The Design and Manufacture of a Fuel-Efficient Biomass Cookstove for Darfur

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Abstract

Fuel-efficient biomass cookstoves were identified as a pragmatic tool for improving the daily lives of internally displaced people living in refugee camps. This paper is an account of a fuel-efficient cookstove project in the South Darfur region of Sudan in 2007. The historical context and design problem space are detailed. Many processes used to refine the design of the Berkeley-Darfur Stove ™ are reviewed. The benefits of the stove are stated, including the economic impact of a stove for a Darfuri family. Several of the unexpected events that were encountered are listed, along with lessons learned. A list of suggested design guidelines for other stove projects is provided.

Keywords

Biomass fuels, cooking, cookstoves, Darfur, design, design thinking, ethnography, fuel-efficient, humanitarian, manufacturing, user needs, stoves, Sudan, sustainability, systems problems

Introduction, History and Problem Context

As of late 2004 the situation in Darfur was reaching a crisis point, as the IDP (Internally Displaced Persons) camps grew rapidly in size and population. The Darfur IDP camps experienced extreme growing pains while relief agencies scrambled to establish basic water, sanitation, food, and related services.

The regions near the IDP camps were soon stripped of any and all combustible biomass, which forced those who collected wood to travel much farther, risking robbery, physical harm, and for women, GBV (gender based violence). The deforestation created many problems related to increased firewood scarcity, higher costs for vendor supplied firewood, and extra hours needed to forage firewood.

Why is Darfur so challenging? Darfur is at the bottom end of the economic scale, as it has few resources, and a large number of affected people. The supply chain is difficult, and the emergency situation in Darfur was exacerbated by the geopolitical realities, extremes of climate & weather, and constantly changing crises. The IDPs in the camps live an extremely existential lifestyle, as they have to adjust to any and all changes, many occurring on a daily basis. For the IDPs, food and shelter are the top priorities, and getting their families fed is their top priority. The many organizations helping to manage and support the camps provide some limited supplies to the camp residents. The support may include basic shelter kits, plastic jerry cans for water, and occasional food distributions. The introduction of fuel-efficient stoves was considered to be one of the most powerful and cost-effective methods for helping the IDPs to help themselves.

A representative from the USAID OFDA contacted Dr. Ashok Gadgil to investigate the possibility of recycling and reusing food waste materials as a biomass cooking fuel. Field research by Dr. Gadgil and his team in Darfur soon revealed two dominant facts: (1) There were insufficient quantities of food waste biomass fuels available, so they could not be a factor in solving the food security crisis. (2) The open cooking method used by the IDPs (three stone fire) was grossly inefficient. The results of the work by Gadgil and his team (Booker, Guerra et al. 2007; Booker, Guerra et al. 2007) indicated that the preferred solution would be to introduce a fuel-efficient biomass stove designed specifically for the IDPs in Darfur. Dr. Gadgil and his team reviewed known biomass stoves, and selected a design known as the "Tara Stove" from India as a basis for the Darfur Stove. The team led by Gadgil continued the stove development work at Lawrence Berkeley National Laboratories and in Darfur.

Brian Tachibana, a UCLA trained mechanical engineer, traveled to Sudan in 2006 to continue the work to refine the stove design and begin production. While in Khartoum, Brian worked on the stove design, met with local manufacturers, and supervised the production of a pilot run of stoves. He also worked with a local foundry to make 5000+ cast iron grates that were used in the initial production of the Berkeley-Darfur Stove ™. When Brian completed his three months in Sudan, the stove design was converging, and the next steps were to continue to refine the stove design, and initiate production in Darfur.

Design and understanding the problem

The initial sources of information were provided with written and verbal briefings, and intense conversations with the project principals, Ashok Gadgil and Ken Chow. A great deal of additional information was sourced from others who helped with the project (see Acknowledgements), and by people in the international stove community, particularly the ETHOS 2007 conference participants.

While it was assumed that the basic information was solid and reliable, there were many open and unanswered questions. For example, the manufacturing capacity of the South Darfur region was unknown. The local materials market was a question mark, and it was not known if the quantity, quality and/or prices of materials would be suitable for manufacturing stoves.

It was expected that field work would involve ethnography and other on-site data gathering. It was anticipated that the Hawthorne effect (Adair 1984) would be in play, and it could be tough to get accurate data when the users were directly observed, as in the original Hawthorne studies. It was also theorized that true responses may be difficult to obtain, as the IDPs would not want to give offense for any assistance, or seem ungrateful. It was accepted that the social psychology of interventions and observations would be a factor in the collection of useful data and feedback.

Though the general problem boundaries could be described prior to leaving for Darfur, it was accepted that a lot of the details would only become apparent when the project was on the ground, and making stoves. The uncertainties and "blank spots on the map" were noted, and the next steps for the project were designed with the unknowns in mind. The plan was to understand the problem more thoroughly, and then promptly get to work on specifics to address the newly identified issues.

Designing the stove intervention

The design challenge was to introduce fuel-efficient stoves into the Darfuri IDP camps so that they were valued, accepted, and used. The fundamental premise was that a successful fuel-efficient stove design would respect the local cultural norms, accommodate the users' needs, and provide real benefits.

A key working premise in the design of the stove intervention itself was the inclusion of the users in all aspects of the project. The sovereignty and dignity of the individual IDPs were considered and respected at all times. The stove users were considered partners in refining the design of the fuel-efficient stove. This strategy proved to be invaluable, as the many comments and suggestions generated by users led to design refinements and changes.

The stove intervention was designed to be measurable and scalable. There is value in doing many rounds of stove testing in a laboratory, yet the real test of a stove design is for it to be used in the field. How well does it work? Are the users' needs being met? Is the new stove being widely adopted? Are there positive changes accruing to the users? Are the changes measurable and repeatable? Are there other unforeseen consequences that need to be addressed?

The fuel efficient stove market is a complex one, especially in Darfur. There are many different actors working towards many different goals. The usual involvement of many agencies and people can greatly complicate this type of humanitarian intervention (Abdelnour and Branzei 2008).

The design of a fuel-efficient stove is just one component of a stove intervention project. The many issues relating to stove use must also be considered; else the project may falter (or fail) for non-obvious reasons. There is no single "magic bullet" that will make a fuel-efficient stove project work. It seems that constant vigilance, awareness of emerging issues, a willingness to identify challenges, and skill in solving them are all needed to accomplish project goals.

Design of the stove

The primary design task for the evolving stove project was to get the stove working well, and begin regular production. The "engine" of the stove was used as-is, with the major dimensions for the combustion area, vents, grates, and more left unchanged. The previous work by the design team had effectively modified the Tara design and tested the result. It was decided that the work to continue in Darfur would address any user issues, and then focus on manufacturing and user training.

The overall dimensions and features of the stove "engine" were used without changes. It was clear from earlier field and laboratory tests that the stove cooked very well. The Tara design was modified for Darfur conditions with many changes. Some of the most visible changes included adding a windscreen to shield the combustion region, which also allow for increased time exposure of the cooking pot to hot combustion gases. Metal stakes were formed in an "L" shape, and used to stabilize the pot in three locations along the outer perimeter of the bottom of the stove.

The basic stove design functioned particularly well in three ways:

(1) The stove facilitated clean and thorough combustion. The provision of excellent ventilation, a grate to hold the fuel, and a sheet metal boundary for the combustion area all encouraged clean burning. The use of small wood was encouraged - as efficiency was not improved by burning large pieces of firewood.

(2) The stove efficiently transferred combustion heat to the cooking vessel as it moved from the combustion area and vented to the atmosphere at the top of the stove.

(3) The stove combustion area was improved by adding wind protection features. This really made a big difference in protecting the stove combustion area under windy Darfur field conditions.

Many different features were considered for the stove design used in Darfur. When some of the goals were contradictory, tradeoffs were made. Some of the thoughts going into the design included:

* Be conscious of the stove height, as women usually sit on stools (bamburs) while cooking.
* Increase the stove lifespan - currently at five years. Increasing stove lifespan to ten years is desirable.
* Improve safety - ensure there are no sharp edges or hot surfaces.
* Reduce stove assembly time.
* Reduce stove part count.
* Improve the labor balance: i.e. what is done in the factory vs. what is done in the field.
* Increase production capacity and ability to respond to demand - estimated to be 300,000+ stoves.
* Reduce costs wherever possible.
* Maintain and/or improve quality.
* Improve the stove supply chain.
* Improve market-based mechanisms to get stoves into the hand of Darfur IDPs.
* Improve stove performance by continued testing - both in the laboratory, and in the field.
* Add features if justified by their cost and/or complexity.
* Simplify the stove design, production and distribution.
* Ensure that a stove can be easily repaired (quickly and inexpensively) in the field.
* Add serial numbers to stoves to assist in future monitoring and evaluation.

The physical configuration of the mature stove design is well described in the design patent issued in 2009 (Gadgil, Chow et al. 2009). The design patent can be accessed online by searching for Patent No. US D590,202 S.

Designing the manufacture of fuel-efficient stoves

As the design of the stove evolved, so did the plan for initiating production. It was fortuitous that the 5000 cast iron grates were ready to use, as getting those made in Nyala would have been difficult, if not impossible. Other options were considered in the event that continuing the production of that specific part in Sudan was economically unfeasible. The next goal for the project was to assemble the tools and lay out the work area - a place where the production of the stoves could begin.

The first goal was to set up a sustainable, local production facility for ongoing production of the stoves. If possible, the materials were to be sourced locally, parts made using local tools and/or supplied by local vendors. The final assembly was to be performed by local Sudanese - so that jobs could be created - which was a secondary goal strongly desired by many groups and people working in Darfur.

More challenges came from the realities of working in a field environment. The primary work area was an open area with a thatched roof and a dirt floor. This was locally known as a “rakuba”, as it was a simple lean-to structure made of local tree branches with a thatched roof. A local species of large wood-boring bee (possibly a carpenter bee) liked the rakuba structure, which resulted in many holes being made in the supporting wood members of the rakuba. Every so often a stream of wood particulates drifted onto the work benches as they were pushed out of the bored holes by the industrious bees.

Local electrical power was generally well regarded. When the ambient temperatures were high (Note: daytime temps frequently exceeded 100F), an electric oscillating fan was used. The electric power was wired in by local electricians, and was generally dependable. Randomly, the entire complex would lose its power, and all electrically powered equipment would cease functioning. A diesel generator was purchased and connected to increase the on-time reliability of electrical power.

Mother with child cooking on a Berkeley-Darfur Stove ™.
The scene is the cooking area in their living quarters in
a peri-urban IDP camp near Nyala, South Darfur, Sudan.
On-site stove evaluation visit - late June 2007
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Simple workplace features and considerations were anything but routine in the field. The varied winds and heavy foot traffic generated lots of dust, as the rakuba floor was made of hard packed dirt. Even work benches were difficult to source, so several were designed and ordered from local carpenters - all built locally from rough sawn wood. The details on workplace realities reinforce the assertion that no affordance should be regarded as either reliable, or consistently available. Ideally, all stove production, assembly and/or repair activities will be insensitive to routine, local impediments.

The primary method used for assembling the stoves was spot welding. The simple method was very strong, mechanically - provided the spot welder was correctly maintained, and the materials being assembled were clean. A good supply of spare parts (including tongs, tips, and conductive flex cables) was brought to Darfur to support the spot welders, along with tools, files and other support consumables. The high quality electric spot welders were sourced from a USA company, and were shipped to Darfur for use on the project. Without direct, continuous supervision, the spot welders tended to go out of specification, and their performance degraded. When the sheet metal parts to be spot welded were dirty or rusted, the quality and strength of the joints were lowered. Though the spot welding worked very well in the initial phase of the project, an alternate assembly method was desired. It was suggested that future versions of the stove use pop rivets to assemble the stoves.

It was originally thought that the stoves could be (and maybe should be) manufactured in Darfur. The answer was complicated and unexpected. The quality of Darfuri manufacturing technology was low, and the overall costs were high. Though the majority of the stove was made of thick sheet metal, the grate was made of cast iron. As there was no cast iron foundry available in South Darfur, the first 5000 grates were made in Khartoum at considerable expense. Following the end of this phase of the project, it was suggested that the stove parts could be made overseas (e.g. India) at a much lower cost, then shipped to Darfur for final assembly. The added anticipated benefits were that the stove quality would be much higher and result in a far more consistent product. Producing stoves in the midst of a humanitarian crisis in-country is challenging. Also, it is likely that the simple act of in-country sourcing of assistance can grossly distort the local market economy. Though many disaster relief programs prefer to buy from local vendors - it is possible that bringing in stove parts or kits may be preferable to get the job done.

One discussion centered on providing a cast iron foundry to use recycled materials, perhaps by shipping simple tools and materials to Nyala to establish a new technical competency. One of the complications is that cast iron requires a much higher temperature than cast aluminum. There is at least one cast aluminum foundry in Darfur that recycles aluminum into cooking pots (tungu-tungus) and lids. That site was visited, and its technical capacity was evaluated. While it was helpful and instructional to understand local production of cooking pots, the visit did not result in any new technology applicable to the manufacture of fuel-efficient stoves.

Some local sheet metal fabrication was possible, but it was found to be expensive and inconsistent. A used Danish sheet metal shear was located in Khartoum and shipped to Nyala. The dimensions of the sheet metal available in Nyala exceeded the shear capacity, so all sheet metal had to be cut by hand before final cuts were made on the shear. No stainless steel sheet metal was available in Nyala, only mild steel reportedly sourced from Malaysia and Indonesia. The dimensions of those materials varied, and the composition/quality of the metal was unknown, aside from it being mild sheet steel. No further identification of the material was available from local vendors.

One of the challenges was to anticipate the priorities for the stove project as it was anticipated to grow in time. One of the benefits used to promote the program was that it provided jobs for local Sudanese. Many of the INGOs/NGOs that were encountered in Darfur were heavily promoting the creation of jobs and income for the IDP families. While it is theoretically possible to create jobs with stove projects, it could be argued that the overarching benefit is to get functional and efficient stoves into the hands of as many IDP families as can use them ASAP. The total gains and benefits accruing to the IDPs would allow them to save time and money - and the money was typically spent immediately on food, clothing, furniture, school supplies and similar urgent items.

Design and the supply chain

The design of the fuel-efficient stove supply chain was an extremely important part of the stove intervention, as it really impacted the ability to scale up the project. The initial project goal was to source all materials within the Darfur region, with perhaps a few parts or tools coming from Khartoum.

The supply chain challenge for Darfur is an extreme one, as the major port (Port Sudan) is the transit hub for nearly all bulky and weighty shipments of aid to Darfur. The distances are great, as the point-to-point distance from Port Sudan to Nyala is about 972 miles. The distance is longer via rail and road.

It was discovered that relying on local suppliers of materials in South Darfur was not cost-effective or expedient. The prices of materials varied tremendously, as the local merchants themselves had a long, costly supply chain. The items in stores were generally brought in by truck from Khartoum, which was a long, dusty shipping route. Some items in the local marketplace were grown or harvested locally (i.e. fruits, vegetables, wood, firewood), and others were salvaged or recycled (e.g. cast aluminum was reused to make cookpots in a local foundry). The sheet metal purchased in Nyala was not cheap, and this may have been due to the perceived ability of the INGO to pay a premium price for the material.

Another complication for bringing in humanitarian aid is how the host government will assess the incoming NFI (non-food items). Will they be considered humanitarian aid, or will a duty be applied? If a stove kit is given or subsidized by donor organizations, will the host government of the recipient country demand import duties? The realities of buying and moving materials strongly influence the design of the supply chain.

In many countries, the UN provides transportation of humanitarian supplies, both food and NFI - so this is less of a concern than a project that must pay expensive transportation costs. In the case of Darfur, the logistics and cost suggested that it made more sense to source the stove components from outside of the country, and ship in boxes of parts to be assembled.

It is thought that a longer term, more sustainable solution for stove materials could competitively source all materials from local vendors. This strategy is probably more applicable to a stove project being established in an impoverished area. In Darfur, the humanitarian crisis parallels that of a ship slowly sinking, so getting the life preservers (fuel-efficient stoves) to the people who need them is the first priority. The supply chain design that manufactures parts outside of the country, imports them and assembles stoves in-country appears to accomplish the project goals with the best set of trade-offs.

Design and feedback from users and observers

The stoves were made from locally available sheet metal made of mild steel. This material will quickly rust with exposure to any water or moist materials. There was some concern that the rust might cause premature failure of the stoves, based on the prediction that the metal thickness might decrease over time if the rust was not prevented or arrested. A field-expedient solution was discovered by accident. It was learned that the IDPs cooked kisra (a flat bread) on metal skillets made of mild steel of varying thicknesses, ranging from 0.2 inches to 0.4 inches more or less. The IDPs would coat the cooking plate with the fat from bone marrow - which created a good surface for cooking the flatbread. A test was made with a stove and bone marrow, which worked well to seal the surface of the stove. The inside of the stove would usually be quickly coated with fire residues, so the greatest benefit for coating the metal with marrow was on the outside surfaces. Repeated coating of the sheet metal and heat cycling (stoves being used) help to seal the stove surfaces - similar to the way that cast iron cookware is seasoned using oil and heat.

Several people asked about the possibility of using galvanized sheet metal, so the stoves would be less likely to rust. It was explained that there is quite a risk in using galvanized sheet metal for any cooking or stove application, as the zinc coating (which is the galvanized surface) will probably burn off, creating toxic emissions that would likely harm anyone breathing them. Caution was used in selecting all stove and cooking materials, as the intent was to introduce new stove technology that was free of hazards or additional risks. Other coatings for the metal surfaces were considered, and none were located in Darfur that were deemed safe and cost-effective. The bone marrow solution was simple, and it worked.

Another design issue arose over the use of metal stakes to stabilize the cookstove. Were these needed and if so, what shape should they take? The stakes were related to the stability issue. The field work helped to address this design feature. About 100 early versions of the stoves were made in Khartoum and shipped to Nyala for the project. Several of those stoves were used for pilot field testing. That version of the stove had three “L” shaped metal rods with blunt ends. The metal rods could be inserted into three holes that were formed onto the outside of the stoves. The stability of the stove was insufficient for making assida - the hot stir bread made by Darfuri IDPs. The second issue was that the blunt ends of the metal rods were resistant to being pushed or pounded into the soil. The need for sharper tips on the metal stakes was noted.

A redesign of several stove components was performed to increase its stability, especially while the stove was used to cook assida. A set of three sheet metal feet was designed and attached to several prototype stoves. Each of the metal feet had a hole in its bottom center to allow for the metal stakes to be used. If the ground was soft, the stakes could be pounded in on the long axis. If the ground was hard, the stakes could be pounded in on the short axis. Each end of the revised stakes was to have a gently pointed end. The local blacksmiths hired to make metal stakes used a hammer to shape the ends of red hot metal - so the ends were instead much sharper than designed. The local blacksmiths also took liberties with the stake dimensions, so there was a wide variance in the finished sizes of metal stakes. As the first few stoves were distributed, the users were given three metal stakes with their stove. The metal stakes are a point of inquiry for future stove designs, as it is not decisively known if stakes are needed or wanted. It is not known if the added cost of three metal stakes for each stove is justifiable. More field data are needed to answer these questions.

An interesting event followed the initial distribution of several dozen stoves to an IDP camp near Nyala. The team returned to the camp a few days later to get user feedback on how the stoves worked for the users, and to collect related information. Our team spoke with the local sheikh and his representatives, and then visited several of the families who were using their new stoves. A group of three older women were dressed in bright outfits, and followed the team around the camp as we went from one location to another. It was explained that the three women had visited every family that had received a stove, and knew what impact the stoves had on the recipients. The women were glad to talk with us, and told us that every family had saved firewood using their new stoves. They also emphasized that the women in the camps were hoping for more stoves in the near future. The women were chatty and animated as all three took turns sharing their observations. There were several nice outcomes from their informal survey. They affirmed that the stoves were highly regarded, and as the three women knew all of the families in the camp - they were uniquely positioned to both make observations and report on them.

The women provided a wonderful and unexpected source of data, and were thanked by our team for their inputs. The women provided several interesting ideas and comments, which were mostly directed at requesting the rapid production of more stoves for the other families in the IDP camps.

Several people asked about the hot metal stove surfaces, and if they could be improved to prevent burns to users. They expressed concerns that people could touch a hot stove and get burned. It is possible to get burned on a hot stove, just as it is possible to get burned on a traditional three-rock fire. It is anticipated that the fire risks to an IDP dwelling are lower when a stove is used in place of a three rock fire. Stove user training should include safety guidelines. All users should be warned that stoves are hot and should not be touched when in use. As the existing market for the stove is at a low economic level, it can be argued that the project goal should be to provide the greatest benefit to the many. The trade-off for simplicity and low cost makes adding a thermal insulation barrier impractical. A stove could be designed and made with thermal insulation, but that would add cost and complexity. In the near term, the need in Darfur might be best met with a stove like the Berkeley-Darfur Stove ™ (BDS) - a design made without thermal insulation.

Several anecdotal reports were heard about stoves being distributed that had quality issues, including sharp edges on the sheet metal, resulting in users being cut. An in-depth follow up of stoves distributed in the Nyala area would provide hard data on any user problems, and also provide better data on the benefits (economic and other) that accrue to the users. It is not known if any of the stoves have been scrapped, dismantled, traded or sold. That type of information, along with the user's reasons for letting go of their stove, would be extremely useful.

Emergent discoveries and unintended consequences

In Darfur, one quickly learns to expect the unexpected. Every aspect of a stove project is subject to being revised as new information becomes available. Being open and accepting of non-traditional values and information is essential for understanding the entire local context. For example, one emergent discovery was that in the IDP camps, the network of information flow (right or wrong) is very strong. This flow of information is facilitated by the surprisingly wide distribution of mobile phones - especially in the peri-urban camps. The local economy is very dependent on mobile phones, and the phones are a useful tool.

The women in the IDP camps displayed a variety of stove cooking methods and practices. Portable stoves were considered a positive, though some IDPs were concerned that their stoves might vanish if left unattended. Some liked to move the stoves several times a day - as their other activities were adjusted/modified according to the time of day. Many women preferred to use the metal stakes to stabilize their stoves, and some preferred to keep their stove stable using their sandal covered feet. It was learned that stability is rarely an issue when cooking sauces (mulah), but it can be an issue when stirring assida, especially as it thickens near the end of the cooking process. The high viscosity of the assida became apparent at the very end of the cooking process, as the flour (usually millet or sorghum) was added by the cook in big handfuls to the boiling water. This created extremely thick porridge-like hot bread, which was usually cooked before the mulah (sauce) dish. The high thermal capacity of the assida kept it warm while the mulah was cooked. The design of the stove permitted the users to move it easily, or keep it staked to the ground. It also permitted the users to adapt the stove to their preferred method of cooking - as every family cooking area that was visited was different.

One surprising emergent use of the stoves involved the preparation of hot water for tea. It was reported by several informants that the stove could burn handfuls of dry grass quite nicely, so precious wood (or charcoal) was not needed to make a pot of tea. It was evident that the Sudanese enjoy their tea very much (some credit the British for this preference). When they do have their tea, many take it lots of sugar, and sometimes with milk (known as “shai ben laben”). The fuel-efficient stoves apparently had a benefit of providing hot water for tea without needing to burn firewood. The perceived value of stoves by the users was greatly increased by this fact.

Charcoal is another interesting factor in the Darfur biomass stove systems. Charcoal is used by many of the Darfur residents for cooking, and for making tea. The cost of charcoal is higher than wood. Many residents in the town cook with charcoal, as cooking with charcoal is seen as having a higher socioeconomic status. Wood was readily available in the camps, but there was very little sale and/or consumption of charcoal observed in the peri-urban camps near Nyala. Much of the charcoal that was used was leftovers from cooking with wood. When a cook finishes heating up food or water, the fire is extinguished and the remaining fuel is conserved. The fire is generally put out with sand, and sometimes with water. The remaining partially burned wood and/or charcoal is saved for future cooking.

Another set of emergent stories concern the importance of scents and smells in the Sudanese culture. Several informants explained a local custom practiced by many Sudanese women known as dukhan - the scenting of a woman’s body by way of smoke infusion. As it was explained to me, dukhan is a custom observed by married women, and is usually not practiced by unmarried women or widows. Dukhan begins when a woman sits under a blanket with a small brazier or clay stove fueled with wood or charcoal (Abusharaf, Studies et al. 2004) As a small fire smolders, scented smoke rises from the fragrant, scented wood placed on top of the fire. The pricey wood may be talih (an aromatic wood), shaaf (acacia wood), sandalwood, or another aromatic wood. The relevance of dukhan for FES projects is to realize that local priorities for spending money may not be obvious. The practice of dukhan is largely unknown to outsiders working in Sudan and Darfur. The role of dukhan and other local traditions (e.g. henna) are important to understand when working on a FES project, as significant amounts of money, time, and energy may be allocated by IDPs to non-food items.

Over time it became more apparent that an ugly, yet functional stove may be preferred over a beautiful fuel-efficient stove. An ugly stove is more likely to stay in use because it has a lower perceived scrap value; thus removing any motivation to sell it on the open market. In the rough world of IDP camps, an ugly and functional stove may have a greater chance of being left alone. A shiny, stove made of stainless steel or other high value materials may have a lessened chance of surviving the IDP camp environment. Alternatively, a high value stove may be at a greater risk of being sold, bartered, or taken by force.

The existential nature of IDP camp life demands that any available resources be used immediately. When money is earned, an urgent need (e.g. food, firewood, medicine) will soon consume it. Cash savings are reportedly rare in the IDP camps, and the trading of food or other assets for firewood is common. The community appears to pull together when more resources are needed, especially when a family member is ill. Families living in the camps loan tools and supplies to each other. When one of the kids is sick - people pool their money to buy medicine and/or get medical support. A thorough understanding of each local IDP camp economy is vital for calibrating FES interventions in Darfur.

The innumeracy encountered in Darfur was a surprise. Several resources suggested that illiteracy in Darfur was to be expected, and that was found to be true. An anecdotal story about innumeracy was related to me by an INGO worker. Five women set up a bakery in the Juba region of Sudan as an entrepreneurial venture. The women were able to bake quality bread, and soon had a good stream of steady customers. Their biggest problem was that they did not possess sufficient math skills to manage their business. This prevented them from determining their profit/loss, or making a fair division of wages from their profits. The solution they developed was to take turns in keeping all profits for the day. The five workers knew that all of the income was theirs to keep every five days. They were reportedly satisfied with their system for sharing profits equitably. The local values and decision-making used to make financial decisions are critical for determining how the IDP populations might invest in stoves. The traditional INGO practice of “giving stoves away” may not be the only strategy for stove dissemination.

The concluding thought for this section is to realize the importance of information management and knowledge management (KM) for those working in the fuel-efficient stove space. The flow of information from one worker to another is often interrupted. When task or job hand-offs in the field happen frequently, and organizational contacts are updated - there is a constant potential for errors, omissions and other problems to arise. Many sources of information are needed to manage and carry out a fuel-efficient stove project - especially in an area that has very high personnel turnover.

Benefits of the stove

The fundamental benefit of a fuel-efficient stove is that it acts as an economic catalyst for its users. Every day that it is used, a FES saves the IDP owners precious money and time. In the bigger picture, the environment benefits from reduced firewood consumption. The lowered consumption takes pressure off the local ecosystem, giving it some room and time to regenerate. The following tables illustrate the primary and secondary benefits of fuel-efficient stoves to Darfuri IDP families.

<u>Primary benefits of a fuel-efficient stove</u>

(1) Saves money.

- (A) About 20 to 50% of a day’s wages are typically used to buy firewood in camp. Over half of this can be saved by using a fuel-efficient stove, depending on the skill of the cookstove user.
- (B) Some IDPs trade some of their food rations for firewood, as food is a substitute for money.

(2) Saves time.

- (A) Time is used to hike to collect firewood.
- (B) The stove can cook food more quickly if large pieces of wood are used.

<u>Secondary benefits of a fuel-efficient stove</u>

(1) Money saved can be spent on food, clothing, medicine, furniture, shelter, and other urgent needs.
(2) Improved air quality - the stove burns cleanly, reducing exposure to products of combustion.
(3) Increased personal safety, as fewer trips outside of the camps to get firewood reduces potential for GBV (gender-based violence).
(4) Improves fire safety - the cooking fire is well contained within the stove.
(5) Food tastes better - many IDPs report that their food tastes better when cooked on a fuel-efficient stove. This is attributed to the clean, hot combustion combined with less smoke.
(6) Less wood is used - this reduces pressure on the local biomass ecosystem.

An examination of the cost and benefits of a fuel-efficient stove produces a strong economic justification for continuing with a stove intervention. The stoves save approximately $1 USD per day as computed in local Sudanese currency. That translates to an estimated payback period for one stove of 30 days, given a total stove cost of $30 USD. In Darfur, the projected one year impact of a stove is $330

USD, leading to a projected savings of more than $1500 USD for a five year period. This economic analysis provides an interesting perspective for supporting the introduction of higher cost stoves. Suppose the total costs for getting a new FES into the hands of a Darfuri IDP were $50 USD. Even at the higher number, the initial cost of a stove is recovered in less than two month's time. And after the initial payback period, the FES continues to provide significant ongoing benefits to the IDP families.

The simplicity and beauty of the intervention from an economic standpoint is that it preserves individual sovereignty - so the users can decide where to spend any savings. One of the Sudanese liaisons shared his thoughts with me - "If you come back in a year, you will see that this family is much stronger and happier because of the money they have saved and used on other items."

Design Guidelines

The challenging, interdisciplinary nature of FES stove projects suggests that design thinking, prototyping, testing, and continuous design refinements are all needed to get first-class results. The following thoughts are suggested guidelines for the design and development of fuel efficient biomass cookstoves.

- **Define the intended stove user experience.** Though defining a stove design with a list of technical specifications is helpful, it's more important to define the experience you want stoves users to have. Use that definition as a design guideline for refining the stove design.
- **Make the solution fit the problem, so the stove easily fits into the users' daily routine.** A less desirable stove design requires the users to change their diet, schedule, and more. Match the stove design to local norms and customs. Do not force users to change their daily routines.
- **Field testing by users is extremely important, and valuable.** It provides information that is not available through any other method, and often provides critical feedback for improving the stove design. Manage the new knowledge wisely, and ensure it is available to all participants.
- **Saving biomass fuel is important, and so is saving time.** Firewood is money, and time is money. The women in IDP camps are extremely busy, and have precious little free time. Anything which saves biomass fuel (e.g. firewood) or time is the same as handing the users money.
- **Keep the stove design simple.** Simplicity is a sensible design goal. Understand that designing a really useful and reliable fuel-efficient stove takes time, probably much more time than you think it will. Complexity is to be avoided, as it usually increases stove part and labor costs.
- **Don't make the faulty assumption that one size fits all.** Every region and user population has different needs. Ensure that your stove design adapts to all users in the region of interest.
- **Ensure the stove design is robust.** Make sure that the stoves will work well in all target environments using different sizes and types of firewood, and that they fit a variety of cooking pots. It was important in Darfur to ensure that stoves worked well with the many different sizes of cast aluminum tungu-tungus (cooking pots) used to cook assida and mulah.
- **Know that the goal is to provide a cookstove that works well and is adopted by users.** Outstanding cookstoves make a measurable difference in the lives of the users and are used daily. Inferior cookstoves are those that are neglected, fail quickly, and are left idle.
- **Consider increasing the lifespan of the stove.** Added costs in materials and labor may be justified if they increase a stove's lifespan. Given finite resources, is it better to quickly reach the largest number of users, or provide a longer lasting stove to fewer users? Urgent humanitarian needs may require the simplest, lowest cost FES that can be produced and distributed.

- **Make the learning curve for new stove users a short one.** It's important to make a stove work well with little or no training. A good stove design works well immediately, and can work even better as users gain experience and knowledge.
- **Assist stove users in discovering ways to save time and money with their new stove.** Help the stove user community establish a tradition of efficient stove usage by sharing their knowledge of using the least firewood for cooking.
- **Identify and prioritize the specific problems that are being addressed with fuel-efficient stoves.** Target a stove's features to the most urgent problems in the user population. Make any design trade-offs with an eye to the overall goals of the intended FES intervention.
- **Require stove users to exchange cash and/or labor to get a stove.** Local market demand for stoves is a strong indicator of the usefulness of the design. A stove that is given freely without any user investment may be poorly regarded, and promptly sold, traded, or discarded.
- **Accept that designing and carrying out a FES intervention in a humanitarian setting is difficult.** The stove problem is a systems problem, one that involves many actors and agencies. Every stove design has complex interactions within the user environment. Appreciate and understand the complexity of the FES system. Expect that there will be unanticipated consequences. Realize that there will be obstacles, and be creative in surmounting them.

Future work

The following observations and suggestions may assist in continuing research on the design, manufacture and use of fuel-efficient stoves. They may also be useful in designing FES interventions.

It would be useful to perform a sensitivity analysis of key variables for stove "engine" to determine performance robustness, and where dimensions are critical. Knowing the effective working ranges of heights, gaps, vents, intake air, exhaust gas flow, heat transfer to cooking vessels and more is desirable. Having proven figures in hand will go a long ways towards informing increasing stove quality and help get the best performance.

It would be helpful to understand how much contribution (if any) a FES makes in Darfur as a source of space heating. As the author's work took place during a very warm season, it was not known if other traditional uses of open fires were being provided by stoves; i.e. lighting, heat and similar. Though cooking is likely the best use of a FES, more benefits may be achieved inexpensively with minor modifications. One interesting potential use of stoves is to provide electricity by using thermoelectric generators (also known as thermogenerators). The waste combustion heat can be used to recharge mobile phone batteries, and power other devices. The cost of these components has decreased over time, leading to the possibility that multiple energy needs may be addressed using a fuel-efficient stove.

Sometimes there is unused space in shipping containers going to humanitarian projects, like those in Darfur. This extra space might be used to move lower priority cargo to address other IDP camp issues. It was learned that the children in the IDP camps have very few outlets for their play time. One idea is to work with organizations that provide soccer balls that don't go flat (www.oneworldfutbol.com) as higher morale may also assist in preventing or mitigating other IDP camp problems. This is another suggestion to find synergies amongst organizations trying to leverage scarce resources, like shipping costs.

Another idea is to design and build lightweight carts that camp residents could use to move firewood. The same carts could be used to carry water stored in plastic jerry cans. Tools like these can be shared in the IDP camps to save time and labor. Of course, the carts would have to work on different types of terrain, like the sandy soil common in Darfur, and would need tires that would not go flat. The phrase “carro hatab” was invented in Nyala to describe a hypothetical cart of this type.

It may be useful to continue to research the FES space, and then model it as a systems problem. Portraying a FES intervention as a systems problem implies that systems solutions may be warranted. There is likely much value to be gained by studying the complex interactions of the IDP camp economy and specifically, the role of biomass fuels. The complexity of the IDP camps and the problems that the residents face daily suggest that any and all synergies be utilized to advantage. A fuel-efficient stove is related to just about all IDP camp issues, including food, security, gender-based violence, nutrition, education, shelter, safety, and more. It seems logical that all organizations working in an IDP camp will have a strong interest in helping to implement and support appropriate FES solutions.

The economics of supplying the stove market is an area where more work is needed. The mechanics of using microfinance (one example is www.kiva.org) and other tools to facilitate free market funding to support stove purchases are attractive. Having users pay for their stoves out of the money they save by not having to buy firewood is an idea with merit, but can it be made to work? Innovative market based solutions are required, as it is unlikely that users will be able to save enough cash to pay for a stove in one transaction. At the other extreme, it appears less likely that donor funds alone will cover the cost of several hundreds of thousands of fuel-efficient stoves that are needed for Darfur.

The nutritional content of milled millet or sorghum is reportedly low. If this is true, then adding nutrients to the flour at the time and place of milling could help address issues of malnutrition and failure to thrive. One project that addresses this is low-cost packets of vitamins/nutrients that can be easily added to the flour when grain is milled. A Stanford class project for a course titled “Entrepreneurial Design for Extreme Affordability” - (Design 2010) worked on this challenge with Project Healthy Children (www.projecthealthychildren.org). As many of grinding (grain milling) operations are run in camps, the addition of nutrients could take place easily and effectively. As the primary goal of introducing FES is food security, other aspects of the food security dilemma might be addressed at the same time.

Several people asked about anti-mosquito tools as they wished for anything to reduce the populations of malaria infected mosquitoes. Several INGOs are providing insecticide treated anti-malaria nets for sleeping areas. The smoke from cooking fires is reportedly useful for repelling mosquitoes and other bugs. The same smoke from cooking fires was said to help keep bugs from infesting shelters, especially their thatched roofs. The downside is that smoke from cookstoves contributes to respiratory illnesses.

Simple tools were in high demand in the IDP camps in Darfur, such as funnels and can openers. The IDPs used a variety of tools to open tins of cooking oil provided by USAID, and then pour the oil into recycled beverage bottles. Even bottle brushes could be used to scrub out the insides of plastic water bottles, allowing them to be reused safely. Can a simple tool to split/cut firewood be developed? Such a tool could increase safety, as the hand axes that are often used can be dangerous. Easier access to small wood pieces would help encourage the frugal use of scarce wood resources. Additional needs were observed for lighting, and for fans to move cooling air in times of very warm weather.

One of the big unanswered questions is what would happen if large numbers of FES were introduced to Darfur? Would the prices of firewood change, and would the overall effect on the IDPs and the economy be positive? Several informal analyses of the IDP economy suggest that money not spent on firewood keeps moving locally in the area of the IDP camps, while a sizable portion of the money spent on vendor provided firewood quickly leaves the area near the IDP camps.

Disclaimers

This paper is based on the author's experiences and opinions. The author is not an employee or representative of any aid organization. All opinions and accounts are either sourced by the author from contemporaneous notes, or referenced from published literature. The views and opinions expressed in this paper are those of the author alone. This paper does not represent any organization or stove program, and is offered in the hope that the content will be of both academic and pragmatic use. Any errors, omissions or misstatements are the sole responsibility of the author.

Many sources of information are initiated or influenced by anecdotal reports. While anecdotes are valuable, and worth recording and considering - they also introduce the potential for errors and/or unhelpful design decisions. It is suggested that any sources of information be evaluated before important decisions are made. The best value of anecdotes may be in using them to set the context for stories about fuel-efficient stoves, and the lives of the people who use them.

As every FES intervention is different, please be advised that the strategies, tactics, and solutions used in the Nyala region in Darfur may not be suitable elsewhere. Ultimately, every fuel-efficient stove program must validate and verify their stove solution in place with actual users. The continuous use of a robust monitoring and evaluation system will help confirm the effectiveness of any stove design.

The information in this paper is neither comprehensive nor exhaustive for the design of fuel-efficient stoves. It is intended to provide an entry point for the discussion of applying the design process to the specific challenge of the fuel-efficient stoves. The expectation is that the discussion and ideas that resulted from the Darfur stove project will help other FES projects.

Acknowledgements

It is very likely that providing stoves to the IDPs in Darfur is one of the most challenging fuel-efficient stove projects in the world. Given all of the challenges, it's a miracle that any stoves have reached the IDPs in Darfur. The good news is that to date, the project has placed about 21,000 stoves in Darfur (source - www.potentialenergy.org). Using a rule of thumb estimate of five people per IDP family, the result is that over 100,000 Darfuri IDPs are now benefitting from their fuel-efficient stoves.

Many people, groups and organizations participated and contributed to the design and manufacturing of the Berkeley-Darfur Stove ™. It is appropriate to acknowledge and thank the many people I met and worked with prior to my Darfur trip, when I was in Khartoum, when I was in Nyala, and upon my return.

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Apologies to those I worked with who were not named above. As it is clear that many people took part in the project over the years - please know that all of your efforts and contributions are appreciated.

Finally, thanks to the people of Sudan, especially the kind and gracious people of South Darfur. Thanks for sharing the complex history, culture, languages, and foods of your country. The world hopes for a better future for Darfur. With any luck, more fuel-efficient stoves will be a part of that future.

Postscript

After returning to California from Darfur in July 2007, the fuel-efficient stove project work started by Dr. Ashok Gadgil continued to gain momentum. The goal of making the FES project work was achieved, and "The Darfur Stoves Project" was formally established later in 2007. The achievements by Dr. Gadgil and the large team of people who worked on the project were recognized globally as being a great success (Chen 2012). The name of "The Darfur Stoves Project" was changed on May 01, 2012 to "Potential Energy" (www.potentialenergy.org). The new organization has grown its geographic area of interest beyond Darfur, and its stated goal is "bringing life-improving technologies to people in developing nations." Fuel-efficient stoves will continue to be a focus of the group's efforts.

Glossary

This following Sudanese Arabic words and phrases are useful in Darfur when working with cookstoves. They are spelled out phonetically in English as approximations for their pronunciation.

Assida (ah-seed'-uh) - stirred hot bread, often served with mulah at all three daily meals. Assida is made by boiling water and adding millet flour. It may also be made with sorghum or other grains.

Bambur (bam-boor') - low seat, a rectangular stool found in Darfuri kitchens. A bambur is generally handmade of locally available wood with a woven seat.

Carro hatab (kah'-row hah'-tahb) - firewood cart

Dukhan (dook'-han) - scenting of a woman's body by way of smoke infusion

Fass (fahss) - hand axe

Haboob (hah-boob') - sandstorm. A haboob is a windy dust storm that can appear quickly. Dark clouds and changing winds signal its imminent arrival. Everyone heads indoors for shelter, if possible.

Kisra (kis'-ruh) - a flat bread. Cooked on a flat skillet over a fire. Usually made with the same batter that is used to make assida. Often cooked on Friday as a special treat.

Kuleka (koo-lay'-kuh) - bundle of wood

Ladaya (luh-dye'-uh) - three rock stove. A ladaya is the traditional, most common cooking fire in Darfur.

Mufrakah (moo-frah'-kah) - cooking tool - traditionally made of a long single branch of wood with a half-moon tip. Used as a stirring stick for making mulah and similar sauce dishes.

Mulah (moo'-lah) - a sauce entrée usually served with assida. Customarily prepared with sliced onions sautéed in oil, then combined with other vegetables (e.g. okra), spices and sometimes meat.

Mushkila (moosh'-kee-lah) - problem. May also be pronounced as "moshkila" with a long "o" sound.

Muswat (moos'-watt) - a heavy-duty cooking tool with a large diameter shaft - usually locally made of wood with a half-moon wooden tip. A muswat is the preferred cooking tool for making assida.

Omda (ohm'-dah) -- a village leader, a mayor. An omda is usually ranked at a higher level than a sheikh.

Qanoon (ka-noon') - a cookstove, which may be fueled by wood, charcoal or some other fuel.

Rakuba (rah-koo'buh) - a shelter, usually with open sides. A rakuba is made with wood tree poles, and a roof made of thatched vegetation. It may be covered with plastic sheets for rain protection.

Shai ben laben (shy' ben lah'-ben) - tea with milk

Sheikh (shaykh) - a chief or village elder, usually a tribal designation.

Tungu-tungu - cooking pot. A typical example is a pot with a lid, both made from cast aluminum. Tungu-tungus are made and sold in several sizes, and are usually locally made from recycled aluminum.

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