Fuel for Life - Household Energy and Health

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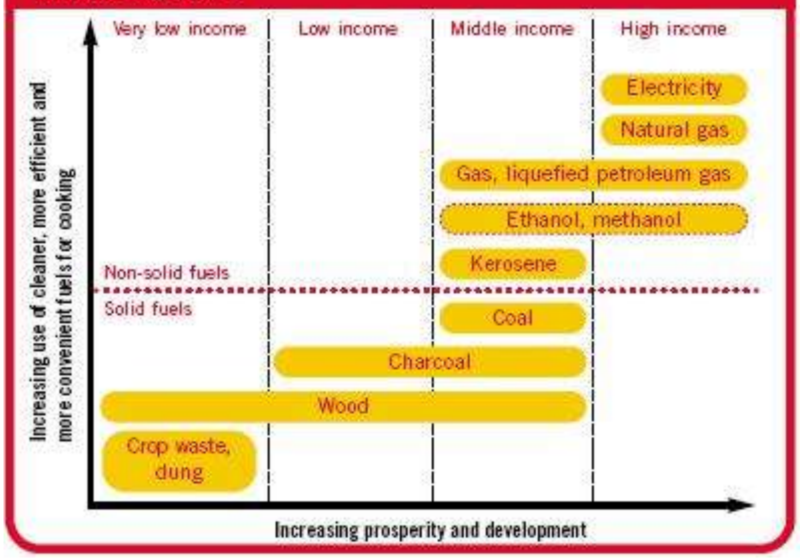
1. Introduction

Energy is essential to meet our most basic needs: cooking, boiling water, lighting and heating. It is also a prerequisite for good health – a reality that has been largely ignored by the world community. More than three billion people still burn wood, dung, coal and other traditional fuels inside their homes (Figure 1). The resulting indoor air pollution is responsible for more than 1.5 million deaths a year – mostly of young children and their mothers. Millions more suffer every day with difficulty in breathing, stinging eyes and chronic respiratory disease. Moreover, indoor air pollution and inefficient household energy practices are a significant obstacle to the achievement of the Millennium Development Goals (WHO, 2006).

Cooking as an enjoyable pastime and passion for a privileged minority – on an electric range or a gas stove in a stylish kitchen in New York, Paris or Tokyo. Cooking as a chore and threat to the lives of the great majority – on an open fire in a shabby hut in rural Africa, south Asia or Latin America.
Opening the door to their homes makes for a hazy welcome: thick grey smoke fills the air, making breathing unbearable and bringing tears to the eyes. The inefficient burning of solid fuels on an open fire or traditional stove indoors creates a dangerous cocktail of hundreds of pollutants, primarily carbon monoxide and small particles, but also nitrogen oxides, benzene, butadiene, formaldehyde, polyaromatic hydrocarbons and many other health-damaging chemicals. Day in day out, and for hours at a time, women and their small children breathe in amounts of smoke equivalent to consuming two packs of cigarettes per day. Where coal is used, additional contaminants such as sulfur, arsenic and fluorine may also be present in the air.

Yet, these families are faced with an impossible dilemma: don't cook with solid fuels, or don't eat a cooked meal. Being poor condemns half of humanity to dependence on polluting household energy practices. With increasing prosperity, cleaner, more efficient and more convenient fuels are replacing, step-by-step, traditional biomass fuels and coal. Climbing up the energy ladder tends to occur gradually as most low- and middle-income households use a combination of fuels to meet their cooking needs (Figure 2).

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



The problem of indoor air pollution has been around since the Stone Age, yet international development agendas still fail to recognize that missing out on clean energy equals missing out on life (WHO, 2006).

2. The technology

For a technology to be acceptable it needs to exhibit ‘desirable product attributes’ – characteristics that make it so much better that people are not only willing to accept it, but really want it at a price which they can afford. Some key attributes include (Bates, 2007):

Effectiveness
A project may set out, say, to alleviate smoke, but through the participatory process it becomes evident that the key criterion for the cook is to save fuel. Thus, the final design must save fuel if the cook is to use it - but does it still reduce smoke? It is important that in the participatory process, the key objectives are not lost.

Prestige
Does the product look attractive? If we want to improve a kitchen, then the cook may want it to look modern, to make the kitchen more welcoming, to keep the place tidier and cleaner. Even if we are installing an ‘off-the-shelf’ stove, we may still welcome advice on how to install it so that it enhances the appearance of the kitchen. If you were the cook, would you want to invite people in to see it?

Time-saving
A stove which requires constant tending, or needs a lot of fuel preparation will take much longer overall to use. It will only be acceptable if some other factor (such as cost or availability of fuel) means people are willing to take this extra time. If a chimney stove is used, it will not be cleaned unless it is easy to clean, and good training and instructions are part of the package.

Quality
For some people, buying a technology will be a major investment relative to their income. Are we confi dent that the product will last? This is vital, both to ensure that people with little money are satisfied, and to maintain the market for that product – bad news travels fast, so high quality training is important.

Accessibility
Where can I buy one? For those without access to public transport, a few miles can be an insuperable barrier to buying a new household technology. Are there local outlets that allow people to discuss products before purchasing them? Access to fuel is another issue that can affect the purchasing of a technology – can I buy or get fuel easily? In the Sudan study, a kiosk selling bottled gas could not be installed until thirty households had gas. Early adopters frequently reverted to woodfuel when they ran out of gas as the walk with a heavy bottle was too long. Once the kiosk was installed, the situation improved.

Spare parts and maintenance
What happens if something goes wrong? If some small component breaks, is a ‘spare’ available? Is someone there who can fi x it safely? Is the model one that has a good

policy of spare parts being available for several years…? If something goes wrong, do people know whom they should contact?

Safety

Burning fuels, and houses made of thatch and wood are a dangerous mix. Any fire that is out of control has the potential to cause injury and destruction. Those using new technologies should expect that their safety has been considered very carefully, and that it is easy for the product to be used correctly. Have good instructions for the use of the technology been given? Have community and individual demonstrations been planned?

Familiarity

People with very little money cannot afford to make the wrong choice. Thus some communities will only make small changes in their cooking practices. The best technology for them may therefore not be the best technical choice. The more expensive, or different, the technology that is being introduced, the greater is the risk. The Nepal case study in Box 1 below is a good example. In this project, several hoods were installed that adhered exactly to the demands of the community even though the team felt that they would only remove some of the smoke. Once the rather indifferent fi ndings were discussed with the community, they were happy to install much more effective smoke hoods as they were active participants in the initiative and felt more comfortable with the technology.

Affordability

The greatest barrier to improving household energy provision is undoubtedly the 'up-front' cost of the product – thus cost and availability of credit will be key factors. People's 'willingness to pay' and the way they prioritise what they buy means that our technology has to have 'Desirable Product Attributes' if it is to be an asset. Since men often have more available money than women, does our technology appeal to them too? A marketing survey commissioned by Practical Action as part of its smoke alleviation project showed that this was the overwhelming barrier to purchasing products. Making revolving funds available made a substantial increase in market size.

Consumer-driven technologies

Technology has the potential to change people's lives for the better, but if we start with the technology, there are real dangers that we will not get the best results from our efforts. The evaluation involving the World Bank, TERI, and Winrock-India in collaboration with the Ministry of Non-Conventional Energy Sources, Government of India indicated that stoves need 'better adaptation to user needs'.

2.1 Stoves for cooking

2.1.1 The Mayon Turbo Stove (MTS)

Features of the Stove (http 1):

High efficiency and clean combustion: high quality, swirling blue flames are created from the twin primary air injectors and the extended inner cone with secondary air holes
Economical: Average annual cooking costs and stove purchase is approximately $15-20 USD for the MTS, compared to $60-200 USD for cooking with purchased firewood, charcoal and LPG
Fast boiling: 1 litre of water can boil in 6-7 minutes
Convenient to use: tapping to introduce new fuel is required approximately only every 7-10 minutes
Low fuel consumption: Approximately 2.5 sacks (25 kg) of rice hull/family/week
Portable and lightweight: steel construction, weighing approximately 4 kg; can be used both indoors and outdoors
Uses a variety of biofuels: Enables the use of many fuels to be used in conjunction with rice hull including corn cobs, peanut shells, cocoa shells, crushed coconut shells, millet husk, and sawdust
Safety: a ring structured holder provides excellent pot stability
Holistic Use of Fuel: ashes can be reused as a soil conditioner, fertilizer, and pest repellent around plants

Figure 3 The Mayon Turbo Stove is a multi-fuel stove that can also burn peanut shell and millet husk mixtures (http1)

2.1.2 HELPS International stove

The HELPS stove is used in Guatemala and incorporates the rocket elbow into a griddle stove (HELPS, 2005; Burnham-Slipper, 2005). The body of the stove is cast from concrete, and claims complete combustion, efficient heat transfer to the pot, and a 60-70 % reduction in fuel consumption from classical designs, though absolute values are not recorded.

Figure 4 the HELPS International stove (HELPS, 2005).

2.1.3 VESTO stove

The stove was developed by Crispin Pemberton-Pigott’s New Dawn Engineering (Swaziland). It is a variable energy, fuel efficient wood burning stove based on a modified 25 litre paint can made of stainless steel. It has preheated secondary air of three types as well as preheated primary air. The primary air and most of the secondary air are separately controlled by two horizontally sliding levers that protrude from one side of the body. It can accommodate fuel from twigs up to 110 mm diameter wood, preferably 200 mm long or less (over-filling a wood stove make a lot of smoke) (http4). The Vesto stove has a two-stage burning process and is known as “gasifier” or “semi-gasifier” stoves (USAID, 2010).

The Vesto was developed from the beginning as a stove that would be mass produced, rather than made through artisanal production in villages. In order to reach a scale of market acceptance and to generate sufficient fuel savings it was necessary to use materials, production processes and marketing strategies that could produce, assemble and distribute the stove at a cost similar to a large pot - in the region of US$20 to US$30 while still allowing for a retailer to sell it profitably (http4).

The VESTO was subjected to a rigorous quantitative stove performance testing using the Controlled Cooking Test protocol combined with qualitative assessment of the acceptability and usability during a time-limited visit to a refugee camp. Results are summarized in Tables 1-3.

Figure 5 The VESTO stove

2.1.4 Maendeleo One-pot Jiko

This stove has been developed for use in Kenya and other East African countries (GTZ, no date). It consists of a ceramic liner that is surrounded by stone and brick insulation. The liner gives optimal sizes for the floor space, combustion chamber height, door and under-pot spacing to ensure efficient combustion and heat transfer. The door restricts the amount of wood that can be burned at a time, ensuring the ‘economy of smallness’. While the stove does not have a grate to raise the wood off the ground and allow air to pass underneath it, the stove promoters recommend that a ‘tongue’ be built in front of the stove. The tongue is a pile of stones smoothed over with clay and it raises the non-burning end of the wood off the ground, to let air circulate freely around it. The stove gives a 40 % reduction in fuel use and costs less than a chicken. No absolute data are given.

Figure 6 GTZ Maendeleo stove (http7; USAID, 2010)

2.1.5 POCA or Maputo Ceramic Stove

In Mozambique, ProBEC and its commercial partner CeramicArte, a ceramics manufacturing company in Maputo are marketing the Maputo Ceramic Stove (also called the Poupa Carvao, meaning 'charcoal saver'). There are glazed and unglazed versions of the stove which sells for 140 meticais and 120 meticais respectively (4 – 5 USD). The stoves save more than 60 % charcoal and have proved to be very well accepted in household field trials (Balmer, 2007).

Figure 7 Maputo stove (Balmer, 2007)

2.1.6 Envirofit G-3300 Stove

The Envirofit G3300 stove is centrally manufactured, easily transported, requires no assembly,designed to burn wood and comes with a 5 year warranty on combustion chamber and 2 year warranty on all other components.

The stove has cylindrical metal exteriors with a handle to facilitate moving it, and a metal combustion chamber where the fire is contained. The combustion chamber is “L” shaped and front-loading, one of the design features that defines it as “rocket” stove. The stove has been designed to control the air flow through the stove in order to optimize the mix of combustible elements (e.g. the air to fuel ratio), improving the cleanliness and efficiency of the burning process. The fuel is burnt in a single combustion stage.

The Envirofit stove comes with metal skirts designed to contain and funnel the heat to the pot bottom more efficiently. The skirts are not integral to the functioning of the stoves, but they have been shown in laboratory environments to increase efficiency (USAID, 2010).

The G-3300 was subjected to a rigorous quantitative stove performance testing using the Controlled Cooking Test protocol combined with qualitative assessment of the acceptability and usability during a time-limited visit to a refugee camp. Results are summarized in Tables 1-3.

Figure 8 Envirofit G-3300 Stove (USAID, 2010).

2.1.7 StoveTec Wood Stove

StoveTec's wood stove is centrally manufactured, requires no assembly, can easily be transported, and designed to burn wood in an outdoor environment. The combustion chamber has a ceramic liner, is front-loading and L-shaped ("rocket" stove type). Fuel is burnt in a single combustion stage. The StoveTec stove comes with a metal skirt designed to contain and funnel the heat to the pot bottom more efficiently. The skirt is not integral to the functioning of the stove but has been shown in laboratory environments to increase heat transfer efficiency.

The StoveTec was subjected to a rigorous quantitative stove performance testing using the controlled cooking Test protocol combined with qualitative assessment of the acceptability and usability during a time-limited visit to a refugee camp. Results are summarized in Tables 1-3.

Figure 9 StoveTec Wood Stove

2.1.8 Philips Natural Draft Stove

The Philips stove is centrally manufactured in India, requires no assembly, can easily be transported, and was designed to burn wood. It comes with a metal combustion chamber burning the wood in two-stages (gasifier principle). No accessories are provided.
The Philips stove was subjected to a rigorous quantitative stove performance testing using the Controlled Cooking Test protocol combined with qualitative assessment of the acceptability and usability during a time-limited visit to a refugee camp. Results are summarized in Tables 1-3.

Figure 10 Philips Natural Draft Stove

2.1.9 Save80

The Save80 is centrally manufactured by Climate Management Ltd. in Zambia, requires no assembly, can easily be transported, and is designed to burn wood. According to the manufacturer the Save80 needs around 250 g of dry firewood to boil 6 L of water within 25 min and helps saving 80 % of fuel compared to an open fire.

The Save80 has a stainless steel combustion chamber where the fire is contained, burn the fuel in a single combustion stage. The Save80 comes with an integrated pot, suspended above the combustion chamber on the metal edge of the stove.

The Save80 stove was subjected to a rigorous quantitative stove performance testing using the Controlled Cooking Test protocol combined with qualitative assessment of the acceptability and usability during a time-limited visit to a refugee camp. Results are summarized in Tables 1-3.

Figure 11 Save80 stove

Table 1 Summary of quantitative stove performance results for the six stoves, showing the average and percentage difference versus the open fire (USAID, 2010).

	Units	Open fire	Envirofit	StoveTec	Philips	Vesto	Save 80
# of Tests	/	54	38	38	38	24	22
Specific consumption	g_{wood}/ kg_{food}	295	143	136	159	202	110
Specific consumption	% diff. vs. open fire	NA	-52	-54	-46	-32	-63
Cooking time	minutes	54	49	50	56	47	52
Cooking time	% diff. vs. open fire	NA	-8	-7	+4	-12	-2

Table 2 A summary of focus group consensus regarding the best stove in four important categories (USAID, 2010).

Criterion	Dagahaley camp	Ifo camp	Hagadera camp
Most fuel efficient	Envirofit and StoveTec	StoveTec	Save80
Safest	StoveTec	StoveTec	StoveTec
Most durable	StoveTec	StoveTec	StoveTec
Easiest to use	Envirofit	StoveTec	StoveTec

Table 3 Stove rankings from the focus groups (most preferred to least preferred) (USAID, 2010).

Stove rank	Dagahaley camp	Ifo camp	Hagadera camp
1	Envirofit	StoveTec	StoveTec
2	StoveTec	Envirofit	Envirofit
3	Philips	Philips	Vesto
4	Save80	Save80	Philips
5	Vesto	Vesto	Save80

2.2 Charcoal stoves

Charcoal stoves can be used for producing charcoal and cooking simultaneously. Charcoal is a valuable byproduct (Figure 2) which can be added to soil to enhance fertility, improve crop yield, reduce fertilizer needs and act as a carbon sink, but also as solid fuel for BBQ, restaurants, water purification and treatment of food poisoning.

2.2.1 Lucia stove

The LuciaStove is a top-filled gasifier stove, which can be operated continuously. Biomass feeding rate ranges from 300 g (=1.25 hrs cooking time) to 1.5 kg/hr. As a retail item, the LuciaStove is intended for lots of 500 or more, and has a focus to set up micro industries in communities. WorldStove constructs the base components and then works with local liaisons to set up small manufacturing plants. These plants do not require welding, riveting or drilling. They serve as a skill based income generating activity for the community. We provide the instructions and guide for assembly of additional stove parts and will work with local groups to set up the plant, and to adapt the LuciaStove to local cooking needs. For numbers greater than 500, the price drops significantly (http5).

This price includes:

- Base components for 500 LuciaStoves
- WorldStove Technical assistance in setting up manufacturing plant
- WorldStove training on LuciaStove assembly and operation
- WorldStove staff time for adjustments made to stove to reflect local cooking needs

Figure 12 The Lucia Stove (http5).

2.2.2 Anderson's TLUD

The Top-Lit UpDraft (TLUD) gasifier stoves fall into two main categories based on having forced air or natural draft. TLUD gasifiers operate with batches of fuel that are pyrolyzed, so they must be emptied and refilled. Therefore, a second fuel canister permits sequentially continual cooking. The natural draft TLUD gasifiers utilize the principles of Anderson's "Champion" stove that won the "Kirk Smith Cat Pee Award" for clean combustion at ETHOS Stove Camp 2005. A 15 inch (38 cm) riser or "pre-pot internal chimney" is needed to achieve the natural draft, but additional chimney height is needed at elevations above 3000 feet (1000 meters). This design is maintained in Andreatta's TLUD testing unit, seen in Figure below (Anderson, 2007).

Figure 2 Reed's Woodgas Campstove (left) for sale on the Internet (US$55) and Anderson's Juntos B+ TLUD gasifier (with removable fuel canister) hand-made in Cambodia with GERES (estimated cost under US$20). For cooking, the pot can be placed on top of the unit or (better) be positioned on a simple pot support structure of any size so that the gasifier can be moved for refilling without disturbing the pot. (*photos: Tom Reed, left, Paul Anderson, right*)

Inner volume of the Champion 2008: 4.4 L
Usable volume for fuel (my assumption): 3 L
Biomass packing density: 0.5 kg/L
Biomass filling: 3 L x 0.5 kg/L = 1.5 kg
Pyrolysis time: 30 min
Char yield: 25 %
Operation per day: 3 hrs/d
Char production per day: 1.5 kg / 0.5 hrs x 0.25 x 3 hrs/d = 2.25 kg / d
Annual biochar production (TLUD 80 % in use p.a.): 2.25 kg / d x 365 d/yr x 0.8 = 657 kg / yr
Investment cost (TLUD): USD 32

Operational cost: 0 USD
Life span (2628 hrs): 3 yrs
Depreciation: 32 USD / 3 yrs = 10.7 USD / yr
Cost of char: 10.7 USD/yr / 0.657 t/yr = 16.2 USD / t

2.2.3 Belonio's rice husk stove

Belonio's rice husk stove (Figure 9) is a small cylinder equipped with a fan in its base, which provides air during the conversion of rice hulls into gas. It was designed as an apparatus that can be easily operated. Fish can be fried in fifteen minutes using the stove. The stove consumes 2 kilograms of rice husks per hour. It does not produce any smoke, and the pyrolysed rice husks can still be used as charcoal (high ash-content) and also as insulating cement for traditional stoves fueled by wood. Plans for the stove are available free of charge from the internet (http2; http3).

Figure 14 Prof. Alexis T. Belonio, recipient of the Rolex Award, with his invention, the *Belonio rice husk stove* (http3).

2.2.4 Anila stove

The modern Anila stove was developed by U.N. Ravikumar, an environmentalist, engineer and Director of the Centre for Appropriate Rural Technologies (CART) at India's National Institute of Engineering. Anila-type stoves use two concentric cylinders of different diameters (see Figure 15). Biomass fuel is placed between the two cylinders and a fire is ignited in the center. Heat from the central fire pyrolyzes the concentric ring of fuel. The gasses escape to the center where they add to the cooking flame as the ring of biomass turns to char (http9).

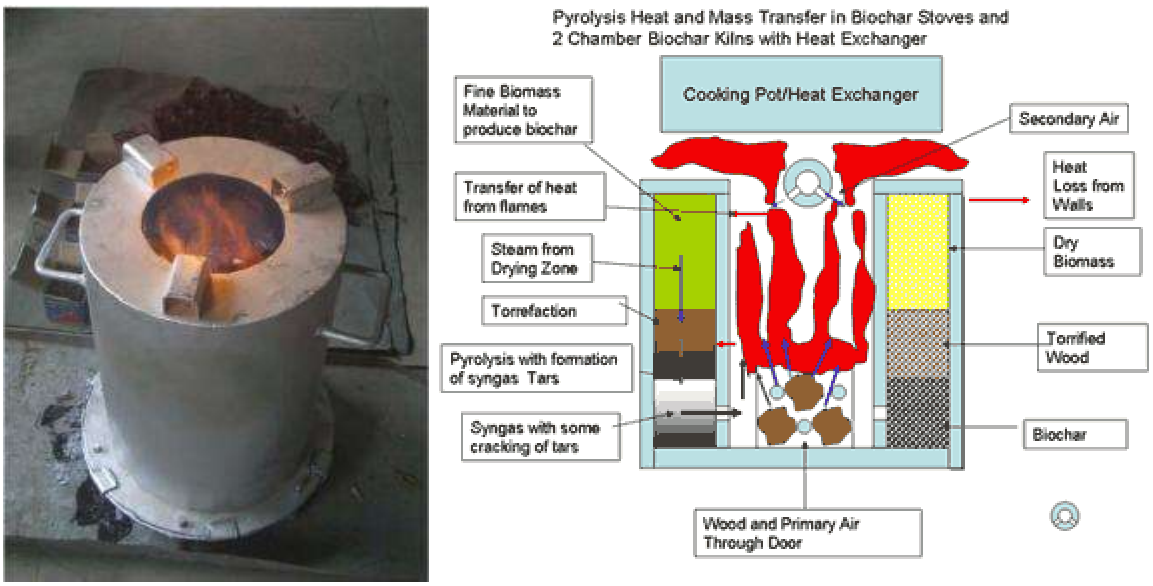


Figure 15 Anila stove (Friese-Greene, 2008; http9)

www.geos.ed.ac.uk/sccs/biochar/documents/WP4.pdf
http://africaclimate.org/2009/01/06/carbon-cycle-and-anila-stove/
http://www.holon.se/folke/carbon/simplechar/simplechar.shtml

2.2.5 Estufa Finca (Farm Stove)

2.3 Improved charcoal kilns

2.3.1 Adam retort or Improved Charcoal Production System (ICPS)

The ICPS (Improved Charcoal Production System) or "adam-retort" was developed in Burundi/East Africa and India. The retort-kiln works on the principles of industrial retort charcoal productions, however the building materials and the operation techniques had been adapted to an "appropriate technology" scale and this retort-kiln can be operated on a village- or small to medium–scale industries level. The "adam-retort" which is a "low-cost retort kiln" is a novelty concerning charcoal production in rural areas or for entrepreneurs (semi-industrial production) with the following advantages (Adam, 2009):

* **High economy** and better **efficiency of approx. 35%** (Instead of about 18% efficiency compared to the traditional systems; calculated from dry weight).

* **Recycling and clean combustion of the pyrolysis gas** during the 2nd phase of operation (retort-system) results in a low-emission of carbon monoxides during the charcoal production! Burning of harmful methane gas. The effective carbonization of the biomass takes only about 10 hours.

* **Low investment costs** (about 500 Euros) and a simple construction of this "low-cost retort kiln" with locally available materials.

* About 3m³ of biomass (corresponding to approx. 700 to 800kg wet wood, or about 600kg dry wood), coconut shells, extruded wood briquettes, etc. can be converted to up to ~ **250 kg of charcoal**.

* An effective **30 hour production cycle (batch operation)** and a simple operation of the plant result in an increased income for its operators. (~3 batches per week).

The right system to be used at forest projects, energy-wood plantations and charcoal makers.

* **Only waste** and residual biomass needs to be burnt (~50 kg) in a separate fire-box to dry and heat the wood and initiate the carbonization process during the 1st phase.

* The "adam-retort" is **semi-transportable** if the set of accessories (metal sheets and welded parts) are moved from one retort chamber to the other. Several retort chambers are built in different areas and one set of metal accessories serves them. Costs are reduced to about half.

Figure 16 ICPS (http 6).

Economics

Biomass filling per batch:	925 kg (dry wood)
1 complete production cycle:	2d/batch
Char yield:	36 %
Production cycles per year:	3 batches/week x 48 weeks/yr = 144 batches/yr
Char production per batch:	333 kg/batch (ADAM: 270kg/batch)
Annual biochar production:	333 kg/batch x 144 batches/yr = 47952 kg / yr
Investment cost:	680 USD
Life span:	3 yrs
Depreciation:	680 USD / 3 yrs = 227 USD / yr
Operational & maintenance costs:	200 USD/yr (USD 170 for 2 bottom black sheet + USD 30)
Biomass transport cost:	2 USD/t x 133 t/yr =266 USD/yr
Biomass cost:	5 USD/t (assumed to be waste) x 133 t/yr = 665 USD/yr
Labor cost:	3 USD/d x 288 d/yr / 3 (working on 1 ICPS only) = 288 USD/yr
Total annual costs:	227 USD/yr + 200 USD/yr + 266 USD/yr + 665 USD/yr + 288 USD/yr = 1647 USD/yr
Cost of char:	1647 USD/yr / 48 t/yr = 34.4 USD / t

3. Summary

Stove name	Manufacturer	Fuel	Costs [USD]
Mayon Turbo Stove (MTS)	REAP-Canada 21,111 Lakeshore Road Box 125 Centennial Centre CCB13 Ste-Anne-de-Bellevue, QC H9X 3V9 Canada Phone: (514) 398-7743 Fax: (514) 398-7972 Email: info@reap-canada.com Registered Charity No: 10787-7839	Rice husks, peanut shells	15-20
HELPS International stove	US Office 15301 Dallas Pkwy. Suite 200 Addison, TX 75001 (972) 386-2901 (972) 386-4294 Fax 1-800-41- HELPS info@helpsinternational.com		150
VESTO stove	P.O. Box 3223 Manzini, MZ200, Swaziland, Southern Africa info@newdawnengineering.com sales@newdawnengineering.com thabsile.s@newdawnengineering.com thabsile@swazi.net; am@mijons.com; crispinpigott@gmail.com	twigs up to 110 mm diam. 200 mm long wood	20-30
Maendeleo One-pot Jiko	Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) Germany	Wood	
Maputo Ceramic Stove	P O Box 13732 Hatfield 0028	Charcoal	4-5

	Pretoria South Africa Email: erika.schutze@gtz.de		
Envirofit G-3300	Manufacturer: Envirofit International Contact: Tim Bauer Email: tim.bauer@envirofit.org Website: www.envirofit.org Postal Address: 109 North College Avenue, Fort Collins, CO 80524-2602, USA	Solid wood (~2 x 2 x 40 cm)	15 (+ duties and tariffs 5 to 10; http8)
StoveTec Wood Stove	Manufacturer: StoveTec Contact: Ben West Email: ben@stovetec.net Tel: +1 541-767-0287 Website: www.stovetec.net Postal Address: P.O. Box 1175, Cottage Grove, OR 97424, USA	Solid wood (~2 x 2 x 40 cm)	65
Natural Draft Stove	Manufacturer: Philips Electronics India Limited Contact: Pawandeep Singh Email: Pawandeep.Singh@philips.com Tel: +91 124 4606000 (Extn. 6066) Fax: +91 124 4606666 Website: http://www.philips.com/shared/assets/Downloadablefile//Sustainability-Annual-Report-2006(2)-16090.pdf Postal Address: 9th Floor; DLF 9-B; DLF Cyber City; DLF Phase 3; GURGAON - 122002; India	Wood (2 x 2 x 15 cm)	<100
Save80	Manufacturer: Climate Management Ltd. Contact: Klaus Trifellner Email: klaus.trifellner@climatemanagement.de Tel: +260 211 238 00-9 -10 Fax: +260 211 238011 Mobile: +260 955 863295 Website: www.climateinterchange.com	Wood (2 x 2 x 15 cm)	<100

	Postal Address: P.O. Box 32978, Lusaka, Zambia Physical Address: 8201/C Lima Garden, Lusaka, Zambia		
Lucia stove	Nat Mulcahy Worldstove Internet	Agro-industrial solid waste	49-70*
Anderson's TLUD	Paul S. Anderson, Ph.D. Illinois State University IL 61790 psanders@ilstu.edu Manufacturer in India : Servals Automation (SAPL) http://servalsgroup.blogspot.com/ mukundanpa@gmail.com; sujatha_pm@yahoo.com; vijayaganapathi1@gmail.com	Wood chips, coconut	32 (2 fuel canisters, 1 concentrator lid, and coupler attached to a pot stand on a tripod)
Belonio's rice husk stove	Department of Agricultural Engineering and Environmental Management, College of Agriculture, Central Philippine University, Iloilo City, Philippines. Produced by: Minang Jordanindo Approtech (Indonesia) http://www.approtech.org/ info@approtech.org atbelonio@yahoo.com	Rice husks	(<20)
Adam's retort	adam + partner Box 50108, Addis Abeba, E T H I O P I A H/P: +251-251-910883624, +251-251-9133343 26 (H/P: +49-(0)175-528 96 24, German Telekom does not work in Ethiopia) www.biocoal.org scda2@ymail.com	Wood, coconut	400

* Minimum order 500 units. Includes technical assistance and training

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http3: http://rolexawards.com/en/press-room/photo-downloads-2008-laureates-alexis-belonio.jsp#photo-download-3. accessed on 3rd Feb 2010.

http4: http://www.newdawnengineering.com/website/stove/singlestove/vesto/. accessed on 3rd Feb 2010.

http5: http://worldstove.com/products/luciastove-for-developing-nations/. accessed on 3rd Feb 2010.

http6: http://terrapreta.bioenergylists.org/content/cocnut-husk-kenya. accessed on 3rd Feb 2010.

http7: http://www.bioenergylists.org/files/images/Maendeleo.jpg

http8: http://www.charcoalproject.org/2010/03/one-companys-quest-to-serve-hot-stoves-to-the-bottom-of-the-pyramid/. accessed on 8 August 2010.

http9: http://www.biochar-international.org/technology/stoves. accessed on 8 August 2010.

http10: http://www.hedon.info/docs/BP58-I2RB-G3300-info-sheet.pdf. accessed on 8 August 2010.

MacCarty, Nordica, Damon Ogle, Dean Still, Tami Bond and Christoph Roden (2008) A laboratory comparison of the global warming impact of five major types of biomass cooking stoves. ***Energy for Sustainable Development***, Vol XII(2), pp. 5-14.

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Appendix

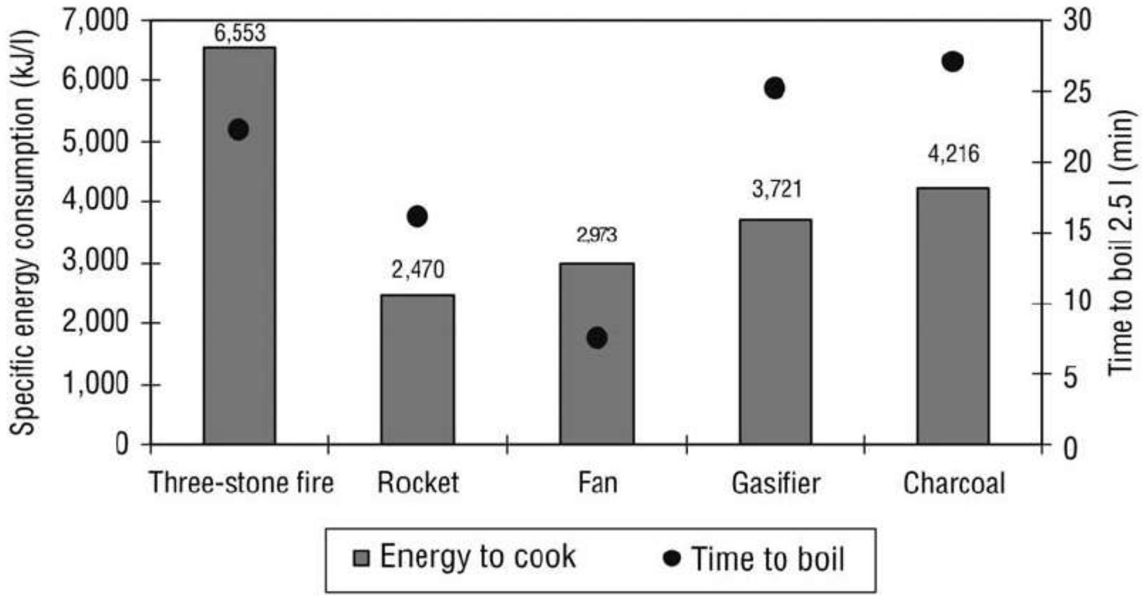

Figure A1 Specific energy consumption (energy consumed to bring to boil 1 l water and then simmer for 30 minutes) and time to boil 2.5 l for the various stoves. Average of three tests. This chart does not include the energy to power the fan, running at 1 W for 37 minutes, or 2.25 kJ of additional energy input. Similarly, the charcoal energy consumption does not consider the energy lost while making the charcoal fuel. (MacCarty *et al.*, 2008)

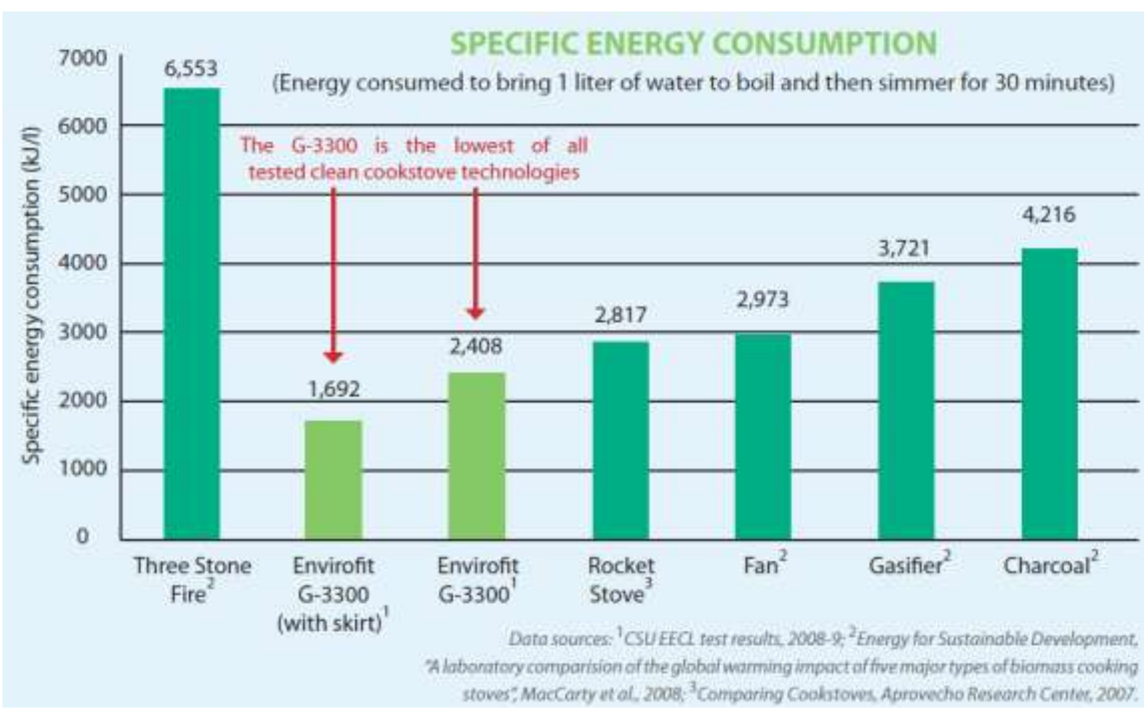

Figure A2 (http10)

Table A1 Gaseous emissions in percentage relative to CO_2 on a molar basis, average of three tests (MacCarty *et al.*, 2008)

	Three-stone fire	Rocket	Philips fan	Gasifier	Charcoal
High power					
CO	3.75	1.74	0.36	2.95	35.46
CH_4	0.13	0.11	0.02	0.27	3.91
NMHC	0.24	0.22	0.37	0.67	1.29
N_2O	0.00	0.00	0.00	0.00	0.00
NO_x	0.05	0.07	0.06	0.06	0.07
Formaldehyde	0.04	0.03	0.01	0.05	0.04
Low power					
CO	12.12	3.24	0.36	4.98	20.60
CH_4	0.29	0.17	0.07	0.48	0.29
NMHC	0.17	0.08	0.05	0.57	0.00
N_2O	0.00	0.00	0.00	0.00	0.00
NO_x	0.06	0.08	0.06	0.04	0.05
Formaldehyde	0.08	0.04	0.02	0.06	0.03

Note

1. Ratios are taken for number of moles of the pollutant emitted and number of moles of CO_2 emitted, and converted to percentage by multiplying by 100. For example, in the first row, the figures would be obtained as (grams of CO/28)×100/(grams of CO_2/44), the molecular weights of CO and CO_2 being 28 and 44 respectively.

Table A2 Specific emissions, or mass of emissions produced to boil 1 l and then simmer for 30 minutes. (MacCarty et al., 2008)

Specific emissions (g/l)	Three-stone fire	Rocket	Fan	Gasifier	Charcoal
CO_2	536	206	277	356	300
CH_4	0.6	0.1	0.0	0.4	3.0
N_2O	0.00	0.00	0.00	0.00	0.00
NMHC	1.4	0.3	0.4	1.5	2.5
CO	37	4	1	7	72

Table A3 Emission factors of selected wood-fired cookstoves (Bhattacharya *et al.*, 2002)

Name of cookstoves	Emission factors[a] ($g\ kg^{-1}$ fuel used)				
	CO	CO_2	CH_4	TNMOC	NO_x
1. Cambodian traditional	25.3 ± 0.9	1580 ± 4	2.7 ± 0.4	22.4 ± 1.2	0.010 ± 0.001
2. Lao traditional	27.3 ± 0.8	1579 ± 5	8.4 ± 0.5	16.3 ± 1.4	0.100 ± 0.001
3. Vietnamese traditional	38.6 ± 1.0	1608 ± 6	3.9 ± 0.4	3.3 ± 0.6	0.070 ± 0.001
4. Nepalese one-pot ceramic	136 ± 3.7	1344 ± 19	26.8 ± 1.7	20.4 ± 1.6	0.100 ± 0.001
5. Thai-bucket cookstove	26.4 ± 0.7	1596 ± 4	10 ± 0.6	8.9 ± 0.5	0.120 ± 0.001
6. Roi-et clay	22.1 ± 0.9	1626 ± 5	4.2 ± 1.3	2.8 ± 0.4	0.100 ± 0.001
7. Roi-et cement	20.5 ± 1.0	1625 ± 7	5.0 ± 0.6	3.4 ± 0.4	0.120 ± 0.001
8. RTFD improved wood/char	19.1 ± 2.4	1603 ± 4	10.8 ± 0.6	6.5 ± 1.0	0.110 ± 0.001
9. Rungsit stove	25.2 ± 1.2	1584 ± 3	11 ± 0.5	10.2 ± 1.3	0.100 ± 0.001
10. Chinese traditional	24.4 ± 2.2	1570 ± 5	5.4 ± 0.8	8.4 ± 1.2	0.100 ± 0.001
11. Malaysian traditional	28.7 ± 1.9	1562 ± 7	8.1 ± 0.2	6.2 ± 0.4	0.160 ± 0.001
12. QB Phil. charcoal/wood	45.1 ± 4.8	1568 ± 4	9.7 ± 0.4	9.5 ± 0.4	0.200 ± 0.004
13. Phil. charcoal/wood	28.6 ± 1.2	1603 ± 2	8.9 ± 0.6	7.5 ± 0.6	0.170 ± 0.004
14. Nepal one-pot metal	136 ± 9	1344 ± 54	26.8 ± 4.6	20.4 ± 4.9	0.070 ± 0.004
15. Nepalese two-pot ceramic	113 ± 11	1408 ± 43	29.5 ± 6.6	7.8 ± 1.2	0.050 ± 0.004
16. Nepalese two-pot metallic	45.6 ± 4.5	1530 ± 17	18.9 ± 2.8	14.2 ± 1.9	0.070 ± 0.002
17. Lao improved cookstoves	51.9 ± 2.5	1565 ± 4	6.0 ± 0.6	10.0 ± 0.3	0.190 ± 0.003
18. Viet. improved cookstove	47.1 ± 4.5	1577 ± 4	5.3 ± 1.0	7.6 ± 0.8	0.150 ± 0.004
19. Indian "Harsha" cookstove	41.2 ± 1.6	1597 ± 3	12.3 ± 0.9	7.7 ± 0.4	0.200 ± 0.003
20. Saengpen, nam char/wood clay	16.8 ± 1.4	1613 ± 3	10.0 ± 0.4	5.3 ± 0.8	0.200 ± 0.003
21. Saengpen, nam char wood cement	15.4 ± 2.0	1612 ± 4	10.5 ± 0.3	5.5 ± 0.8	0.150 ± 0.004
22. Bang Sue stove	22.1 ± 0.5	1585 ± 5	12.4 ± 1.2	9.5 ± 0.3	0.110 ± 0.004
23. Bang Sue modified	24.7 ± 0.8	1581 ± 5	14.0 ± 1.9	7.9 ± 0.8	0.130 ± 0.004
24. Malaysian improved	18.7 ± 1.8	1603 ± 2	13.7 ± 1.2	9.3 ± 0.3	0.110 ± 0.004