Cooking Stove Improvements

Design for Remote High Altitude Areas
Dolpa Region

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Report date: **Kathmandu, Revised 8 April 2005**

ABSTRACT

Metal and mud cooking stoves are analysed in Dolpa, a remote high altitude district in Nepal (over 2000m) where poor firewood efficiency of cooking stoves has been observed whilst the area is already largely deforested. Current metal or mud stoves have the air-intake above the firewood, lowering gas temperatures and causing incomplete combustion. More than 20 improvement options are presented in a table. These lead to higher burning temperatures, reduced firewood consumption and lesser soot development. Modifications have been made to lower manufacturing costs. The paper briefly explains the principles of the improvements and provides detailed sketches of the solutions. Improved cooking efficiency requires chopping of the firewood into small pieces, but the additional time spent is balanced against the considerably less time spent in the collection of firewood. The prototype stove has been field-tested and modified several times to produce a model that is easy to manufacture and is acceptable to the villagers.

Information is based on the author's personal experience and technical information from the stoves discussion group at www:repp.org/discussiongroups/resources/stoves.

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Photo Front Page: Metal stove in Dunai with pressure cookers, water kettle and large front opening.
Photographs and drawings by Sjoerd Nienhuys (SREA). E-mail: snienhuys@yahoo.com

1. INTRODUCTION

A fact-finding mission was realised in December 2003 to the Dolpa district in northwest Nepal. The identified main area of concern among the local population was the lack of firewood and good cooking stoves for either cooking and/or space heating[1].

The World Wildlife Fund (WWF) has a temporary office in Dunai (altitude 2100m) from which it coordinates activities in upper Dolpa (nature reserve park area at 2500–3500m) and in the buffer zone of lower Dolpa (2000–2500m). High firewood consumption and the associated forest degradation are issues of concern to the local population and the WWF. The WWF and municipality staffs in Dunai were interested in realising a demonstration project in the area, with the objective of saving firewood. The new stove should be more affordable to the local population than the existing models.

Because the WWF encounters similar problems in the high altitude park areas of the Solukhumbu (Mt. Everest region) and Kanchenjunga (eastern Nepal), the beneficial effect of better cooking stoves would be widespread and could eventually be replicated in all 20 high altitude districts in Nepal. These are all remote areas and inhabited by low-income populations. The development of better cooking stoves has the attention of the Alternative Energy Promotion Centre (AEPC) of the Government of Nepal.

Five years ago, the research department of the Kathmandu University (KU) initiated a cooking stove improvement programme in the Jumla district (northwest Nepal).

The KU, with strong subsidy support from an external organisation, has installed 2155 metal cooking stoves in Jumla. It is now extending the programme to the Humla district (northwest Nepal) and is focussing on the further improvement of firewood efficiency of their old model.

The current stove improvement proposal is different from that of the KU in a number of aspects, as it will try to develop a technology that would require thinner metal; hence less weight and less need for subsidy. The stove would be locally assembled, generating employment and service capacity in the district. The lower weight will reduce transport problems and costs.

Many families still use a tripod over an open fire inside the house.

[1]A field visit report was made by the same authors in December 2004 on the installation of the stoves in Sagarmantha in the Khumbu (Mt. Everest) region entitled: *Installation of Improved Metal Cooking Stoves in Khumbu Region – Field Visit Report*. Two detailed drawings of the chimney vane cap and the roof passage are included in the annexe of that report.

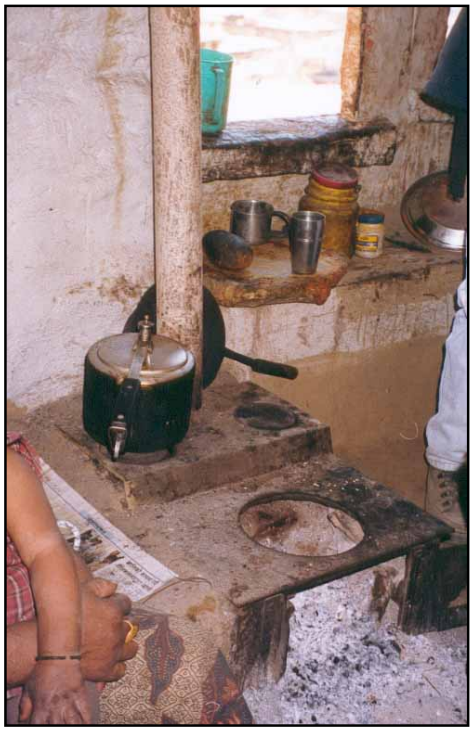
2. OBJECTIVES

The foremost objective is to improve the local living conditions of the high mountain population (low-income people) by demonstrating and providing cost-efficient energy solutions that result in the saving of large amounts of firewood and kerosene (fossil fuels) and a reduction in smoke emissions in the houses. This will lead to reduced Indoor Air Pollution (IAP) and with that an improvement in the general health condition of the users of cooking stoves, being mainly the women. Firewood efficient cooking stoves will also reduce the demand on the natural forest reserves and indirectly reduce soil erosion. The following aspects were taken into consideration:

- **Cost Reduction:**
  - **In Weight.** Current stoves are heavy (40-50 kg). As the manufacturing cost is based on the weight of the metal, reducing the weight will result in lowering the manufacturing and purchase costs. In many cases, the transport cost is equal to the manufacturing cost.
  - **In Labour.** By shifting as much as possible the assembly of the components to the remote mountain areas, where salaries are 50% lower than in the towns, the purchase cost will also be reduced. Prefabricating (cutting) the sheet metal can be realised in town, while the labour intensive assembly can be done in the mountain villages. With prefabrication, only the required metal is transported with no excess or waste; transport of flat sheet components is easy.
  - **In Electricity Needs.** Currently many stoves are welded electrically, which can only be done in towns, as there is no high electric power available in the remote mountain areas. The assembly technology should therefore be based on folding the metal joints.
  - **In Operation.** Reduced firewood consumption, and thereby reducing the amount of firewood needed to be purchased, will make the stove more affordable without long-term financing requirements. The overall cost reduction is related to a combination of the purchase cost and the user cost. Time saved from firewood collection can be used more productively.

- **Improved Energy Efficiency.** Most of the rural energy in Nepal is used for cooking (98%). Reducing firewood consumption can be achieved through a combination of faster cooking and higher firewood efficiency. In Dolpa, no case was identified where stoves were used solely for room heating, a process automatically occurring while cooking[2].

- **Improved User Utility.** Because of their "modern" appearance, villagers like the metal stoves; even when in some cases these stoves have higher firewood consumption than mud stoves. Increasing the user utility of the stoves (in combination with better firewood efficiency) will be a reason for the villagers to purchase these stoves. User utility can be enhanced, for example, by incorporating water heating or a *roti*-maker[3].



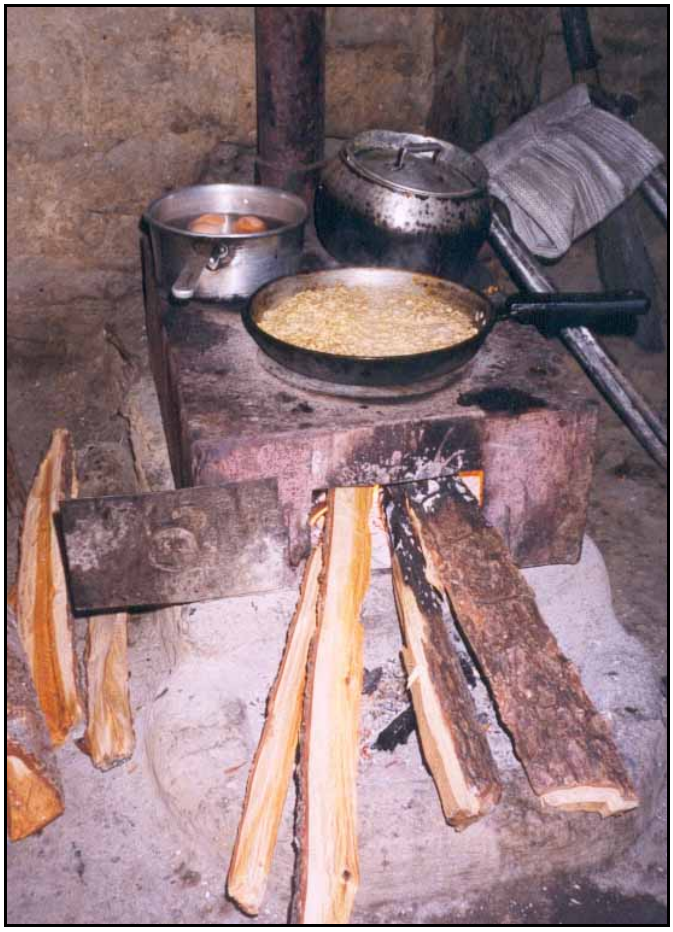
Old stove next to a permanently open window. In this case, the owner knew that the stove used more firewood than the mud stove but still preferred the metal stove. Space heating is only useful when thermal insulation has been resolved.

[2] In mountain regions with higher income (Sagarmantha), space heating becomes increasingly important.
[3] A *roti* is a dry cooked/roasted bread of 15-20cm in diameter.

- **Local Manufacturing and Service Centres.** Current designs require cutting and welding of rather thick metal sheets (1.6mm body with a top plate of 4.3mm). A new design with thinner sheets should allow hammering and folding of stove components without electric welding. Manufacturing with thinner sheets (1.2mm and 0.7mm) will allow local assembly and maintenance. Local manufacturing improvement needs to be accompanied with the setting up of local training and the development of service centres through which the villagers can order stoves or contract installation.

- **Reduced Subsidy Levels.** High customer subsidies on purchase and transport are not sustainable. In the development phase of a consumer product, some subsidy will be required until the moment the product can be manufactured and sold in large numbers. A stove that demonstrates firewood savings will be a self-financing piece of equipment. Such equipment can be bought through local savings and loan organisations. Good marketing can totally replace the need for subsidy.

- **Promotion by Demonstration.** Rural people will not buy an article on advertisement alone. They need to see the product and confer with peers on the advantages and disadvantages. Ten stoves were placed in houses of intelligent homeowners in the same number of villages. These could be viewed and commented on by the villagers. This way consumer feedback is obtained and adjustments can be made based on the comments of the end-users.



Although many metal stoves have doors, these are never closed.
Long sticks of firewood usually lay on the floor in front of the stove.
Air intake above the firewood reduces fire temperatures and firewood efficiency.

3. PRODUCER ANALYSIS

Nepalganj is a small town near the Indian border, where small industries make various articles that are then transported by air to the remote Dolpa, Humla and Jumla districts of the Karnali region.

Manufacturers in Nepalgunj

The following observations are related to the metalworkers in Nepalgunj:

a. The few metalworkers in Nepalgunj, who claimed to have made stoves before, did not have any samples in their workshops, nor drawings or manufacturing details about the stoves they had manufactured. When making other stoves they need a sample to copy.
b. These metalworkers could/would not provide precise figures about costing or production numbers, probably related to fears for government or other taxation.
c. They did not do any advertisement or promotion because the mountain stove was not asked for in Nepalgunj, being a tropical low-land climate (altitude 500m). They only produced stoves on the basis of an order from an NGO, donor organisation or commercial trader.
d. From analysing their products in the field, there was little quality control as the various stoves were very roughly finished. The price of the stove was per weight.
e. One of the metalworkers was able to make cast-iron components, provided they were ordered in sufficient numbers (more than 50 per series).
f. The metalworkers had adequate equipment in their workshops, most of them operating on electricity, but production activity of any kind was very low. They did not have a concept of series manufacturing, the use of jigs or cost reduction with increased quantities.
g. The metalworkers that had made stoves used electric welding equipment for the assembly of the pieces. The entire stove was sold to the trader or NGO, often without a chimney.

It is recommended that, in a stove improvement programme, manufacturing manuals should be developed with clear drawings, which can be easily understood by sheet metal workers. With the introduction of new stoves, training of stove makers need to be done and a marketing network needs to be developed. Only with a marketing network in the mountain region, can sufficient stoves be ordered and manufactured; thereby allowing series manufacturing and a reduction in price.

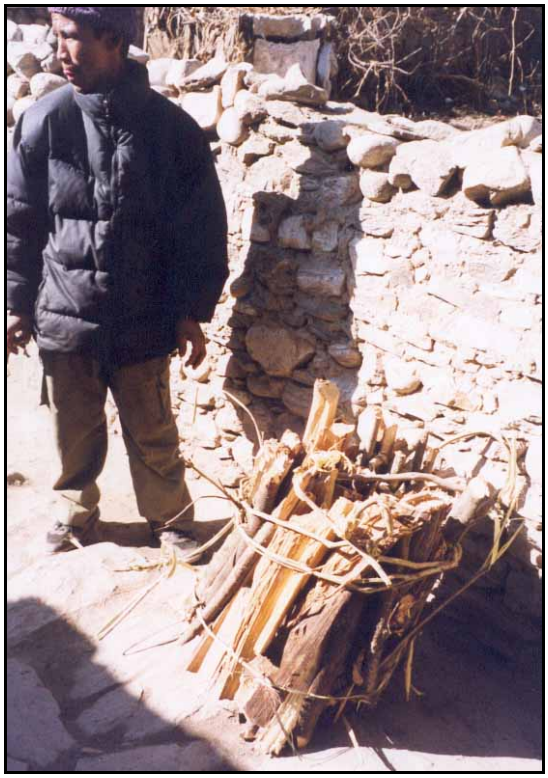
Existing stove type with three doors and *roti* slot sold without chimney in Dunai for NRs. 5000 (USD 70)[4]. This stove was similar to the first model the KU had introduced in the area.

[4] The exchange rate is fluctuating around 1 USD = NRs 70-75.

Discussion with Sisters Organisations

The following observations were made related to the discussions with the Sisters Organisations (women groups running Saving and Loan Schemes):

a. The Sisters Organisations were all very interested in better stoves, in particular with regard to the reduction of smoke in the kitchen. They considered the few types of metal stoves present in the area as an improvement to the traditional tripod or mud stoves, although with most designs the firewood consumption had increased as compared to the mud stoves. The metal stoves were considered expensive in terms of purchase cost and transport.
b. The Sisters Organisations operate in many villages and are able to extend loans to villagers for a variety of purposes. There was no objection to lending money for better stoves and no collateral would be required. The interest rate would be 2% per month on the outstanding amount. All funds saved were outstanding in loans. The Sisters Organisations currently do not undertake trading in any hardware.
c. The Sisters Organisations had a lack of useful information on technologies, such as stoves, greenhouses, PV, illumination, solar cooking or other technical issues.
d. The above point illustrates that provision of complete and detailed information about the several technical options available is essential. Only through good information networking can the best consumer products be disseminated to the remote areas.



Firewood bundle of 50 kg or NRs. 200 (USD 3).
One load of pinecones costing NRs. 20.

Credit Service Development and Training

If series of stoves are manufactured under controlled circumstances and delivered to the Sisters Organisations, these can sell the stoves on credit. With such a mechanism, the Sisters Organisations can be capitalised to expand their saving and loan services to more sales of stoves. The members of the Sisters Organisations will require training on financial issues and stove technology.

4. USER ANALYSIS

Discussion with Villagers

The following observations were made related to the discussions with villagers:

a. Whenever they can get hold of a metal stove, they would prefer to do so, even if the metal stove consumes more firewood than the mud stoves. This is because the chimney from the metal stove evacuates the smoke from the kitchen and the heat generated inside the metal stove is more intense, shortening the cooking process.

b. Some villagers like the metal stove because it looks good and has many doors, a *roti* slot and a chimney. The stove is invariably in the kitchen. During the winter, the villagers sleep in the kitchen area. Small houses have only one room.

c. The metal stove design available in the market was not good; it consumed too much firewood.

d. Long pieces of wood stick out of the front door of the stove and accumulated ashes inside the stoves are seldom removed (photo page 3).

e. A large quantity of soot accumulates on the ceiling of the rooms, which frequently falls down in the cooking area and into the pots. Soot also accumulates as a thick layer in the chimney.

f. Smoke in the kitchen escapes through open doors and windows. Smoke irritation is less for those people sitting low to the ground and away from the fire. For people (women) doing the cooking, the smoke is a continuous and serious health problem.

g. During the summer, some villagers prefer to use mud stoves to limit the heat radiation into the room. During the winter, open fires are kept inside the house, in the middle of the floor, for both cooking and space heating. However, the main purpose is for cooking.

h. The villagers and government officers in Dunai (the main village in Dolpa) need to buy firewood in bundles of 50 kg (one *buri*, costing NRs. 200). Outside Dunai, villagers are allowed to collect deadwood in the forest reserve areas. It costs about a full day's work, including the walking, to collect and transport one *buri* of firewood.

i. The villagers from Dunai and the surrounding areas are allowed to collect fallen pinecones from the forest reserve area for a fee of NRs 20 per day, payable to the park authorities. In this case, the villagers are able to collect a full load (50 kg) of pinecones in a day.

j. All villagers used pressure cookers, but none of them used energy-saving thermo boxes (hay boxes) for slow cooking of rice or beans, two of the staple foods in the region. The largest pressure cooker used was 5 litres with a 21.7cm diameter and a height of 12cm to under the handle. The most common size was 2 litres with a diameter of 17.4cm and a height of 6.4cm to under the handle.

k. Pots and frying pans are used on top of the stoves. Some villagers elevate the pots with stones so the fire goes around the sides of the pots. This also provides light for cooking.

l. Firewood-efficient solutions are needed for both metal and mud stoves because not everybody may be able to invest a few thousand rupees for a full metal stove and it is unlikely that substantial or individual subsidy will be forthcoming.

Stove with two large doors (openings) and stones to elevate the cooking pot.
Yellow flames around the pot provide some illumination in the kitchen.

Illumination While Cooking

Illumination was highly appreciated, but in most of the villages, no electricity was available. It was indicated that the closed metal stoves had the disadvantage of the fire providing insufficient illumination for the cooking process; whereas with the open tripod fire or mud stove, the yellow flames provide some illumination.

It is recommended that research be realised to produce illumination from a wood fire for the areas having no electricity; otherwise stove users will continue to favour open fires for the minimal yellow light they provide. Only closed stoves with good air/heat regulation are firewood efficient.

Product Development

The introduction of a new and better consumer product, such as a cooking stove, requires thorough research and field-testing of the product before it can be mass-produced. For each geographical region and user-group, different types of wood stoves may be required. The following differences were noted between the Dolpa and Sagarmantha regions:

Feature of the Stove	Dolpa Region	Sagarmantha Region
Two-hole stove	Acceptable as open fire with one cooking point being common.	Acceptable for small families, but not sufficient for teahouses to cook multiple dishes for tourists.
2-inch firewood entry in the elbow-shaped burning chamber	Mixed reaction. People like to minimise chopping. Bundles of firewood are usually of small sizes.	For teahouses, not practical as it requires further chopping of the large rhododendrons and fir trees. Firewood comes in large pieces only; chopping is the task of the cook.
Water heating facility	Much liked but considered to be expensive.	Considered an essential feature; teahouse owners will have little problem paying.
Roti maker	Considered essential to be incorporated or separate.	Not really an issue. More important is keeping the pots shiny clean.
Chimney pipes	A necessary new feature.	Using existing smoke hoods over fireplace.
Complete combustion	No illumination by the yellow flames of the fire.	No charcoal remains that can be used for other purposes (burning incense).

Analysis of Several Stoves

Adult is one person; child is counted for half a person.
Explanation of second column: 2(2+1) = 2 meals for (two adults and two children)

No.	No. of Meals Per Day	No. of Meals Per Week	Firewood Use Per Week	Total Cost Per Week in NRs	Stove Details	Stove Cost in NRs
1	2 x 15	210	200 kg	800	Mud stove in restaurant with two places for pots.	Time, no cash
2	2(2+1)	42	50 kg	200	Mud stove with tripod in single room/kitchen.	200
3	2(2+2.5)	63	130 kg	520	Metal stove, old model, next to open window.	5000
4	2(6+2)	112	130 kg	520	Mud stove with tripod in kitchen, being separate from bedrooms.	200
5	2(5+1.5)	91	100 kg	400	Metal stove in large kitchen bought 4 years ago from local trader.	4000
6	2(4+1)	70	100 kg	50	Metal stove, 9 years old, locally made, tripod used, pressure cooker exploded.	600 in materials
7	2(2+2)	56	75 kg	20	Mud stove and open fire.	Time
8					Metal stove + warm water attachment used only in winter, no chimney.	6000
9	2 x 4	56	100 kg	400		
Total	61	700	885 kg	2910		
	Average	**One Meal**	**1.26 kg**	**4.16**	**The restaurant is most energy efficient per meal because of continuous cooking of many meals**	

Currently a household is using 1.26 kg pinewood per meal. This can be brought down to about 0.5 kg firewood per meal with stoves that are more efficient.

One (improved) metal stove, available from a trader in the market of Dunai, was measured (see photo page 4). The observations were as follows:

- The stove was a "look-alike" from an earlier model of an improved stove from the Kathmandu University (KU), but apparently not with the same interior. This proves that a stove programme needs to be developed incorporating entrepreneur and manufacturing trading.

- The additional side door was permanently closed. It had a long top r*oti* slot. From a stove in use, it could be seen that the *roti* slot produced a lot of smoke and it substantially increased the burning chamber.

- The stove was sold <u>without</u> a chimney at a cost of about NRs. 5000. The owner in one house commented that buying the chimney was too expensive and so used the stove without a chimney.

- The top plate was very thick (4.3mm) and the holes were rather roughly cut (jagged edges).

- Weight of the stove was about 40 kg. Manufacturing cost in Nepalgunj was NRs. 45/kg = NRs. 1800. Air transport cost from Nepalgunj was NRs. 57/kg or about NRs. 2280. Profit = minimal NRs. 500. Local carrying by porter for freight is NRs. 8/kg to Dunai (2 hours) = NRs. 320. Total = NRs. 4900 or about USD 70 based on prices of 2004.

5. METAL STOVE ANALYSIS

The following list provides an overview of the specific details of the metal stove found and what can be done to improve its performance.

Description of Stove Element	Advantages of Stove Element	Disadvantages of Stove Element	Suggested Improvements
1. Top plate thickness of 4.3mm.	Strong and durable. The plate will pass the heat to the pot with good contact. Plate remains warm after stove is out.	Difficult to make. Plate is very heavy, thus costly to buy and transport. Plate consumes a lot of heat for warming up.	A thinner top plate of 1.2mm. A chimney valve is necessary to regulate draft and avoid that the warm stove evacuates warm air from the kitchen/room.
2. Side plate thickness of 1.6mm.	Strong and durable. Plate contains heat in fire chamber.	Difficult to cut or fold manually or without heavy equipment. Costly.	Side plates of 1.2mm maximum or 0.7mm for manual folding. This will lower the cost.
3. Central front hole cut into the top plate with a diameter of 18-19cm.	Average large pot (4-5 litres) or frying pan sits on the top plate, bottom of pot/pan is exposed to the fire.	For smaller pot rings are necessary. Only the bottom of the pot receives fire heat. Distance between fire and pot is fairly large.	Lower the pot into the hole as deep as possible to increase contact area between fire and pot. Support under the pot is necessary. For smaller pots, make rings to close the gap around the pot.
4. Two small rear holes with a diameter of 10-11cm.	Small pots can be put over the holes to keep warm or slow cook.	Only the bottom of the pot receives heat from fire. Holes are often not covered letting smoke escape into kitchen.	Only one hole in the rear with a minimum size of 20cm. The rear side of the stove should be tapered towards the chimney with baffle under the hole.
5. Chimney is attached to the rear side.	This keeps the top surface of the stove short.	No particular disadvantages.	Connect chimney to the top improves outflow of gasses or draft.
6. Chimney (3" diameter) of 1.3mm steel sheet.	Probably the most economic diameter for smoke removal. The thick steel plate will last many years.	Thick sheet will cause cooling of gas and deposit of soot in chimney. Expensive in material and transport.	Use thin sheet (0.3mm - 0.45mm), costing less in material and transport. A thin chimney will release more heat into the room; reduce soot deposit in chimney.
7. Side door on stove.	Possible easy cleaning or firing.	Side door is permanently closed and expensive.	Do not make a side door.
8. Door on inlet.	None. Theoretically the door can be closed, but this is not done.	Door is always open, thus allowing top air intake. Results in incomplete combustion and soot.	Omit door. Introduce mouthpiece that allows only air intake from below. Narrow mouthpiece will allow better combustion.
9. Front loading door 20cm wide and 12-15cm high.	Easy lighting of fire and allows large pieces of wood to stick into the door. Long sticks can lay on the floor.	The high door allows air to be sucked into the stove above the firewood, thus cooling the gasses and cause inefficient burning.	Make door height low using wood sizes of maximum 4cm section. Introduce "rocket" principle, and improve air intake, raising fire temperature 50 - 75° C.
10. Large fire area in front stove.	Allows large quantities of wood to stick into front.	Large fire chambers are inefficient for complete burning and heating pots.	Reduce width of fire chamber to slightly more than the maximum pot width.
11. Ashtray under front door.	Metal grate between the fire area and the ashtray can allow air to enter.	The ashtray is almost never emptied, thus useless as no air can enter from below.	Allow the ash to be easily removed through the front opening once the fire has been extinguished.
12. Baffle before the second hole.	The flames are directed upwards towards the pot in the rear.	No real disadvantages, slight cost increase.	Create baffle directing the heat towards the cooking hole.

Description of Stove Element	Advantages of Stove Element	Disadvantages of Stove Element	Suggested Improvements
13. Internal oven in the back.	Oven is used for keeping food warm or baking bread.	Additional metal ware and thus increased cost. Few people bake bread.	Can be optional feature for rich people. Not for standard design.
14. *Roti* slot in the front 23 x 2.5cm.	The long *roti* slot allows *roti's* to be made while pots are on stove.	The r*oti* slot allows smoke to escape and increases size of burning chamber.	Design a *roti* maker for the top of the stove, using a waffle iron.
15. Cover ring on front hole for smaller pots.	The cover ring allows smaller pots to be placed on the wide opening.	Pots do not sink into the fire opening and therefore still have a reduced area for heat transfer.	Pots should lower into the cooking hole onto a support. Around small pots a tight fitting ring should be placed to minimise heat escape.
16. Full metal bottom	Integral part of the stove and oven.	Large plate, costing money.	In soil-floor houses not required. Thinner base plate can be made.
17. All metal stove has legs.	Allows stove to be placed on wooden floor in traditional houses.	Legs are very short and, with full heat, the floor may catch fire.	Make a stone basement covered with thin sheet metal (0.7mm).
18. Stove has single metal sides.	Low material costs.	Firing chamber too large and not insulated reduces firewood efficiency.	Reduce fire chamber size and make from stainless steel or chrome steel.
19. Water heating with fixed pipes, 10 ltr. barrel.	Automatically heats the water during the cooking process.	Expensive design. Small water quantity can become very hot. Barrel of iron will rust.	Redesign water heating with storage in large, strong plastic barrel of 60-80 litres. Less costly in transport and does not rust.
20. One tap point on small barrel.	Hot water can be used for cooking.	Water becomes very hot. High temperature causes increased heat loss.	One tap point for hot water directly behind the stove. One tap point for warm water on larger barrel.
21. Chimney damper.	Not existing.	With high wind, excessive draft and heat loss.	Damper to regulate draft and control fire/cooking speed.
22. Direct roof passage of chimney.	Low cost.	Water leaking alongside the chimney. Fire hazard if chimney soot catches fire.	Roof passage with spacer and exhaust of residual smoke hanging in the room.
23. Chimney vane cap.	Avoids rain from entering or back-fall of air with flat roofs.	Poor design does not prevent back-fall of air.	Good chimney vane that provides sufficient suction for every wind direction; also on low flat roofs.
24. Light during cooking.	Incomplete burning of wood produces yellow light.	Incomplete burning causes excessive firewood consumption.	Illumination by using firewood gasses not yet well researched or resolved satisfactorily.

Mud stove for two pots in a restaurant. No chimney.
The continuous use of this stove makes it fairly efficient compared to one-meal stoves.

6. DESIGN OF ONE-FAMILY STOVE

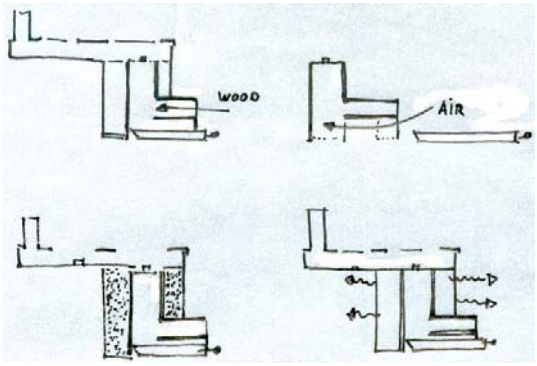
The following design details have been developed for a two-pot, one-family stove and not for larger teahouse or hotel operations. This is for the following reasons:

a. The total amount of firewood consumed by the families in the region is far larger than the amount consumed by the few hotels or restaurants; hence, the savings through a better one-family stove will be larger than with improving stoves for teahouses.
b. The teahouse and hotel owners in the region are obliged (by the park authorities, such as WWF) to use kerosene for the cooking needs of tourists[5].
c. The tourist trekking period is only a few months per year; the teahouse owners are using firewood for their own cooking as a family.
d. The poverty level of the families is far lower than the poverty level of the teahouse owners.
e. The existing households have only one open fire tripod, cooking one pot at a time.
f. When the model works in one area, it can be replicated in other areas.

The copy of the current metal stove in the region has one large hole in the front and two small cooking holes in the rear. The two small potholes in the rear are both inefficient. As the new design is supposed to be more efficient, the double holes in the rear have been eliminated.

Description of Proposed Stove Improvements

1. **Air Intake Under the Fire.** Improving the burning efficiency is assured by the air intake being below the fire and the reduction in the firewood sections. The mouthpiece has a shelf.



2. **Smaller Wood Sections.** Smaller wood sections burn better than thick wood sections**.** The maximum section of the firewood pieces is 4-5cm thick (1½" - 2"). Lengthwise cutting (splitting) of firewood is easier than crosswise cutting. There is a trade-off between collecting large quantities of firewood or doing a little extra chopping.

3. **Rocket or Elbow Principle[6].** The burning chamber is designed according to the "Rocket" or elbow principle which incorporates the above two points. The burning chamber needs to be as small as possible and produce a vertical flame under the first pot.

4. **Ashtray Under Elbow.** The amount of ashes will be greatly reduced by improved combustion. The ashtray can be made of thin metal. At the location of the ashtray, the burning chamber or stove does not need a bottom sheet.

5. **Separate Burning Chamber.** The separation between the burning chamber and the rest of the stove allows these components to be made from different material qualities. The burning chamber can be made from chrome steel or stainless steel (light and durable) or 2.5mm (gauge-10) mild steel. The sides can be made from 0.7mm sheets or galvanised steel sheet.

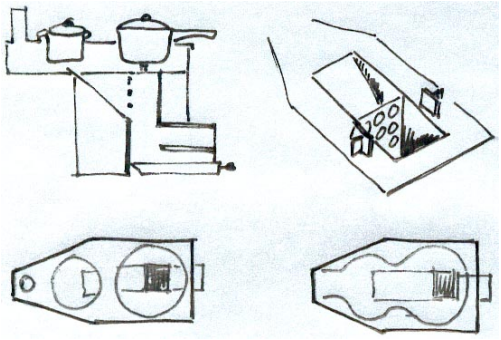
[5] Unfortunately, this ruling is not adhered to as many teahouse owners cook their own meals and those for the tourists on wood stoves.
[6] The "Rocket" principle was developed by Larry Winiarski from the Aprovecho Research Centre in USA and widely acclaimed as one of the major improvements of the wood burning stove's efficiency.

6. **Insulating the Burning Chamber**. The airspace between the burning chamber and the outside of the stove is a good insulator, giving the outside of the stove a low temperature. This space can be filled up with wood ash during the summer when no heat radiation of the stove is required.

7. **Sunken Pot Principle**. To increase the contact between the hot gasses and the fire, the pot is lowered into the top plate to just above the burning chamber.

8. **Flue Gas Funnel.** To increase the heat projection to the second pot, an inclined funnel is made from the burning chamber towards the second pothole.

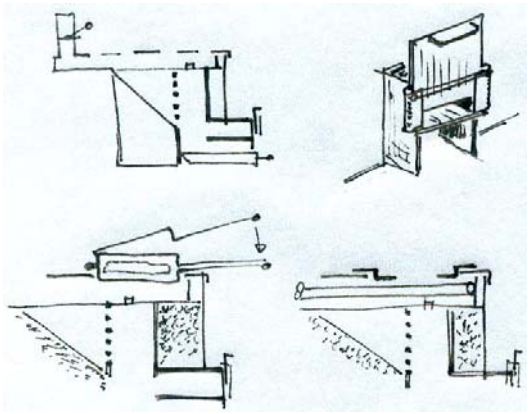
9. **Small Pot Supports**. Two small T-shaped supports keep a space between the bottom of the pot and the top of the burning chamber to avoid closing the flue outlet by the pot.



10. **Stove Shape**, **Pot Skirt and Baffle.** The stove is made narrower after the first cooking hole and towards the chimney, saving material. To enhance the contact of the flue gasses with the pot, a pot skirt and a baffle are incorporated.

11. **Draft Regulation (Air Regulator and Chimney Draft).** The air regulator is fitted at the front of the mouthpiece of the elbow-shaped burning chamber and slides automatically down onto the wood sticking out of the opening. The air intake through the wood-feeding opening remains minimal. The chimney draft regulator needs to be manufactured in such a way that it can be easily positioned in a full range of positions. Because of the long chimney, opening the draft regulator increases the fire intensity.

12. **Pot Rings.** Pot rings fitting precisely in the cooking hole and around the cooking pots are required to avoid either smoke escaping alongside the pot into the kitchen or quenching the heat because of sucking air into the stove, caused by high draft from the chimney.



13. **Chopping Firewood.** Firewood is supplied in 50 kg (NRs. 200) bundles, consisting of large sticks about two feet in length. To minimise chopping labour, long sticks are used (see photo page 3) and gradually pushed inward when burned. The thick (burning) sticks are lying on a pile of ashes. It needs to be explained to the villagers that the stove requires far less firewood for cooking, but the wood must be chopped into sticks smaller than 2" in section. Time saved in the collection of firewood is slightly replaced by additional chopping. Long sticks need an additional support in front of the stove.

14. **Long Chimney.** The chimney removes the smoke from the kitchen and creates the draft in the stove. A minimal 4m long chimney assures sufficient draft at all times. The chimney should be from thin non-galvanised sheet metal (28-gauge=0.3mm) to allow fast heating (less soot deposit), good heat radiation and low transport cost. Regular cleaning of the chimney is recommended. Chimney sections are 120cm long and need to be replaced when rusted through. For exterior chimney pipes, 28-gauge (0.3mm) galvanised sheet steel is used.

15. ***Roti* Maker.** The current "modern" metal stove has a *roti* slot in the thick top plate. The use of this feature, however, causes large amounts of smoke and heat loss. A better solution is a waffle iron that fits with a side rim into the large front opening.

16. **Warm Water Tank.** A stove in Dunai (photo right) had a fixed external warm water tank of 10 litres. The pipes were of GI iron. This stove was only used during three winter months and the owner used it without a chimney inside the house. A tank that is fixed permanently against the stove will be rather small. Any internal tank will be even smaller and expensive because it enlarges the entire stove body and probably needs to be made from stainless steel to avoid rusting.

17. **Heat Pipe with Large Warm Water Storage.** It is proposed to make the top plate of the stove in such a way that a heat pipe can be fitted into the stove. The heat pipe can be attached to a large water barrel of strong durable plastic with flexible attachments. First, this design does not increase the basic cost of the stove body. Secondly, the villager can buy the warm water facility separately at a later time. Thirdly, the amount of warm water will be substantially larger (60-100 litres) than with an attached tank. Fourthly, the 60-100 litre blue plastic (chemical product) barrels are commercially available on the second-hand market (frequently used for trekking expeditions). Fifthly, the design allows direct tapping of steaming hot water from the stove outlet while the stove is working. Lastly, it allows tapping of warm water from the barrel at the lower point.

To avoid accidental flooding of the kitchen/room, the outlet (low) and the inlet (higher) of the water pipes to the barrel can be fitted with ½" stop valves. The suggested design has been field-tested in the Pakistani Himalayas and is very much liked by the mountain population. For the positioning of the hot and warm water taps, it must be indicated if the stove is for left-side use or right-side use. The warm water barrel with the pipe connections needs to be placed just above the stove, while there should be a height difference of about 30cm between the low cold-water outlet and the higher warm-water pipe inlet.

GI pipes inside the stove connect to hot water-resistant flexible pipe and water storage barrel. When the stove is on, steaming hot water is drawn from the higher tap.

18. **Roof Passage.** Villagers tend to underestimate the importance of a long chimney pipe. This is required for good draft. The stove draft can be regulated with the chimney valve. Many villagers pass a chimney horizontally outside the wall, causing insufficient draft. Vertical roof passages give problems of leakage along the pipe. When the thick soot in the chimney catches fire, the roof can also catch fire because the chimney pipe touches the roof beams and internal materials

under the soil covering. A good roof passage allows a separation between the 3" chimney pipe and the roofing material. The new roof passage also allows a small quantity of air (and usually smoke) to be evacuated from under the ceiling, thus keeping the room free from smoke. A top-skirt piece allows for a waterproof connection with the roof surface of the house.

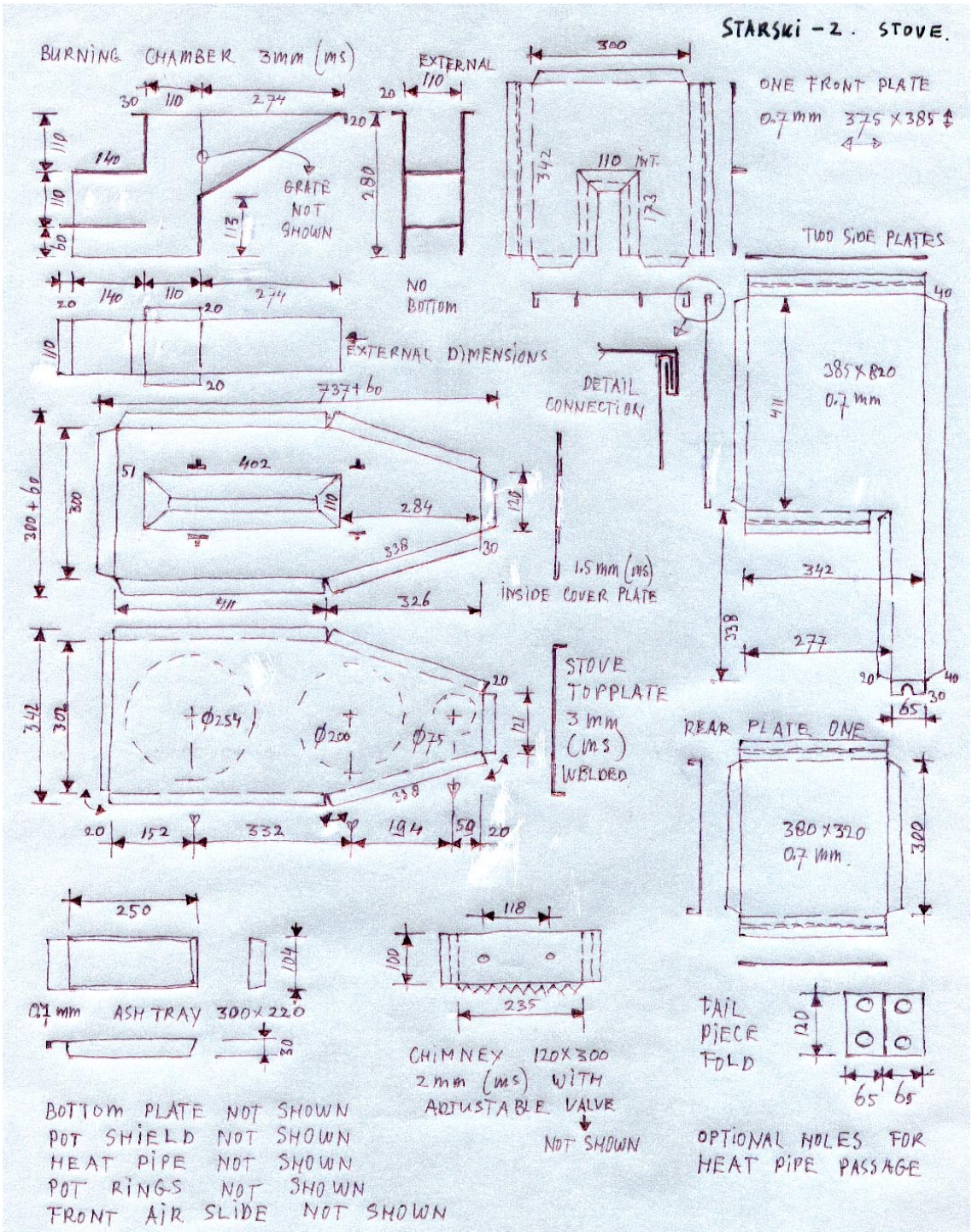
19. **Chimney Vane Cap.** Many chimneys end just above the roof and are strongly affected by varying air circulations around the roofs caused by adjacent rooms or roof edges. Most problems are avoided by Λ-shaped caps or T- and H-shaped pipe extensions. The vane cap design is inserted into the chimney top to prevent downdraft problems occurring under any wind circumstances. For the roof passage and vane cap, 26-gauge (0.45mm) GI sheet is used[7].

Low-cost chimney vane cap made of 26-gauge GI sheet metal, a pin and a bolt.
Easily swivels around with every wind direction and avoids back-draft, especially on flat roofs.

The following page provides a sketch of the prototypes that have been distributed in the villages. It is expected that some small design modifications and corrections on dimensions will still be required before a final model is obtained.

From each component, a cutting drawing needs to be made. In addition, an assembly manual will be necessary.

[7] For detailed sketches of roof passage and vane cap, see the report: "Installation of Improved Metal Cooking Stoves in the Khumbu Region, December 2004".


STARSKI – 2. STOVE.
BURNING CHAMBER 3mm (ms)
EXTERNAL
ONE FRONT PLATE
0.7 mm 375 x 385
TWO SIDE PLATES
GRATE NOT SHOWN
NO BOTTOM
EXTERNAL DIMENSIONS
DETAIL CONNECTION
385 X 820
0.7 mm
1.5 mm (ms)
INSIDE COVER PLATE
STOVE TOPPLATE
3 mm (ms)
WELDED
REAR PLATE ONE
380 X 320
0.7 mm
ASH TRAY 300 x 220
CHIMNEY 120 X 300
2 mm (ms) WITH
ADJUSTABLE VALVE
NOT SHOWN
TAIL PIECE FOLD
OPTIONAL HOLES FOR
HEAT PIPE PASSAGE
BOTTOM PLATE NOT SHOWN
POT SHIELD NOT SHOWN
HEAT PIPE NOT SHOWN
POT RINGS NOT SHOWN
FRONT AIR SLIDE NOT SHOWN

7. USING IMPROVED STOVES

Most of the technical points to improve the stoves are mentioned above. In addition, the following observations and rules are relevant in its use.

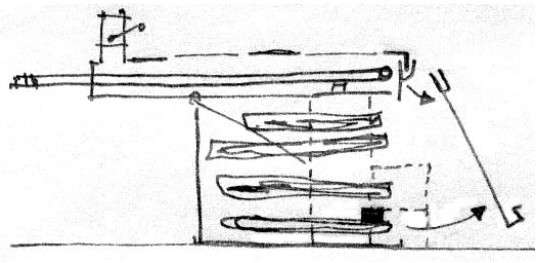
- With short cooking periods (in the morning breakfast, in the afternoon dinner) thin metal stoves are more heat efficient than thick metal stoves or stoves with a large soil mass. Heavy metal or mud stoves will absorb substantial heat during their starting-up period for which firewood is required.
- With long cooking periods (such as in restaurants) heavy-mass stoves can be more firewood efficient than light-mass stoves, provided they are used continuously.
- Once extinguished, heavy weight metal or mud stoves remain warm and may assist in keeping the room warm. However, this will not work at all if the chimney cannot be closed with a damper. When the chimney cannot be closed, the warm stove will evacuate all the warm air from the room through the chimney.
- In a sunken-pot design, aluminium or stainless steel cooking pots will rapidly turn black with soot. This is not liked by the women as they spend lots of time cleaning the pots. In other models having a closed stove surface, the stove is less efficient. In addition, the cooking pots need to have flat bottoms to obtain good heat transfer. Many villagers have cooking pots with ball-shaped bottoms and are not prepared to buy all new cooking pots. Using black iron pots reduces the urge for cleaning.
- The acceptability of stoves depends very much on the ability of the people to realise their local cooking needs. The more efficiently this can be done with a new stove design, considering the amount of firewood used and the speed of cooking the stoves provides, the better the new model will be accepted. For these reasons, any design should be field-tested with the end-user population.
- Using a ventilator can increase the fire intensity at high altitudes. Several types of hand-operated ventilators exist.
- Some villagers use charcoal for room heating and burning incense. The improved stove will burn the wood completely, eliminating the production of charcoal. Some villagers see this as a disadvantage when they need charcoal for burning incense.
- When stoves are needed for room heating, the thermal insulation around the burning chamber should be kept empty during the winter period, so more heat radiation will result.
- The additional feature of water heating is very much appreciated by the villagers. A stove that performs both functions of cooking and water heating at the same time has a higher overall firewood efficiency. Heat pipes inside the stove or smoke water heaters (back boiler) can be utilised for this purpose.
- The introduction of improved cooking stoves will be hampered when:
  a. There is still an abundant amount of free or low-cost firewood and biomass.
  b. There is insufficient control on the use of firewood for tourist cooking services.
  c. There is no local service point where stoves can be ordered or services provided.
  d. The stove is difficult to operate or regulate in fire intensity.
  e. Time saved from firewood collection is spent entirely on chopping the wood.

Gassifiers

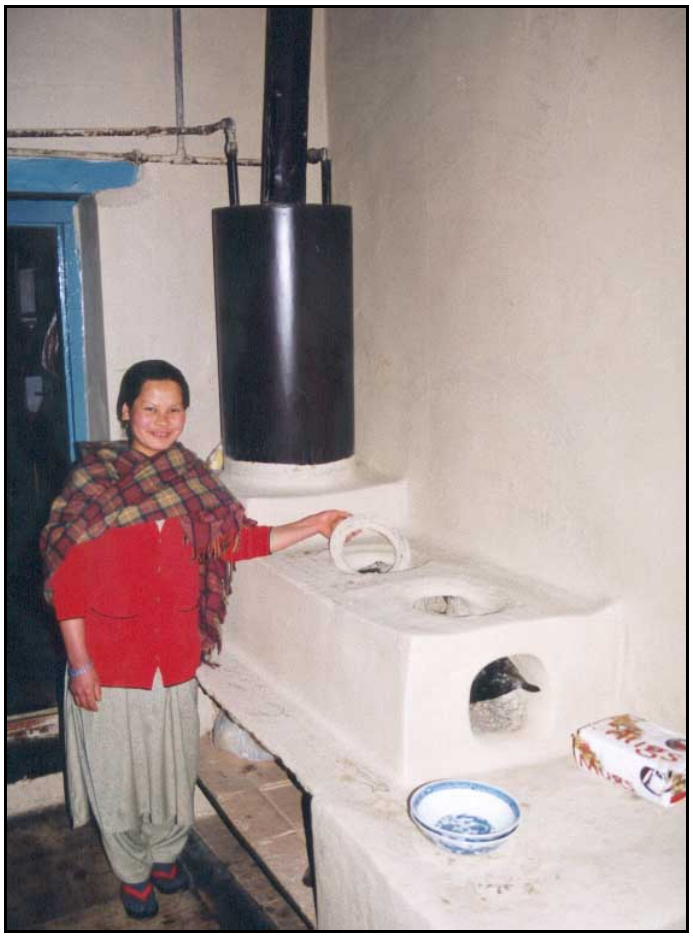
Further improved cooking stoves are based on the gasifier principle. This, however, requires the firewood to be chopped into even smaller pieces, as well as technically more complicated installations, costing more money. In addition, gasifiers only function efficiently in continuous processes. Because cooking in a household is a short duration process, presently available gasifier cookers are not an economical option for low-income people in remote areas.

Semi-Gasifier Stove

The current stove model can be modified by making the front plate of the stove as a door that can be taken out (arrow in sketch right). The space around the burning chamber is then filled with firewood and the door closed. The heat from the burning chamber will dry and partly gasify the wood. Wood gas will enter the burning chamber through an opening in the bottom of the burning chamber and assist the ongoing fire (black square in sketch).



The next day both the charcoal and very dry wood can be taken out of the compartment. This can be used for rapidly lighting the stove again and obtain excellent heat. Further product development is needed here.



Smoke water heater in a hotel restaurant in Jomsom.
On this stove, a mouthpiece and air-intake regulator will improve firewood efficiency.
Large mud stoves contribute little to space heating.

8. CHANGING COOKING BEHAVIOUR

One of the most energy efficient methods of cooking is with a pressure cooker. A pressure cooker requires very little water and reduces cooking time due to high temperature inside the pot. This is especially important in high altitude areas. Most people living in high altitudes are already accustomed to using pressure cookers. However, further firewood economies can be obtained by such measures as:

- **Lid on the Pot.** Cooking should to be done with lids on the pot, not with open pots. All research indicates that considerable energy is lost through evaporation of water surfaces during the cooking process. When the food has been brought to the boiling point, it needs to be placed on the second cooking hole, allowing simmering.

- **Shorter Cooking Time.** Slow cooking habits have evolved in periods when firewood was abundant. For that reason, many common dishes are prepared over a low fire for a long period of time. For high altitudes, the stove has a double function of both cooking and space heating. Because of this double function, long cooking periods are often found in recipes for traditional dishes in cold mountain areas. Space heating is ineffective in poorly insulated houses.

- **Sarai Cooker.** The Sarai Cooker consists of a stacked set of pots with a full skirt, going over the top of the stack. The use of this pot and skirt combination increases the cooking efficiency with another 10-15%.

- **Good Regulation of Heat of Fire.** The cooking efficiency increases when the cook can easily regulate the heat intensity of the fire. The draft regulator, fan, sliding door in the front of the stove, two different cooking holes and feeding of firewood are all measures to regulate the fire intensity. This has to be learned by the cook.

- **Thermo Box or Hay Box.** With the cost of firewood rising rapidly due to its scarcity, cooking behaviour needs to be changed to become more firewood efficient. The use of the thermo box is one option. When rice or beans reach cooking temperature, the well-closed pot is placed in an insulated container (hay box). The cooking process continues inside the insulated container without the need of a fire. After about a half hour, the rice or beans are perfectly cooked.

- **Small Pieces and Less Water.** Other ways of reducing cooking time, and with that the amount of firewood needed, is to cut vegetables into small pieces before cooking. This will also require less water.

- **Preheating Water with Solar Energy.** Other technologies to reduce firewood consumption are based on the direct use of solar energy, for example, in preheating the water in a solar cooker or a solar water heater (SWH). Most cooking processes require water. All water preheated by means other than the stove will reduce heat demand from the stove; thereby requiring less firewood.

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ANNEXE I

DESCRIPTION OF SHEET METAL THICKNESS

Metric Sheet in mm	Imperial Sheet in mm	Imperial Gauge	Characteristics	Used For
2.5		10	Cutting by blowtorch or corundum disks.	Burning chamber of stove.
2.0	2.03	14	Difficult to cut with light machines, but a blow-torch can be used, leaving very irregular edges. Easy to weld electrically.	Mild steel plates hammered into light concave dishes for baking *chapattis*. Used for the top plate of the stove.
1.5	1.63	16	Can be cut by hammer and chisel, but leaves jagged edges. Fairly easy to weld electrically. Poor quality of MS plate will give uneven surface of stove.	Top plates found in some stoves, but these do not stay flat without additional measurements.
1.2	1.22	18	Fairly easy to cut with large manual plate scissors. Can be manually folded and hammered over rail ridges. Can be fixed manually with soft rivets. Slightly difficult to weld electrically without burning holes. Cut sides remain sharp.	Recommended for general stove body construction, all movable parts and pieces that need folded sides. Folded rims are rather strong. First used for sides of new stove.
0.9	0.91	20		Stainless steel.
0.8		21	200-litre oil barrels (SMS). Easy to cut with chisel and plate cutters. Care must be taken with electric welding to avoid burning holes. Gas welding recommended.	Many stoves are made from recycled oil barrels (low cost). Durability about 5-6 years, depending on use. Material suitable for making heat shields.
0.7	0.71	22	Metal trunks and a wide variety of products are made by manual sheet metal workers, using folding techniques and rivets for attachments.	Possible minimum thickness for sides of the new stove. GI sheets will give good appearance of the stove.
0.6	0.56	24	100-litre tar barrels. Easy to work when new sheets are used. Very difficult to weld because both electric and autogenic welding may burn holes. For all pieces that need precise cutting and folding, this material is most suitable.	The metal sheets come mainly in stretched version. Durability low when it comes in direct contact with fire. Galvanised and non-galvanised.
0.5	0.46	26	Thin sheet for covering of doors, shutters. Recommended to use only galvanised or painted versions for outdoor use.	Can be used for chimneys (non-galvanised) or for wind vanes (galvanised). Burns easily in fire.
0.3		28	Rather thin sheets. If not galvanised, it will easily rust when exposed to humidity in exterior application.	Can be used for inside chimneys (non- galvanised). Replacement when rusted through.

All new sheet metal comes in two types: MS = mild steel and SMS = stretched mild steel.
The stretched mild steel plates are stiffer and flatter due to cold deformation and rolling.
Most galvanised sheet steel and all corrugated roofing sheets are of the stiff SMS material type.
When SMS (cold deformed) sheet is strongly heated, it reverts back to MS.

Metal bars can be also common mild steel (smooth). Reinforced concrete (RC) bars come in cold deformed quality, being considerably more stiff and stronger than MS bars. Cold deformed RC bars have twisted ridges and indents around them for better adherence to the concrete.