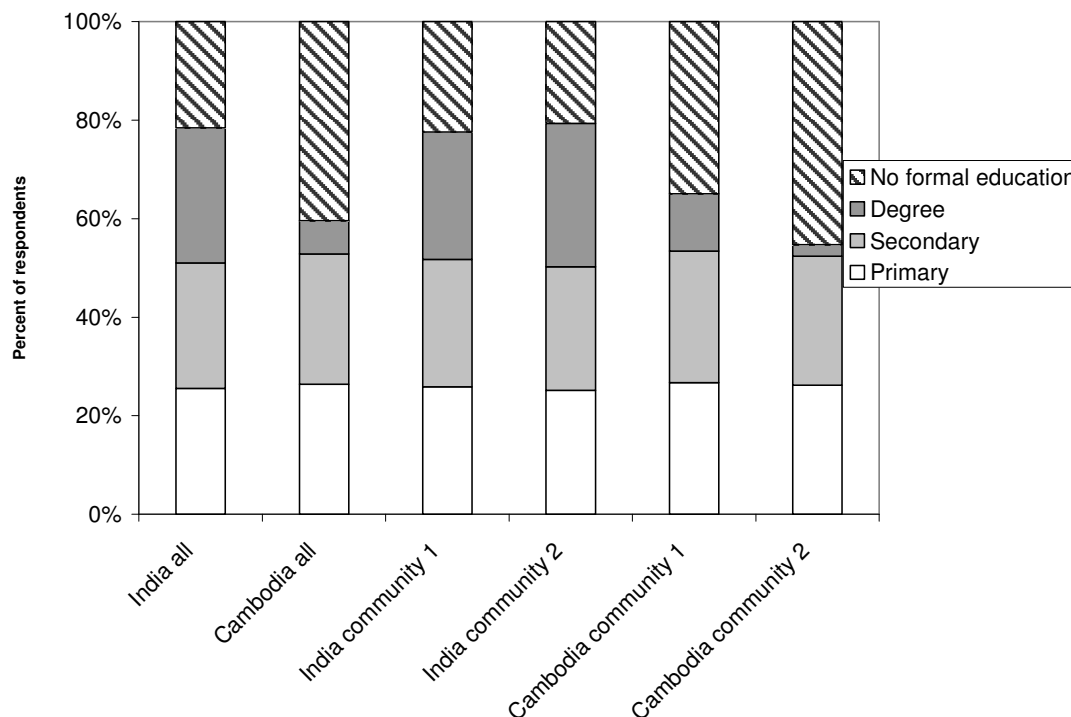


Fig 19: Percentage of respondents from India and Cambodia also in the sub-groups 1 and 2 in both Cambodia and India who have no formal education, and completed Primary, Secondary and Degree level qualifications.

The graph above shows that the primary education levels are similar across all the sites, but the number of those with degrees drops dramatically in Cambodia, compared to India. The second area (Don Keo Commune - Cambodia 2) has a low level of degree educated people (an average of 0.14 people per household, n=50), and also higher levels of people with no formal education.

Housing

There is a difference in housing standard between India and Cambodia, and a difference can also be seen between the two areas in Cambodia - the two communities in India are largely the same. In India, concrete floors are more common than the mud floors found in Cambodia. Almost all the households in India had electricity, with less having access in Cambodia. Brick walls and running water was the norm in India, whereas in Cambodia, wooden or thatch walls were commonly found.

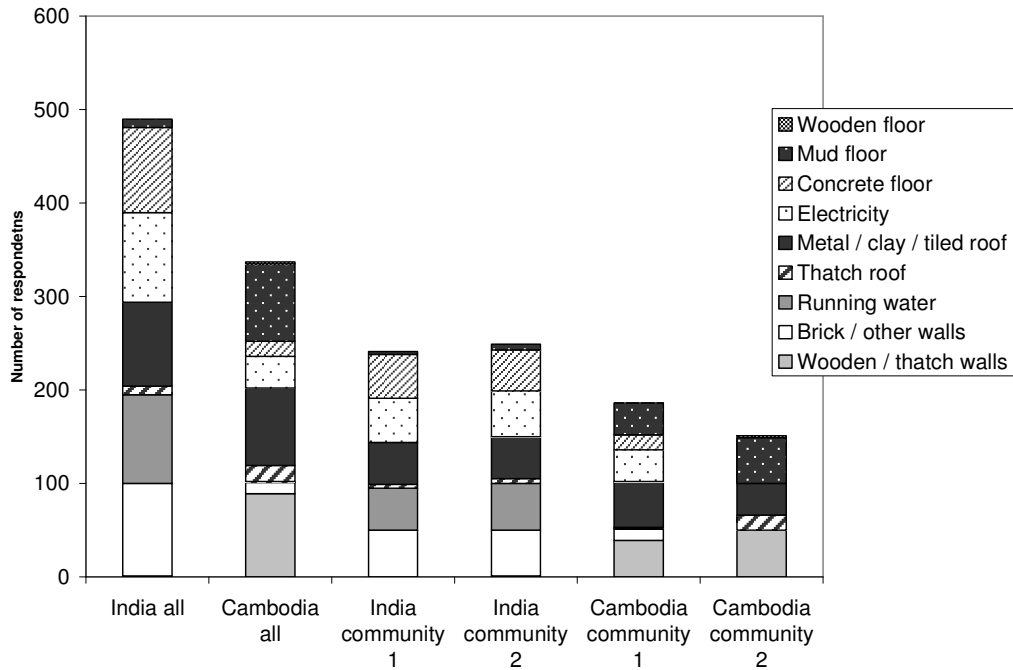


Fig 20: Percentage of respondents from India and Cambodia also in the sub-groups 1 and 2 in both Cambodia and India with selected housing standard indicators.

Durable assets

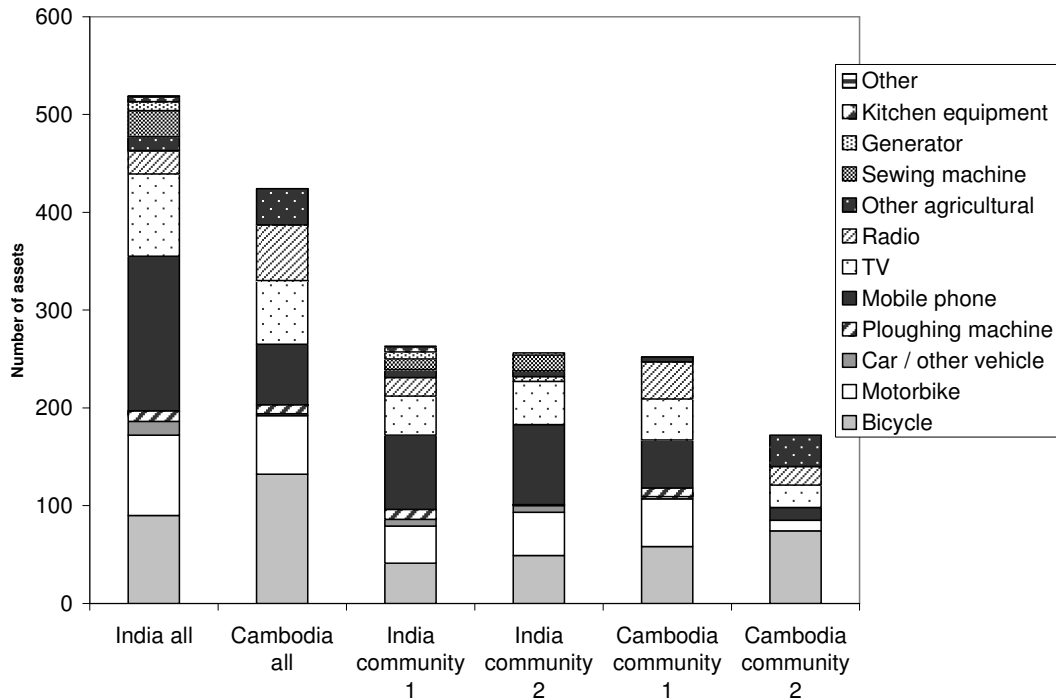


Fig 21: Percentage of respondents from India and Cambodia also in the sub-groups 1 and 2 in both Cambodia and India with durable assets (number of each item per household recorded).

The number of assets owned in India is 5.2 per hh (n=100), and it is 4.2 in Cambodia (n=101). The type of assets is fairly constant across all groups, with a higher occurrence of agricultural equipment in Cambodia, and the presence of more cars, generators and kitchen equipment in India.

Baseline stove

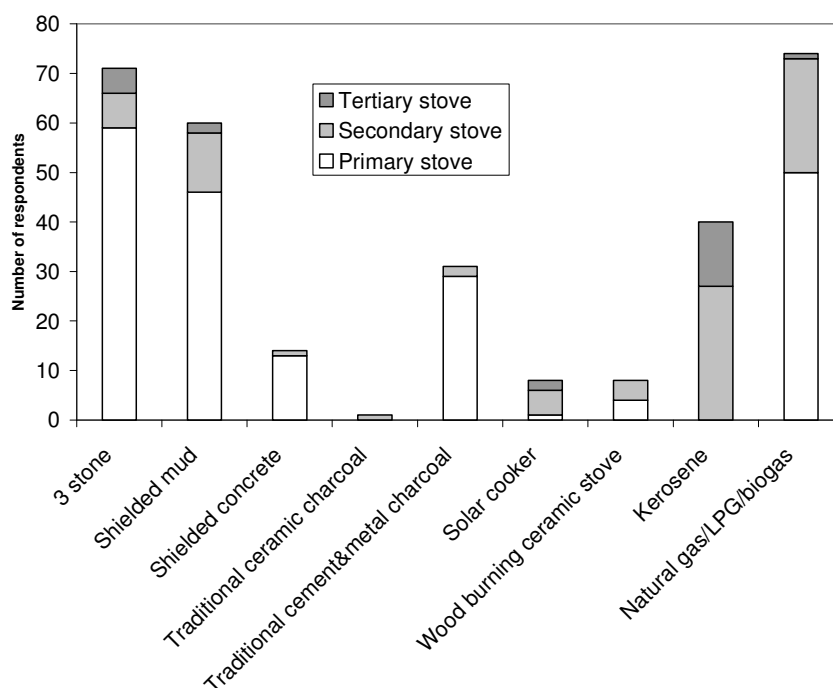


Figure 22: The baseline stoves used by the respondents from Cambodia and India

Overall, most people use a three stone or shielded stove, a traditional cement and metal charcoal stove or a gas stove as their primary stove. Many people use a kerosene stove as their secondary stove, and also there are some who use solar cookers.

There is a significant correlation between the cost paid for the main household stove and the number of durable items owned by the household ($p=0.277$, 0.000 (significant at 0.01 , two tailed)). There was found to be no correlation between the percent family literacy rate and the cost of the stove. This suggests that families with a higher disposable income spend more on a cook stove. It may also imply that the poorest cannot afford to spend as much money on cook stoves.

The mean time that a family had their main stove was 3.6 years (s.d. 0.26, $n=168$), and times ranged from 0 years to a 'lifetime' (the country life expectancy was used for this value). It is interesting that this life time is a lot lower than the mean in the small sample that did the stove testing and this suggests that we cannot extrapolate the results from the small sample without further research. Judging by the average time that the users in the small sample hung on to their stoves, they might have been much less willing to exchange their stoves for improved ones compared to the wider population.

The cost of the main stove ranged from 0 to 111 USD and the mean was 20 USD (n=199); however 86 respondents (53 from Cambodia and 83 from India) did not spend anything on their main stove. Two participants from India reportedly spent 400 USD and 660 USD on stoves, since they had biogas plants, but since this scale of unit has other applications these figures were not taken into account for the cost of the stove. However it does suggest that some respondents have disposable income to spend on initiatives such as biogas and improved cook stoves (though whether subsidies were made available for purchasing such equipment needs to be checked).

The most common reason given for getting a new stove was to replace a broken old stove. However reducing fuel consumption was mentioned, as well as reducing the time to collect wood (for those who had moved to LPG stoves). Only one participant stated that the reason for change was that she wanted to reduce the smoke - and in that particular case she moved from use of a three stone fire to a shielded mud fire. Other reasons for change included that the new stove looked good, could be used easily and would cook food well (n=110).

Use of stove

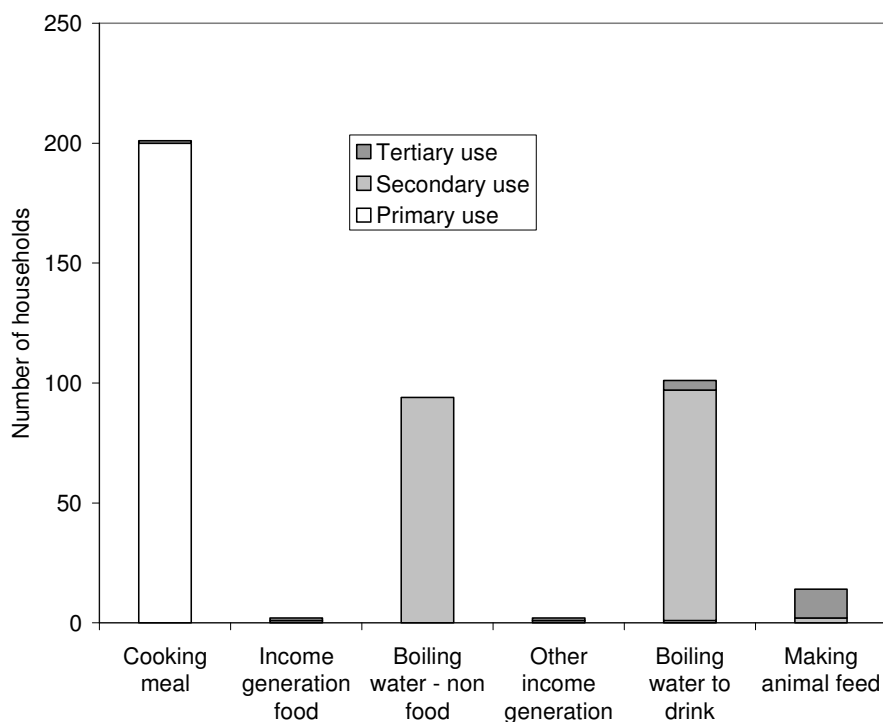


Fig 23: Cooking tasks undertaken by the respondents

Cooking a meal for the family is the main use of cook stoves, and almost exclusively the secondary use in Cambodia was boiling water to drink and in India was boiling water for a non-food use - which was bathing in most cases. This difference could be due to the difference in temperature, which meant it was more likely for Indians to bathe in hot water, and also due to the quality of the available water, which required boiling in

Cambodia. Different uses demand differing requirements from the stove in terms of functionality. Cooking, depending on the task being done, also required different functions from the stove, which all affect the suitability of a stove for a household.

Fuel

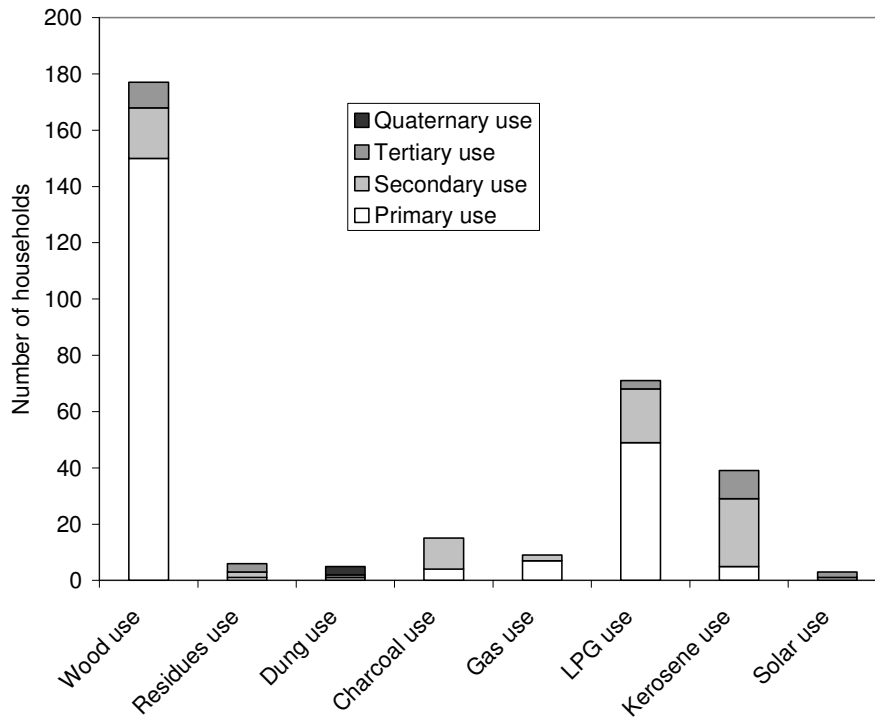
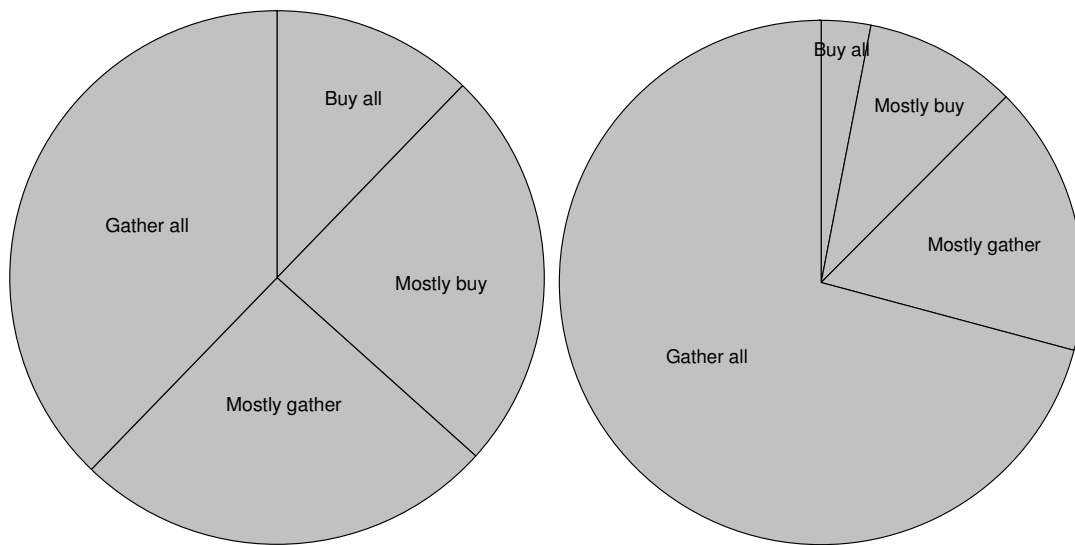


Fig 24: Fuels used by the respondents

The average monthly spend on fuel in Cambodia is 0.84 USD (n=97), of this 0.42 USD was on wood and residues; 72 people reported that they spend nothing on fuel. In India average monthly spend on fuel is India is 4.7 USD (n=95), of this only 0.32 USD was on wood, residues or dung and 23 reported that they did not spend anything on fuel. The increased spending on fuel is largely from LPG use in India, and the use of LPG may also explain the lower amount spent purchasing wood in India. The money spent on wood could be reduced through adoption of improved stoves since the gasification stove is more efficient, and, if residues with no other use are available, can be reduced to zero. However other reasons for using other stoves and fuel types may override the benefits of saving this relatively small amount of money.

Wood sourcing

For those who use wood, the majority (68) in Cambodia (n=101) gather all their wood, with only a small proportion buying all their wood; however in India (n=100) more move towards buying some or all of their wood with only 31 gathering all their wood. This might reflect greater population densities and pressure on wood fuel sources in India than in Cambodia.



a. b.
 Figure 25. The source of wood in a. India and b. Cambodia

The primary location for gathering fuel is on public land, with only 17 gathering fuel from agricultural land (n=162).

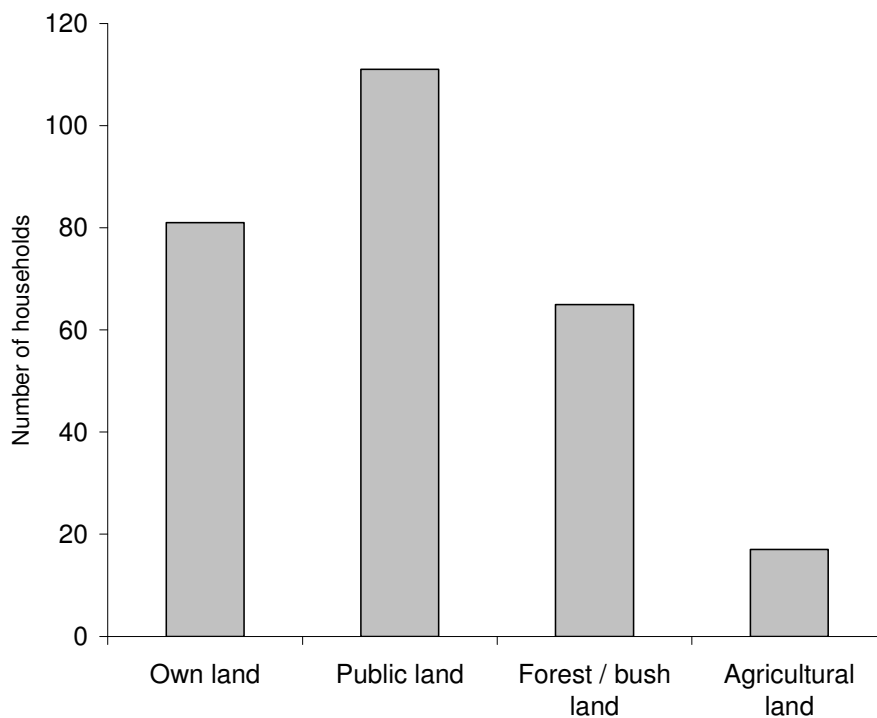


Figure 26: The source of gathered fuel

Respondents reported that they collect fuel wood on average 11 times per month, with 1 time per year being the least, and every day being also reported.

72% of respondents (n=162) said they spent more time than 5 years ago collecting fuel, with 26% saying that they spent the same amount of time as 5 years ago. Only 2% stated that they spent less time collecting fuel. 1% said that availability of fuel had increased, 30% said that the availability was the same, with 69% suggesting that fuel was less available than 5 years ago. Some respondents bought wood as well as, or instead of, gathering it, and some suggested one or more reasons for this (n=85): they were convenience (80%), clean / better quality to buy (61%), time (58%), no availability to gather (21%), ill health / too old to gather (5%) and an emergency (1%).

Farming

The respondents were mainly farmers, with 28% in India (n=98) with no farm and 20% in Cambodia (n=99) with no farm. Average farm holdings were 1.16 ha in India (n=72) and 0.89 ha in Cambodia (n=77). Farmers reported the use of various input into their farm. The use of more inputs was reported in India than in Cambodia.

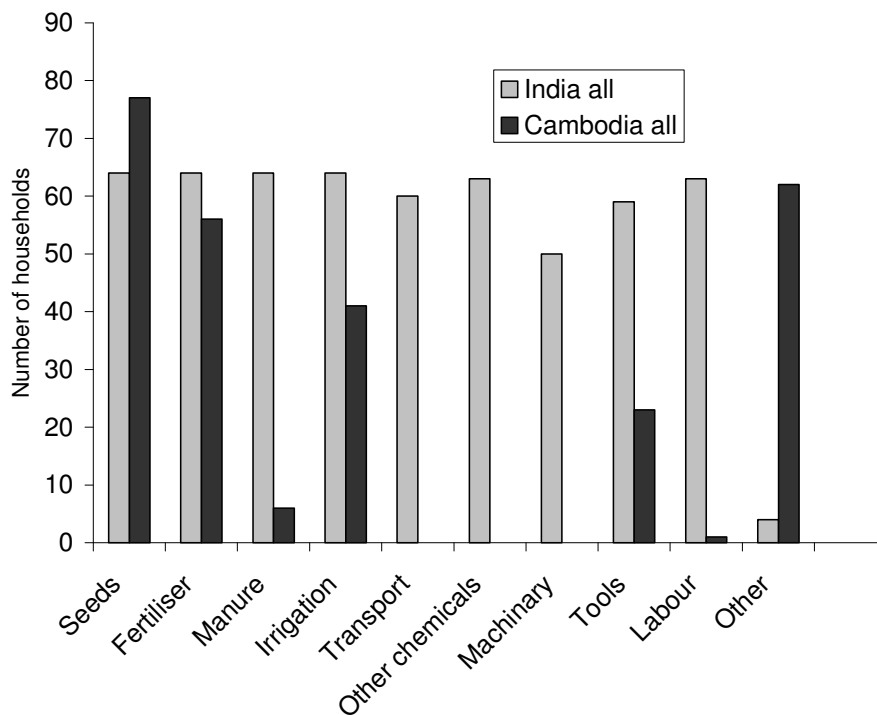


Fig 27: The use of inputs on farms by households

Respondents also reported the amount spent on various farm inputs (n=138). For those that do use the inputs, the average they spent was up to over 200 USD per year on tools and labour in India, but in Cambodia less was spent on inputs, the majority being on seeds, an average of around 50 USD per year.

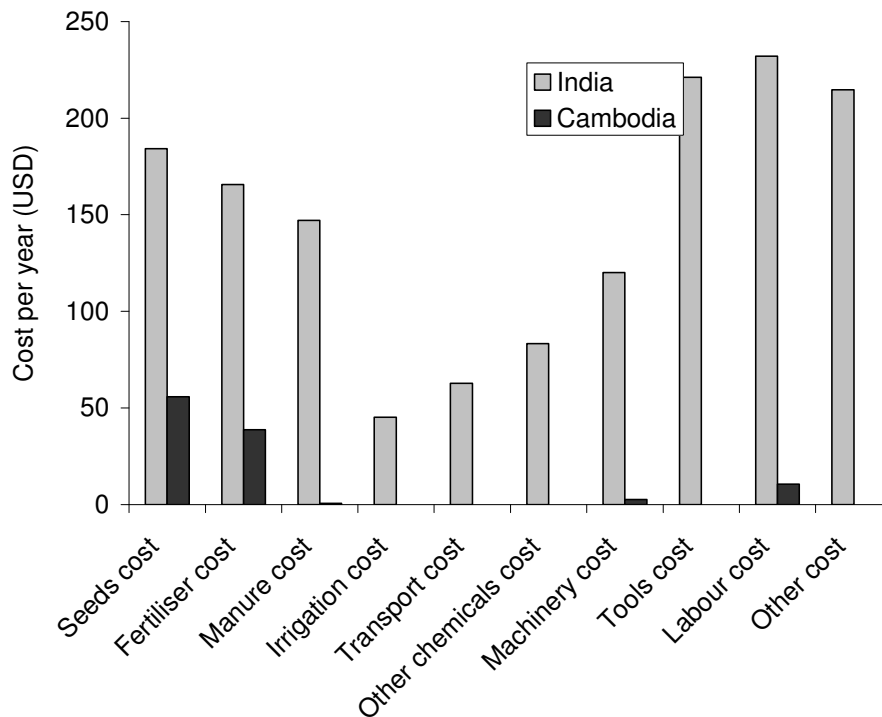


Fig 28: The cost of inputs on farms per household

The cash crops planted were also recorded as a measure of wealth (i.e. the land can be assumed to be surplus to that required for feeding the family). In India 35 respondents grew sugarcane, and 12 grew oil crops (mainly sunflowers), and in Cambodia one farmer grew sugarcane. The farmers also described the main problems with managing their farm (n=134). In India, the Indian farmers listed more problems than the Cambodian farmers, and 34% of those who responded suggested that fertility / poor soils were a problem when managing their farm, although other factors were more problematic, including capital, climate / weather variability and vermin / loss from animals. Other factors included drought / irrigation, technical knowledge, weeds, fire, technology availability, high rainfall, lack of / poor access to markets and thieves.

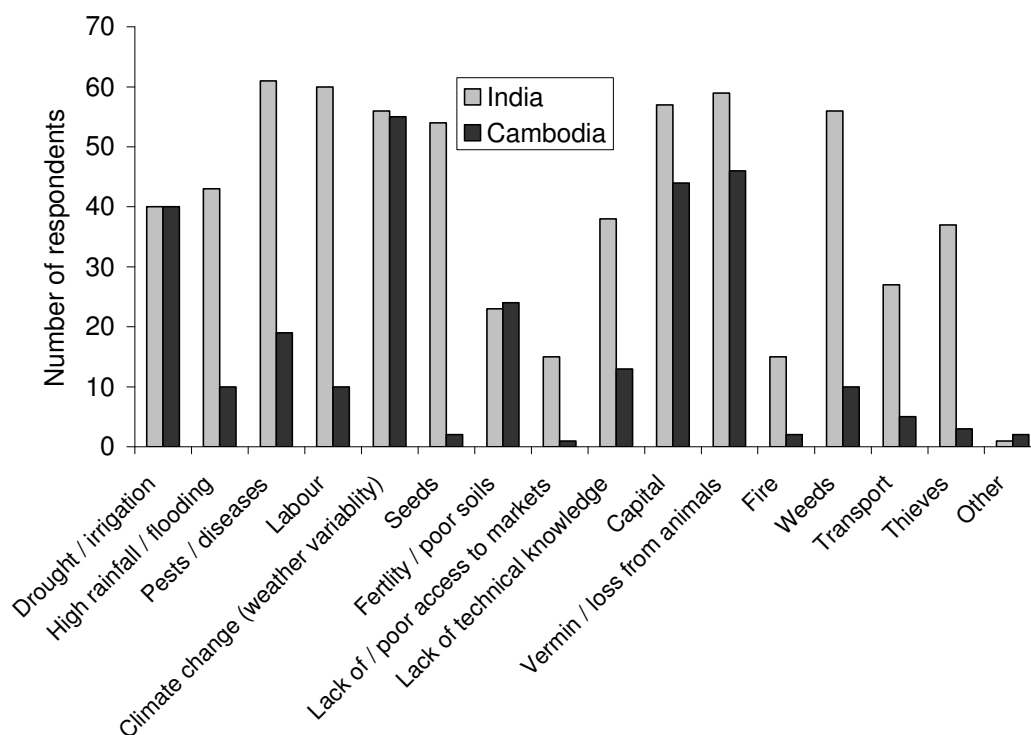


Fig 29: The problems which respondents encounter when managing their farm

Information about profit from the farm was gathered; however in Cambodia 50 out of 65 respondents stated that they did not make any profit - they merely got enough or not even enough to feed the family. In India, farmers stated profits of on average 1082 USD (n=67) per annum.

5.6. Women's Discussion Groups

Data was collected in women's group meetings using participatory rural appraisal (PRA) techniques. These meetings were set up as informal opportunities for women to discuss with the researcher some concepts related to cooking and household energy. Since the women are heavily involved in cooking, it is particularly important to include women in a context where their opinions will not be influenced by the presence of men.

Table 8: The location and participants in the women's group discussions

Location	Date	No. respondents	Note
ARTI Development Centre, M.S. India	Rural 29.09.2010 Phaltan,	23 Women	4 villages represented
Siem Reap	03.12.2010	20 Women	1 village represented

Several questions were posed (see below) and concepts discussed using PRA methods. The women were invited to write on flip chart paper (though not all the women were literate), and also to rearrange concepts into the correct order according to their views.



Figure 30: Image showing a group activity examining the roles of family members in cooking related tasks (right) and one of the outputs (left)

Table 9: Group activity results examining the question: What are the biggest worries for you and your household?

India	Cambodia
Money	Health
Education	Money
Health	Housing
Food	Food
Fuel	Managing the farm
Water	Education
Housing	Fuel
Managing the farm	Water

In India, money and education come at the top of the list, while in Cambodia, health and money head-up the list. Fuel did come up as an issue that causes concern, however; fifth on a list of eight items (India) (below food and more important than water); and 8th on a list of nine items (Cambodia) (again ranked above water).

Table 10: Group activity results examining the question: What activities do you spend most time doing?

India	Cambodia
Cooking	Looking after children / elderly relatives
Looking after the animals	Making handicrafts
Washing clothes	Looking after animals
Working on the farm	Working on the farm
Looking after children / elderly relatives	Going to the market to sell goods
Gathering fuel	Cooking

Fetching water	Gathering wood
Cleaning	Going to the market to buy goods
Construction of the house	Washing clothes
Making handicrafts	Fetching water

In Cambodia the women were also asked who was responsible for the cooking related tasks, including collecting wood (men and women), chopping wood (women, sometimes men and boys) and cooking (women, occasionally children). The men do most of the wood collection since they tend to work in the Angkor park, so can collect wood on their way home. Therefore the link between reduction of need for fuel through a more efficient stove, and the benefit of reduced workload and time spent collecting wood, may be more difficult for a family living in this context to see. It is worth noting here that the Angkor park area is well wooded, far more so than many parts of Cambodia.

Table 11: Group activity results examining the question: What are the most important uses of your stove?

India	Cambodia
Cooking meals for the family	Cooking meals for the family
Boiling water (non food use - bath)	Boiling water to drink
Making tea	Making animal feed
Making animal feed	Brewing alcohol
Frying tobacco	Cooking
Income generating cooking	Income generating cooking
Boiling water to drink	Boiling water (non food use - bath)
Light	Heating water for textiles / dying

Table 12: Group activity results examining the question: What is your perception of commonly used stoves?

	Traditional stove India	LPG stove India	3 stone fire Cambodia
Speed of cooking	X	<input type="checkbox"/>	
Cleaning	X	<input type="checkbox"/>	
requirements			
Taste of food	<input type="checkbox"/>	X	
Portability	X	<input type="checkbox"/>	<input type="checkbox"/>
Ability to vary flame	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Safety	X	X	X
Socio-cultural	X	X	X
Flexibility of	<input type="checkbox"/>	<input type="checkbox"/>	X
different feedstocks			
Smokiness	X	X	
Cost	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Fuel requirements	X	<input type="checkbox"/>	X
Suitability to cook	X	<input type="checkbox"/>	<input type="checkbox"/>
major food			
Fire maintenance	<input type="checkbox"/>	X	
required			
Heat retention	<input type="checkbox"/>	X	

The results in Table 12 again suggest that cook stove users do not automatically value an LPG stove as being superior to their traditional stove.

Box 12: Results from Womens Groups in India and Cambodia

Womens group output - India

Cooking inside for food, outside for boiling water (always firewood).

Also according to preference, some do all inside the house.

Only 1 lady uses LPG regularly – for her small business selling packed lunches.

Who is by the fire? – daughter in laws and children.

Government housing not built according to the type of stove women use! So they have only small windows. Also only small windows to stop intruders / thieves.

Biggest smoke problems, sore eyes, coughing and throat problems.

See pictures from the workshop.

Womens group output - Cambodia

20 women - North Saras Srang village.

All have families (married with kids), only 2 are single/ widowed.

They all use a 3 stone fire, and some also a New Lao stove (14).

Some have a fixed stove, with the bricks fixed in mud, or a mud shield built.

Mostly use wood. Mainly men chop, and women collect, but some men who work will collect on their way back.

In the dry season they cook in an open place, then in a more sheltered place in the wet season.

All cook meals for the family three times per day, and boil water.

Cook for at least 3 hours every day.

Water comes from wells, some are clean and some are not so clean, so mostly boil (not always)

Only the women are in the kitchen, children are often out working, and men also working. Only if women are ill do men cook. Sometimes children help to cook rice.

They notice smoke leads to coughing, sore eyes and breathing difficulties.

They can try to move out of the path of the smoke.

5.7. Summary of Additional Data from Workshops and Meetings

Box 13: Key Points Arising from the E-Seminar, Autumn, 2010

- The biochar producing ability must not be at the expense of diminished ease of use or efficiency levels of the stove.
- Gasification stoves do provide benefits in some situations, in part because they can use materials not used in traditional or conventional stoves (biomass waste).
- Biochar can be stored by users in a metal container which can be used to extinguish the biochar, although the cost of the metal container is another expense.
- TLUD stoves are often not designed for char production, although they are often capable of char production, so it is an option if the user does wants to empty the stove to save the char.
- Emptying a stove is difficult – the stove is hot, and it is dangerous and difficult to extinguish (especially when you are in the middle of cooking!). The char can be quenched with water while in the stove, but this can induce rusting depending on the type of metal used, which shortens the life span of the stove.
- The TLUD-FD (Forced Draft = with fan) does not usually produce any char, but the benefit of this design is in the increased emissions reductions and efficiency.
- A good TLUD cooking stove will give from 20 to 50 g of char from 1 kg of fuel if it is left to burn out (2 to 5% char yield). If you stop the process when the flame is over it will be from 50 to 100g (5 to 10% char yield). Other TLUD stoves will provide almost double this quantity of char, but at the expense of reduced efficiency in conversion of energy content of the biomass for cooking.

6. Project Outcomes

6.1. Online resources and Webinars

Hedon blog page

<http://hedon.info/Biochar>

Wordpress site

<http://biocharinnovation.wordpress.com/>

This site is publicly available and was updated during the project to show current progress. There were 8640 views of the site between its launch on 18.07.2010 and 02.02.2011.

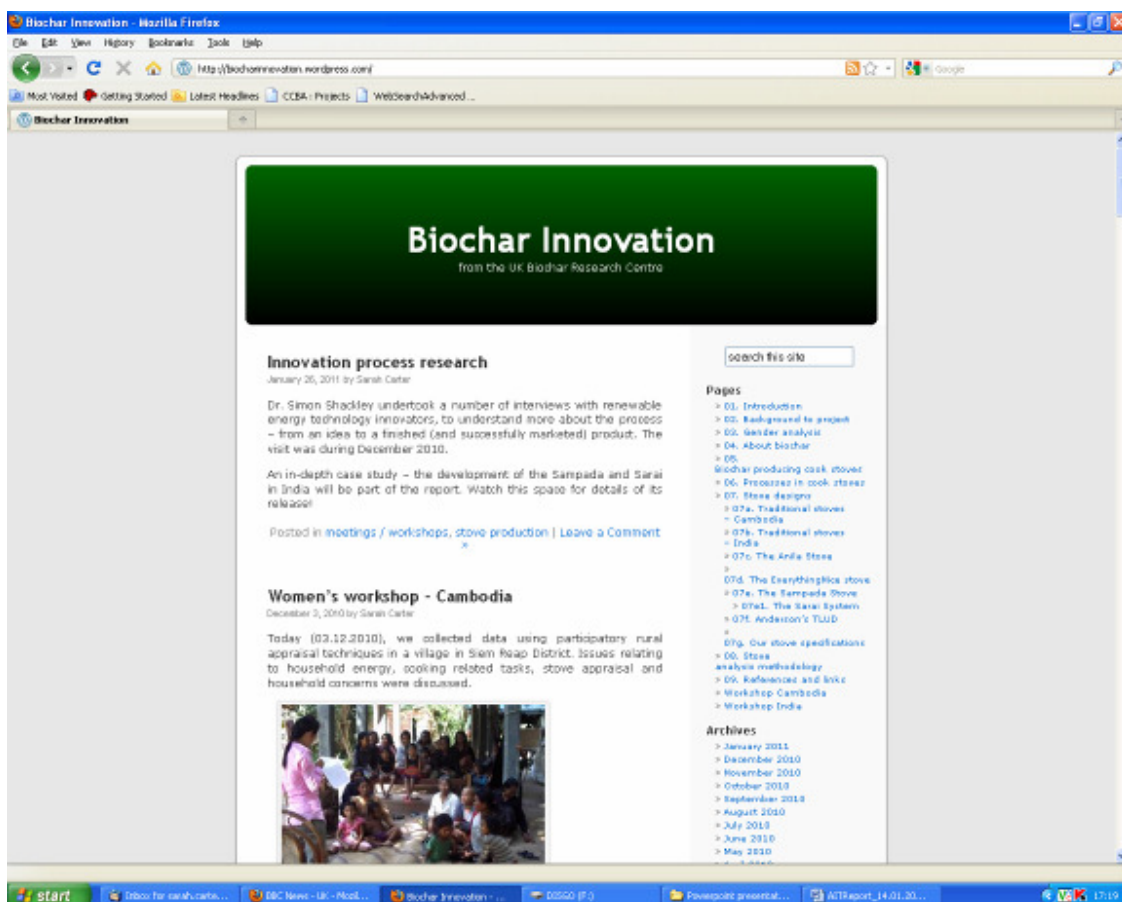


Fig X: Screen shot of the

The results from initial stove testing were shared immediately on bioenergylists:

<http://www.bioenergylists.org/content/testing-Sampada-sto>

<http://www.bioenergylists.org/content/testing-andersons-tl>

<http://www.bioenergylists.org/content/testing-everythingni>

<http://www.bioenergylists.org/content/testing-anila-stove>.

Biocharm project - online discussion meeting

6.2. Workshops

Two workshops were held. The workshop held 22-23 November 2010 in Siem Reap Cambodia was a huge success. The proceedings are available for download from the workshop page: <http://biocharinnovation.wordpress.com/workshop-cambodia/>.

Reports from meetings are available on request.

Stove donations

Stoves used in the project were donated to GERES Cambodia and ARTI India.

7. Overall Assessment and Recommendations

Back in the 1970s, the pioneers of improved cook stoves (ICSs) were motivated by concerns around deforestation and unsustainable resource use. This resulted in a focus upon fuel efficiency. In the 1980s, the reduction of IAP became the key-driver in improved stove design, while in the past decade or so, the climate change benefits of ICS have increasingly risen-up the agenda (both reduction in black carbon emissions and in fuel use per unit of useable heat generated, with consequent benefits for resource use). In the modern era, these concerns have converged and the 'win-win' scenario (climate change mitigation and health improvements through reduction in IAP) has commanded new levels of interest from funders, donors, many governments and NGOs. The biochar-producing ICS introduces a new dimension – a stove which produces a solid carbonaceous residue that can be incorporated into soil and enhance plant productivity in addition to acting as a long-term carbon store. We might refer to this as a 'win-win-win' scenario (i.e. above two benefits plus benefits to soil).

The gasification stoves (some designs of which can produce biochar) has conveniently combined the benefits of greatly reduced smoke with more efficient use of biofuel and is one of the major contenders amongst ICSs. At first glance, these benefits alone would seem to be irresistible and should have swept away the traditional designs, yet this has not been the case to the puzzlement of the designers, innovators, many NGOs, funders, etc. The energy ladder is an important part of the explanation of why expectations have not been met. In households with somewhat larger incomes, usually in peri-urban and urban neighbourhoods, charcoal stoves are already widely-used in many countries, which have similar benefits as the gasification stoves, being largely smokeless and an homogeneous energy dense fuel. The charcoal is likely to cost more money than purchasing the requisite firewood, but this is usually considered to be a price worth paying.

There are also some technical reasons which help to explain why the micro-gasification stove has not replaced traditional stoves or improved wood stoves such as the Rocket or improved charcoal stoves such as the New Lao Stove. An important reason why not is the enclosed features of the gasification stove (due to the requirement to limit oxygen), meaning that biomass cannot be readily added to adjust the fuel amount to the cooking need during cooking – this results in either too much or too little fuel being used, both with adverse consequences. Through sufficient practice it might be possible to work out exactly how much fuel is required per cooking operation, but this is inevitably subject to some uncertainty and is clearly less desirable than use of a stove where fuel can easily be added as required (e.g. through the fuel inlet at the bottom of the Rocket stove into which sticks can be inserted). A second limitation of the gasification stove is the inability to regulate the flame intensity (turn-up/down ratio). Cooks value this feature of a stove and where fuels can be inserted during the cooking, the flame intensity can be moderated, albeit it not with the precision of an LPG stove. It is possible that future stove designers can overcome these problems, but they remain a limiting factor in the acceptability and uptake of micro-gasification stoves, compared to combustion designs. In one sense, it can be questioned whether 'improved' cook stoves are indeed improved and, if so, from whose perspective? If they do not meet the requirements of users they can hardly be regarded as improved, even if they do have benefits in terms of fuel

efficiency and reduced smoke formation. May be they are improved from the perspective of environmental sustainability, fuel flexibility and health, but apparently at the expense of ease-of-use by the cook.

Cooking and eating are fundamental biological, social and cultural practices. They are deeply entrenched and imbued with rich meaning and significance. Provision of food to the family members is also one of the key responsibilities of certain family members (usually the woman and sometimes female children). This means that cooking cannot be easily compared to other activities and practices or domains of consumption. Buying an ICS is not, in that sense, akin to purchasing most other products or goods.

In theorizing consumption practices, sociologists have identified three key aspects that need to be kept in mind - the technology or equipment itself, the skills and capabilities to utilize such technologies and the meanings and signification imbued to such. Technical or efficiency improvements by themselves are likely to be viewed positively, but it is the fit of these changes in technology with skill & capabilities and with the meaning given to a technical change, that is paramount and will shape consumption practices (and purchasing decisions). Having the right skills and capabilities to use an ICS is vital, but so also is the cultural perception and meaning of an ICS to the user. It is obvious, but vital, that the intended user needs to be able to access suitably prepared biomass as (preferably more) readily (and at the same cost where relevant) as they can obtain fuel for their usual stove; and that they have the appropriate skills to easily and effectively use the ICS. Yet, what is equally important, is how the ICS is perceived in a socio-cultural sense: what does it mean, if anything, to own and use an ICS?

Surprisingly little is known about how decisions are taken within households about purchasing a new ICS and an ethnographic method of in-depth observation would probably be required in order to fully understand this in a given context. Due to widespread socio-cultural variability, it is also likely that many such studies would be required before a true appreciation of ICS purchasing behaviour was acquired. Reflecting some of our results, in their Mexican field research Bailis et al. found that: "Among potential stove users, fuel savings and air quality are of modest concern. ... The .. study surveyed improved stove adopters and found only half cited fuel savings as an important factor in their decision to adopt the new stove. Many respondents considered the aesthetics of the stove important. In addition, several noted a valuable co-benefit of improved indoor air quality: family members spend more time in the kitchen" (page 1699, [36]). The need for more such research is one of the key recommendations of this report and we hope to be able to submit a grant application in pursuit of this in due course. However, this aspect of cooking as a unique social practice may help to explain why the energy-ladder remains an important challenge to introduction of biomass-utilising ICSs. If cooking is amongst the most important of household practices, and if access to charcoal, then LPG, CNG, etc., are regarded as superior cooking fuels (e.g. in terms of ease of use, safety, turn-up/down heat control, etc.) then movement up the ladder is sensible if incomes permit. There is also the issue of 'lock-in' to consider. As infrastructure for 'superior' fuels advances, the benefits of their use increase, costs per unit use decrease as positive returns to scale set-in and practices begin to be locked-in. If bottled compressed gas is readily available, and efficiently and conveniently delivered upon request, then its use is likely to become normalized and practice embedded. In these situations, an appeal to an ICS using biomass, despite its cleanliness and efficiency, might not be attractive.

There are, of course, good reasons why biomass ICS can be made an attractive proposition. The escalating costs of 'superior' fuels rises is obviously a huge advantage. As we also found out through our empirical research, even after households have acquired stoves that use fuels such as LPG, they frequently continue to utilize wood stoves due to the cost-savings, the purposes of different stoves and as a hedge against price and supply shocks [36]. The co-existence of fuel options means that introduction of ICSs would still have benefits even with progression of households up the energy ladder: cooks frequently decide not to ascend the energy ladder it appears.

If infrastructure for use of biomass ICSs could be improved, it is also feasible that lock-in to a biomass-fuelled improved cook stove could also apply. For example, if biomass fuel could be prepared in the appropriate fashion and efficiently delivered to users, alongside effective repair and maintenance of the ICS, a biomass ICS lock-in could compete alongside lock-in to supposedly superior fuels and cooking technologies. The final point to make here is the obvious one that there are still a large number of individual households which are simply too poor to utilize more expensive fuels, hence will continue to rely almost exclusively upon biomass for their cooking and heating needs.

An implication of the above argument is that in a context of rapid socio-economic development and change, predicting how demand for ICSs, or for cooking devices that utilize liquid or gaseous fuels, will change, is fraught with uncertainty and inherently unpredictable. In Maharashtra, where some of the field work was undertaken, the economy is presently growing at 9% per annum. Large numbers of people are migrating into the cities and peri-urbanisation is proceeding at a rapid pace. In such a context, existing socio-cultural practices are coming under pressure and subject to change and, in terms of how this impacts upon cooking practices and selection of cooking implements and fuels, this will play out in unknowable ways.

The perspective of Participative Distributed Innovation Processes (PDIPs) takes explicit account of the active participation of the users in innovation. Many improved stove projects have involved users as test subjects and, where such involvement becomes active, rather than passive, a key condition for effective innovation is met. Pemberton-Pigott [38] asks a very pertinent question, namely why some technologies are called 'appropriate' whereas other very successful ones, such as the mobile phone, would never be referred to in these terms. One market-oriented response to this question would be that where innovation is really successful, there is no real need for intermediaries such as aid agencies, NGOs, development or government agencies, etc.,. It could be argued that everything should be 'left to the market' and that those technologies which are adopted are, by definition, successful ones. The role of intermediaries other than firms would then be limited to devising appropriate regulations and standards-setting. Yet, the PDIPs perspective recognizes that markets can and do systemically under-invest in some activities simply because they do not create sufficient revenue to individual market players (usually firms) and there happen to exist other investment opportunities available to those firms that deliver a higher return on investment. A classic case is the pharmaceuticals industry and its chronic under-investment in creating drugs for diseases prevalent in less-developed countries but not in developed countries, where the more attractive revenues and return on investment are available. In such a situation, social welfare (the 'public good') is maximized by state, or other agency, intervention to increase investment through special incentives, price regulation, access and intellectual property agreements, and such like. A very similar argument can be mobilized to justify state or other agency investment in ICSs. Because

of the low (or non-existent) incomes of biomass stove users, private companies are unable to extract large revenues or profits from adopters of biomass ICSs. The benefits to society from their more widespread adoption, however, are highly evident, with respect to climate change, sustainable resource use, health and local social and economic development. This provides the rationale for public investment in the ICS programmes, though obviously does not guarantee their success.

So, what about investment in the biochar-producing ICS? Does a PDIPs perspective support investment in this particular type of stove? To answer this question we need to briefly review what we have found out about biochar and gasification stoves. In the trials it was found that users had several main reservations about biochar production from stoves.

i) The difficulty in removing char from the stove

In the TLUD type design (Sampada, Champion, EverythingNice), char could only be obtained from the stove through hot removal (tipping) or cold removal (water quenching). Hot removal would be better achieved through using a sliding door (as per some stoves), but still incurs certain risks of fire, burning, etc. Cold removal by quenching is problematic because it will result in faster corrosion of the metal from which most stoves are manufactured. The Anila stoves does not suffer from this problem as the charred biomass in the outer fuel chamber will cool down once the cooking operation is over and will not smolder to form ash. Stove designers have not focused upon production of char for removal from the stove and it is possible that they can design TLUDs to overcome this limitation. (E.g. it may be possible to limit air into the gasifier, though smouldering combustion can offer at a slow rate with very little available air).

ii) The competing use of the feedstock

In the case of the Anila stove, it seemed strange to many stove users to add biomass to the outer fuel chamber as it was not clear to them what was the value of this additional process. If it can be demonstrated that biochar has obvious benefits, and if sufficient quantities can be produced in stoves, then cooks and other household members will begin to make trade-offs between fuel use and biochar production.

iii) Competing use of the char

Char has a value as a fuel and this is likely to be more appreciated by stove users than biochar without clear demonstration of its benefits. Char is appreciated as a clean and energy-dense fuel and it will appear counter-intuitive to many to bury it in the soil. However, char from small pieces of biomass would probably need to be processed prior to its use in stoves, e.g. through turning it into pellets or briquettes. In some situations, therefore, char might be used as biochar because its use as a fuel is not feasible. A further problem here is that more biomass ends up being used where biochar is produced and this additional fuel collection costs time and removes more biomass.

In order to counter these very real disadvantages, the benefits of applying biochar to soil would need to be very evident to the stove user and her household. As yet, evidence for such benefits is still being gathered and is some what mixed. Our own field trials provide a mixed-picture of the effectiveness of biochar in existing agricultural contexts (see Box 14).

Box 14: Results from Biochar Pot and Field Trials in India and Cambodia

The pot trials in Cambodia demonstrate that biochar can have a strongly positive effect upon yields. There was a statistically significant (95% confidence level) response to increasing biochar additions for lettuce (harvestable mass, root mass, number of leaves



and stem length) and for harvest and stem length in the case of cabbage.

The irrigated rice field trials showed a statistically significant increase in paddy yield with a 41tha^{-1} addition of carbonize rice husks (CRHs) in the case of one farm, but not in another farm that used the same variety and was located close by (100m). We cannot account for the difference in response. A variety of non-relicated

exploratory trials with vegetables and irrigated rice also gave positive results with respect to yield. The Indian pot trials did not show such a clear result as those in Cambodia. Three applications stand out as increasing fresh biomass relative to the untreated control: biochar at 20tha^{-1} , biochar at 20tha^{-1} with chemical fertilizer and chemical fertilizer only. Higher biochar applications (40 , 60 and 80tha^{-1}) appear to reduce overall fresh biomass weight compared to the 20tha^{-1} level and/or synthetic fertilizer applications. The Indian maize field trials using ARTI's single-kiln derived biochar from sugarcane trash and corn cobs did not show any statistically significant yield response. However, there was some evidence (not statistically significant) of a declining yield with biochar additions beyond 20tha^{-1} . The increase in maize yield for the 20tha^{-1} biochar application was significant at the 92% confidence level compared to the control.

Source: *Biochar for Carbon Reduction, Sustainable Agriculture and Soil Management* (BIOCHARM) project, [39].

The PDIPs perspective suggests that the intended users of ICSs are already facing quite a challenging context. A range of gasification designs is already in circulation and the key challenge might be a much better understanding of user needs followed by consolidation around a standardized design, potentially with the benefit of state-of-art engineering principles, as has been suggested by Garrett et al. Adding yet another dimension to this problem, i.e. production of biochar, might not be the best use of limited RD&D resources. It would also be necessary to compare production of biochar in a stove with that in larger dedicated units, such as the slow pyrolysis unit of Pro-Natura (e.g. in terms of costs, feasibility, efficiency, resource use, investment costs, and so on).

The empirical results of this project, and their interpretation using the theoretical framework adopted from the innovation studies literature (Participative Distributed Innovation Processes, PDIPs), suggest that biochar-producing stoves, at least with current designs, may be over-complicating an already rather confused and complex 'improved' cookstoves landscape. Garrett et al. make some very cogent arguments to

the effect that more coordination and harnessing of scientific RD&D is required to understand the 'cookstove user space' and to provide a range of validated designs which can meet those varied requirements. If the cookstove user space comes to include a niche for biochar producing stoves, then this variant can be incorporated into the design suite. The challenge for the biochar community is to demonstrate that this niche does, or should, exist; the challenge for the improved cook stoves community is to demonstrate that efficient, clean stove designs exist which integrate the safe extraction of biochar (for which a demand exists) and which do not compromise other desired design features of the stove.

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