OCCASION

This publication has been made available to the public on the occasion of the 50th anniversary of the United Nations Industrial Development Organisation.

DISCLAIMER

FAIR USE POLICY

CONTACT

Please contact publications@unido.org for further information concerning UNIDO publications.

For more information about UNIDO, please visit us at www.unido.org

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org

14747

1985

TOWARDS MASS PRODUCTION OF WOODBURNING STOVES*

by

K. Krishna Prasad
Department of Applied Physics
Eindhoven University of Technology
Eindhoven, The Netherlands

* Prepared for the UNIDO stove meeting on March 18 - 20, 1985, Vienna, Austria.

1. INTRODUCTION

The work on woodburning stoves rests on seven propositions-

(a) Half the world's population eats food cooked on fires fuelled by wood and agricultural/animal waste.
(b) About 60% of all fuel consumed, particularly in rural areas of developing countries, is accounted for by the cooking task.
(c) The traditional cooking fires are energy-inefficient, physically hazardous, unhealthy and inconvenient to operate.
(d) The deforestation has created fuel scarcity making an already bad situation much worse.
(e) The prospect of substituting woodfuels by fossil fuels or other forms of renewable sources of energy is remote.
(f) Growing more trees is inadequate to meet the emerging fuel scarcity situation.
(g) Energy conservation through the introduction of superior hardware backed by software measures helps in alleviating the hardship caused by fuel scarcity and promotes welfare for the concerned population.

This is the background against which the mass production of stoves has to be viewed. While mass production techniques have been widely criticised as not being in the interests of the poor in developing countries, unfortunately alternatives to these techniques have not been shown capable of assisting large numbers of the poor and deprived. A serious criticism against the mass production method is its propensity to produce large amounts of luxury goods that do not cater to the basic needs of life. Fortunately for us stoves could be considered as a basic need and, in some form or another, is used by every family in the world. Since most people in the developing countries are said to be needing stoves with superior performance for one reason or another, it seems reasonable to assume that the market for stoves is quite large. Next, due to the indigent nature of the customer, the stove is required to be of low cost. Since the fuel supply situation is quite tenuous, it is also reasonable to state that the market penetration rate needs to be quite high. The mass production system seems to meet these criteria adequately. It is this promise we shall examine in detail in this paper.

Before taking up the issue of mass production of stoves, we will present a state-of-the-art review of stoves at the field level and in the lab. The review will also indicate a few general considerations that determine fuel consumption characteristics, design and construction of stoves. Finally, we present the dissemination experience to-date. The review is not meant to be exhaustive, but merely illustrative.

2. A STATE-OF-THE-ART REVIEW OF STOVES

2.1. A historical perspective

Traditional fires employed in developing countries are not satisfactory from many points of view - this has been known or articulated for at least 40 years now. Improvement of the situation by the introduction of superior hardware has been going on for roughly the same period. The first efforts were made in India by introducing the so-called "smokeless chula" (Raju, 1966) in 1947 or so. This design, or its variants, go by other names like HERL chula, magan chula, etc. As far as can be established at present, neither the design nor its production has received sufficiently close engineering scrutiny. Moreover, there is no report that indicates something like 100,000 stoves per year were introduced. However, a portable ceramic version of magan chula is said to be commercially sold in Madurai (South India) at the rate of about 2000 per month (De Lepeleire et al. 1981). Whether the production capacity has increased in Madurai or whether the work has spread to other parts in India are questions that have no answers at the moment.

The second work in the early period was due to Singer (1961) in Indonesia. Singer constructed several prototypes, and provided test results. But again these are heavy stoves generally belonging to the category of the smokeless chula in India. All such stoves need to be custom built in each individual home and are generally quite large. There are no reports to suggest that the Singer stove took off on any significant scale in Indonesia.

The recent interest in stoves, as a problem worthy of international attention, was triggered by two bench mark papers. The first was the graphic description of the deforestation and its impact on energy availability for the poor by Eckholm (1975). The second was on Lorena stoves in Guatemala by Evans and Wharton (1977). This latter decidedly gave the big push in favour of high mass stoves, particularly those that can be built out of mud by the owner.

The Lorena stove went international instantly. The original paper was heady stuff. It proclaimed a product that could be built anywhere, by anybody, in any size and could be used for cooking any food, burn any fuel so long as it is solid, remove smoke from the cooking environment and to boot save fuel. Barring the last two points, the rest of course could be achieved by the traditional open fire. No matter. With the addition of the last two points, Lorena did sound like a made-to-order product for the international volunteer from the West, disgusted as he/she was with the opulent, wasteful and corrupt ways of his/her society. Lorena held another edge over its rivals from India and Indonesia. One saw the latter presented invariably in the form of a set of engineering drawings that suggested the need for a professional mason equipped with metre scales, plumb-bobs and similar tools of his trade. On the contrary Lorena was presented as free hand sketches with fingers, fists, palms, arms, spoons and ladles as tools of measurement and and construction. This presentation went very well with international aid bureaucrat who on the average is not in tune with the prosaic ways of an engineer and who was also raised on a diet of rhetoric that aid should be channeled to help the poorest of the poor.

In the final analysis, the Lorena stove has survived nowhere else except in Guatemala. It has performed reasonably well in Guatemala due to the excellent institutional support of CEMAT. At other places either such support was unavailable or people working on stoves started looking at other alternatives that seemed to be more attractive. This disappointing experience with Lorena stoves has had a severe backlash against the whole business of mud stove technology. As we will point out in the following section, when properly designed, built by trained manpower, operated and maintained with care, the mud stove can be a useful product.

The description above roughly represents the status of work as of the beginning of 1982. In the next two sections we will present some results of more recent work.

2.2. State-of-the-art: Stove in the field

In this paper we have tried to distinguish between stoves in the field and stoves (including stove ideas) in the laboratory. This division is rather arbitrary and indicates the difference between those that are being used in the developing country kitchens due to the efforts of diverse development groups and stoves that are for most parts just slightly better than conceptual designs.

The bulk of the work at the field level is still confined to mud stoves. But there are some distinct changes that have come about in their design and manufacture in the past three years or so.

The first change is the so-called insert stove. This is a ceramic stove with and without chimney, usually to accept two pans. The insert is made by a professional potter according to specifications provided by the designer and sold through conventional market channels. The user is advised to install the stove and coat it with a mud paste on the outside of the insert. The approach has considerable merits in the sense that the inside dimensions of the stove - the dimensions that control the process efficiency of the stove - can be subject to a regimen of strict quality control. The second advantage is that the training problems associated with owner-built mud stoves are held to modest proportions. The third advantage is that newer design concepts can be brought in to the manufacturers with less effort since fewer manufacturers are involved. All these advantages accrue to the disseminating agency. The user also derives considerable advantages. She/he will get a product with guaranteed performance and will have to spend a minimal amount of learning about how to build a stove. The design is not so prone to damages and as such the maintenance effort is smaller. As compared to the simple ceramic stove, the design is more stable on the ground and will run cooler.

This type of design has been used in Indonesia by Dian Desa, in Sri Lanka by Sarvodaya, and in Nepal by RECAST. The Dian Desa programme has set up two production units with about 5 artisans each producing a total of 1000 stoves per month (Sudjarwo, 1983). The Sri Lankan and Nepalese efforts, as far as the present author could gather, have not reached this capacity.

The second innovation in mud stove construction technology is the use of moulds. These moulds assist in accelerating production and standardizing the quality of stoves. For example in Ethiopia it is claimed that two people take two hours to make a complete stove with gypsum moulds (Makuria, 1983). Similar results have been reported from Peru using wooden moulds (Sangen, 1985), and India (Sarin, 1983). In spite of the advantages possessed by this system of manufacturing, none of these stove programmes have been able to successfully instal more than 100 to 200 stoves. A major bottle-neck appears to be the collection and preparation of the material before the casting process can start.

The third innovation is the ASTRA stove. This is an exceptionally well-engineered stove. It is a three-pan stove with closed combustion chamber capable of accepting long sticks of wood. It uses metal reinforcements for the bridges between pans, a metal cover for the fuelwood box and a metal door for air flow control. The rest of the construction is out of mud. Because of carefully designed passages and the closed combustion chamber the design is capable of achieving an efficiency of 40%. It is said that over 600 of these stoves have been introduced in half-a-year during 1984.

The final example we consider in this section is a metallic stove, the Ouaga metallique. It is a modified version of the so-called shielded fire (Visser, 1981). Unlike the laboratory version, the field version is designed to accept long sticks of wood. Since the combustion chamber is open, the efficiency of this design drops to as low a value as 30% from the 50% that is obtained with the laboratory version. A production level of 60 stoves per days is shown to be reached in a workshop equipped with an electric / welding set, a drilling machine, a pair of /arc shears, and a few measuring devices. Apart from the workshop owner, 4 others were involved - two skilled mechanics and two apprentices. The training required to achieve the above-mentioned production level was 3 days (Bussmann, 1984).

These are some typical new innovations that have been introduced in the design and manufacture of stoves in the past 3 years or so.

2.3. State-of-the-art: Stoves in the laboratory

There have been a few laboratory developments that hold considerable promise for fuel conservation. We shall describe these briefly in this section.

The first is a stove that separates the total process of combustion in two parts. It is essentially a shielded fire with provisions for admitting separately primary and secondary air with independent controls (Krishna Prasad et al. 1985). After the stove is lit, the primary air port is closed and only secondary air is used to burn the volatiles liberated from the wood. During this phase, which continues till the food mixture comes to boil, very little charcoal, that is formed as part of the wood combustion process, will burn. In the second phase - the simmering phase - no fresh wood is added, the secondary air port is closed but the primary air port is opened. With a proper adjustment of the primary air opening, it is possible to keep the food mixture simmering for over an hour (this assumes that the initial phase lasts for about 25 minutes or so). Such a stove has tremendous potential for saving fuel - factors of 3 to 4 can easily be obtained.

A second development is that due to Bol (1985). He has developed the so-called white stove which maximizes the radiant transfer to the pan. The stove is made out of metal but with a light weight insulating layer. The insulation material used goes by the trade name Fibre frax. The stove burns very well and efficiencies of the order of 40% are reported. It has a distinct advantage over the ordinary shielded fire (Visser, 1981) in that it is not tied to a single pan size. There is no doubt that efficiencies will differ with variation of pan sizes. But the flexibility will be obviously appreciated by the users. The insulating material is relatively new on the market and obviously needs to be imported into developing countries. The costs seem to be comparable to that of Ouaga metallique. Like Ouaga metallique it is designed to accept long pieces of wood. However, the fuel loading port is quite small and the wood needs to be split into thin pieces. Possibilities of using alternative insulating materials are presently under investigation.

A third development is an interesting use of the ASTRA stove. We quote from the original paper of Lokras et al. (1983).

"In the first phase, the power output is maintained at a continuous high value. All the pans are brought to boil, I and III pans being interchanged the moment I pan starts boiling. The first phase continues till III pan (now in I pan position) has already boiled for 5 minutes. The II phase starts with the removal of firewood from the stove leaving the burning cinders, if any, on the grate. The primary-air inlet port is closed completely to prevent cooling of the stove by the entrance of ambient air. The pans are left undisturbed till the food is cooked to the desired level. Following this method, SFC was reduced from 150 to 66 g/kg for obtaining 8.66 kg cooked food with the phase I power output of 5.4 kW. The total time taken was 53 minutes (on-period, 28 minutes and off-period, 25 minutes) as against 45 minutes in the constant output mode. In general, for about 8 kg cooked food, SFC value ranged between 60 to 80 g/kg and the total time around 60 minutes, the two phases extending for almost equal periods. The temperature range of food during the second phase was between 98°C (boiling point) and 86°C over a period of 30 minutes after the flames were put off. This clearly indicates that the power output from the stored energy of the stove is enough to maintain the food contents at temperature levels which are adequate for cooking. Also, the use of this stove in the 2-phase cooking mode brings down the SFC from 312 g/kg for the conventional stove to a remarkably low level of 60 to 80 g/kg."

None of these ideas are yet being practised in the kitchens, but hold tremendous promise both in terms of fuel savings and convenience in use.

2.4. Fuel consumption characteristics of stoves

There has been considerable debate on the method of measuring fuel consumption of stoves. My colleagues and I have written extensively about it (for the latest effort on this problem see Bussmann et al., 1985) and there is no point in repeating all this here. What I wish to discuss here is the fuel consumption characteristics of a family of designs.

In order to get an idea of the behaviour of stoves, we will simplify the analysis by considering a single cooking task, say cooking a mixture of 1 kg each of maize and beans in a known quantity of water. The estimation of the water quantity is carried out below for a first approximation.

(a) Part of the water is absorbed by the food. Beans absorb 2 kg of water/kg and maize 1.2 kg/kg. These quantities may vary with species and some research on these would be useful.

(b) A second part is left in the food to provide a saucy mixture and is determined by the recipe. I arbitrarily take it to be 25% of the total weight of the dry food mixture.

(These two need to be validated by experimentation and observation of actual cooking).

(c) The cooking of maize and beans involves a long simmering period. I assume this to be 2 hours (again requires some observation). During this period water will be lost due to steam formation. This is governed by stove design.

Thus according to the above estimate 3.7 kg + a quantity accounted for by evaporation of water is required to cook 2 kg of maize and beans.

The stove design is characterized by 3 principal quantities as far as its fuel consumption is concerned. These are given below.

(a) P_{max} or the maximum power usually measured in kW is the maximum burning rate permitted by the stove. For air-dried wood with a heating value of 15 MJ/kg, a burning rate of 1 kg/hr gives a power of 4.167 kW.

(b) r, the turn-down ratio, determines the minimum power, $P_{min} \equiv P_{max}/r$, that a stove can deliver.

(c) η, the efficiency, is a function of the design. For a well-matched pan-stove combination, η does not vary very much with P and in the following will be assumed constant.

This information is sufficient to estimate the fuel consumption of different stoves. Table 1 presents the estimation for a whole family of designs and the Appendix gives the formulas employed for arriving at these estimations. Table 1 shows various design possibilities to achieve fuel economy. D_0 is our reference design - the prototypical traditional fire. Efficiency has been assumed to be 8% and r is taken to be 1.5 from our experience in the laboratory. It is easy to show with the formulas in the Appendix that this stove uses 70% of the total fuel in the simmering period for this cooking task.

D_1 is a stove design that concentrated on efficiency improvement without concern to other aspects of stove design. Efficiency doubled, but fuel consumption dropped by just 10%. This is the technical basis for the rather generic comment against efficiency as a suitable indicator for the fuel-consumption characteristic of a stove. There are other problems with the design. One has to start with 8 kg of water as against 6 kg. If not, the food gets burnt! There is a marginal gain of 8% in cooking time.

D_2 is essentially D_0 redesigned to operate at half the power level of D_0. Nothing else is changed. The fuel consumption is cut by 40%. There is a penalty to be paid - the cooking time increases by about 15%. In order to achieve the lower power levels, wood needs to be split to smaller pieces. Lastly, one has to start with smaller quantity of water. Otherwise, the cooked food will be watery and moreover, the promised fuel economy will not be realized.

D_3 changes the turn-down ratio only; everything else same as in D_0. Fuel savings is achieved without the penalty. But the wood has to be cut into shorter lengths since higher turn-down ratios are possible to be achieved only through closed combustion chamber and air-control. The stove is more expensive and operating instructions are essential.

D_4 combines the virtues of D_1 and D_2. It saves 50% fuel with no time penalty. /This clearly shows that it is insufficient to merely double the efficiency for achieving a saving of 50% fuel for this cooking task./ D_5 combines the principles of D_1, D_2 and D_3 into a single unit and thus saves fuel by a factor of 3.3. ~~Other~~ Disadvantages are the same as those in the designs D_2 and D_3. HD

Stove designs → / Quantities ↓	D_0	D_1	D_2	D_3	D_4	D_5	D_0^*	D_5^{**}
P_{max}, kW	12.5	12.5	6.25	12.5	6.25	6.25	12.5	6.25
r	1.5	1.5	1.5	3	1.5	3	1.5	3
Efficiency, %	8	16	8	8	16	16	8	16
m_e, kg	2.13	4.25	1.029	1.06	2.13	1.06	0.355	0.53
t_b, minutes	35	23	59	29.5	35	29.5	26	26.7
m_f, kg	5.75	5.16	3.47	3.47	2.875	1.7375	1.95	1.17
t_c, minutes	155	143	179	150	155	150	46*	89

Table 1. Fuel consumption characteristics of different stove designs.

Notes: (a) Simmering period: 2 hours.
(b) D_0^* is D_0 with a haybox and 20 m simmering period on the stove.
(c) D_5^{**} is D_5 with presoaked beans and 60 m simmering period.
(d) * + haybox time.
(e) m_e ... mass of water evaporated; t_b... time to boil; m_f ... mass of fuel used; t_c... total cooking time.

D^* is a traditional fire, but uses a haybox. Fuel saving is nearly as large as in D_5. This approach requires operator training and some planning of cooking. The major advantage is that there is no need to tend the fire for two hours and thus seems to be worth the while of the cook to readjust her work schedule.

D_5^{**} is D_5 but the beans and maize have been soaked overnight cutting the simmering period by half and fuel consumption shows a dramatic reduction by a factor of 5! Again some planning and some rescheduling of household work will be required. There are some questions about toxicity of the beans when they are not cooked long enough and the water quality for soaking. These require more investigation.

There is ample evidence now available to suggest that much larger fuel savings than D_5^{**} is feasible. Of course one can quibble about the 8% efficiency I have assumed. But for long cooking sessions, the problem of tending the fire becomes substantial and higher efficiencies would be very difficult to achieve. In fact Cáceres (1984) points out that families with 11+ girls achieve something like 40% fuel-savings by detailing the girl to tend the fire.

This discussion shows that there are many ways to achieve fuel economy and stove builders have unduly concentrated on efficiency improvement. To beat this there is a tendency to suggest that the SFC is a universal attribute of a stove. That this is not so is clearly brought out in table 2. SFC is a strong function of the type of food to be cooked. The protagonists of SFC suggest that automobile manufacturers do not indicate the efficiencies, but SFC's. This is true. But this argument ignores an important point. The automobile manufacturer provides three SFC's - one for a speed of 90 km/hr, a second at 120 km/hr and a third for city driving. If SFC has to be used, then such an approach needs to be devised.

We should like to quote another field result from Guatemala (Cáceres, 1984). The families were able to start the cooking of maize and beans (which is said to take three hours to cook) the previous night and leave it overnight. The food was nearly ready to be served in the morning before the husband went to work. Apparently the partial effects of stored heat (which probably was small) and haybox princple (probably the pan was partially sunk into the stove body) contributed to this. This had twin advantages of fuel savings and comfort since the woman ~~needs not to have~~ does not need to get up some four hours before the man leaves for work or stay up for longer hours in the night. These advantages do not necessarily show up in laboratory tests.

The detailed results presented in table 1 could be compactly incorporated into a Stove Diamond prepared by Bussmann (1984) along the lines of a Maize Diamond used to demonstrate the merits of superior agricultural practices. Fig. 1 shows the diamond for the cooking task. It clearly shows that the mere introduction of

	Lentils	Red beans	Black beans
t_s, s	3600	7200	10,800
m_e, kg	1.06	2.12	3.18
$m_{w,f}$, kg	3.06	4.62	5.68
$m_{f,b}$, kg	0.803	1.325	1.603
$m_{f,s}$, kg	2.000	4.000	6.000
m_f, kg	2.803	5.325	7.603
SFC (kg of fuel/ kg of food)	0.93	1.52	2.17

Table 2. Specific fuel consumption of design D_0 for three cooking tasks (1 kg each).

a piece of hardware will not achieve the desired objectives. One needs to combine it with appropriate inputs of software ideas. Of course the user could be greatly assisted by the designer by incorporating suitable features in the hardware.

This brings us to other aspects of product design that need careful consideration. These become important in devicing mass-production systems. Some of these have been pointed out in an earlier work by the author (Krishna Prasad, 1983). Others can only be found out by inputs from the experience derived from the sales side of the stove enterprise.

3. THE PROSPECTS FOR MASS-PRODUCTION OF STOVES*

3.1. Introduction

FAO projections (1981) of populations living in regions of acute scarcity or deficit fuelwood supply suggest that the customers for improved stoves will be about 500 million or so in the year 2000. This number can be thought of as an upper limit. All present prognostications indicate that the number is unlikely to be less than 100 million.

The 'demand' projections have to be seen in the context of the performance of existing stove projects. Cáceres (1984) compiled the information available on the numbers of stoves introduced in different countries. Table 3 is an extract from this compilation. The total number adds up to about 50,000. There are two missing elements in this compilation. The first concerns the growth of introduction rate with time and the second has to do with the growth rate of stove populations with time. It should be emphasized that these two are not identical. The first is determined by the expansion of 'manufacturing' capacity and matching of this capacity with 'marketing' ability. The second element is ~~determined~~ /in addition governed/ by the concept of the half-life of a stove, originally introduced by Tim Wood (1982) and worked out in detail by Krishna Prasad (1983).

Information on the first missing element is available for a project run by Safai Vidyalaya in the state of Gujarat in India. Table 4 indicates stove introductions by this organization in the years 73/74 to 82/83 (Skutsch, 1985). A total of about 35,000 were introduced in the 10 year period. The table clearly shows an oscillatory behaviour of the introduction pattern. It remains to be seen whether an upward swing will follow the slump in the years 81/83 and if that swing will be larger than the previous cycles. The latter may well be realized given the initiatives taken by the Government of India in the stove field (1983).

As far as the author is aware, there has been so far no systematic effort by any project to collect data on the second missing element mentioned earlier.

Due to the paucity of data and whenever data are available, due to their unreliability, the whole work on stoves has been subjected to a furore of criticism. The best known of this type of work is that of Earthscan (Foley & Moss, 1983). Design, construction, economics, project planning, execution and monitoring have all been points on which critics have attacked stoves. A more balanced assessment is that due to Manibog (1984), who, after examining all aspects of the problem, comes to the conclusion that harsh judgements are too premature. The efforts to-date, which in the first place were never intended to cater to mass markets, have taught a number of valuable lessons in technical aspects of stoves on the one hand and the planning and execution of stove projects on

---

* Stoves in this section connote both wood and charcoal stoves.

Sl. no.	Country	Year initiated	Materials/types	Number built
1.	Guatemala	1977	mud massive	7000
2.	Indonesia	1978	mud light	3400
			ceramic liner	6000
3.	Sri Lanka	"	mud + ceramic	2140
			ceramic liner	4000
4.	Burkina Faso	"	brick + cement	4000
5.	Nepal	"	mud light	1200
			ceramic liner	5300
6.	Niger	1979	mud	1000
7.	Senegal	1980	mud small	5000
8.	Ethiopia	"	pressed mud	2000
9.	Kenya	1981	mud ceramic	1000
			metal + ceramic	5000
10.	Mali	1981	mud	1000

Table 3. Dissemination programmes of woodstoves in developing countries.

Source: Căceres (1984)

Year	Stoves introduced
1973 - 74	1288
74 - 75	1091
75 - 76	672
76 - 77	5191
77 - 78	899
78 - 79	4999
79 - 80	6479
80 - 81	6631
81 - 82	4345
82 - 83	2775

Table 4. Stoves introduced by Safai Vidyalaya in Gujarat

Notes:
(a) Safai Vidyalaya is an organization promoting sanitation among untouchables and involves seven diverse activities.
(b) Source: Skutsch (1985)

the other hand. Thus at present there is some kind of uneasy truce between the two camps of stove purveyors and their critics.

With the 'demand' postulated on the basis of FAO projections, one could justifiably state that the attempts depicted in tables 3 and 4 cannot be expected to meet this demand. This leads one to believe that there is a case for new initiatives. We will examine one such initiative - the mass production technique. The nature of the system to be installed is strongly dependent on one parameter - the market the system has to serve. The market also determines the design type. As a first approximation, we will simplify the analysis by restricting the design type to metal stoves.

3.2. Market stratification

Table 5 makes an attempt at estimating the market size for metal stoves in Africa. Populations in 1982, projections for the year 2000 and the 1982 urban population have all been taken from the World Development Report (1984). The report mentioned above does not provide urban population projections in the year 2000. We have taken it to be the arithmetic average of two values. The first value is derived from the assumption that the urban population grows at the same rate as the total population. This value will definitely be too low if we take the experience of the past 25 years. The second value is derived from the assumption that the urban population grows at the same average rate that prevailed in the years 1970 - 82. We believe that this growth rate will not be feasible in the coming period. There is some support for this belief. The World Development Report mentioned earlier shows that there is a slow-down of urbanization in the years 1970 - 82 compared with the decade 1960 - 70. This is not a surprising outcome if we note that most of these countries have experienced considerable decrease in economic growth and a few of them even show negative growth. In the absence of [redacted], urban growth will also slow down. Thus the choice of the arithmetic average of these two extremes is a reasonable guess. There are two reasons for taking this trouble. In urban areas there is a reasonably organized fuel-wood market and thus there is a cash incentive for buying fuel-saving stoves. The estimates for 2000 will be necessary because the market penetration rates are such that stoves will not be bought instantaneously. We will say more on this point later.

/economic growth/

The total stove market for a given country has been estimated on the basis of the following assumptions: the average family size is 7; each family needs two stoves (since we are considering single-pan metal stoves); the life-time of a stove is 2 years. This last choice has been dictated by three considerations. A longer life-time will inevitably involve superior materials and consequentely superior production facilities. Inevitably such a stove will cost more with an adverse effect on the possible market size (thus we might lose the battle for mass production even before

Sl. no.	Country	Population ($x 10^6$)				Stove market in 2000 ($x 10^6$)		
		Total		Urban		Maximum	Urban	Probable
		1982	2000	1982	2000			
	SAHEL							
1.	Chad	4.6	7	0.87	1.9	1.0	0.27	0.45
2.	Mali	7.0	12	1.33	2.6	1.7	0.35	0.77
3.	Burkina Faso	6.5	10	0.71	1.6	1.4	0.21	0.64
4.	Niger	5.9	11	0.83	2.2	1.6	0.87	0.71
5.	Senegal	6.0	10	2.04	3.5	1.4	0.44	0.64
6.	Sudan	20.2	34	4.65	10.3	4.9	1.3	2.2
	EAST AFRICA							
7.	Ethiopia	32.9	57	4.93	11.0	8.1	1.4	3.6
8.	Malawi	6.5	12	0.65	1.6	1.7	0.26	0.76
9.	Rwanda	5.5	11	0.27	0.62	1.6	0.08	0.72
10.	Burundi	4.3	7	0.09	0.25	1.0	0.02	0.45
11.	Uganda	13.5	25	1.21	2.2	3.6	0.27	1.6
12.	Tanzania	19.8	36	2.57	7.9	5.1	1.0	2.3
13.	Kenya	18.1	40	2.71	7.8	5.7	0.98	2.6

Table 5. Stove market sizes in several countries of Africa.

Notes: (a) Population data from World Development Report (1984).
(b) Stove market figures estimated on the basis of urban population estimates (see text).

we start. Finally, such a built-in obsolescence will not only provide time for the engineering fraternity to come up with better designs than the ones contemplated now but also hold the capital costs of production systems to modest proportions.

If we assume that the stove design we are considering can be sold only in urban markets, the market size shrinks dramatically. These estimates have been based on the assumptions that the family size is 6 and only ¾ of the families in urban areas will use fuelwood or charcoal, the rest using fossils for cooking. Some recent studies in Guatemala (Căceres, 1984) and Mali (Krist-Spit, 1984) show that the market for stove designs of the portable type would be 60% and 45% respectively. We have used the latter number as being more representative of Africa in deriving the figures in the last column in table 5.

What has been considered so far is the fragmentation of the market due to the presence of national boundaries and the rural/urban split. There are two other forms of market division illustrated in table 6. The table depicts the fuelwood consumption in Bangalore, India, according to household incomes and applications of cooking and water heating (Reddy & Reddy, 1983). The table reveals many interesting features. In an overall sense, 45% of all households use fuelwood for either water heating or cooking and water heating. While 25% of the total number of households use fuelwood for cooking, all the 45% use it for water heating. The Reddy & Reddy paper did not show the fuelwood consumption for cooking and water heating separately for those households that use fuelwood for both cooking and water heating. For a first approximation we assume that the fuelwood demand for water heating remains the same for both classes of users at each income level. With this assumption it is easy to show that 67.5% of all domestic use of wood is for water heating. The data also show that the number of households using fuelwood for cooking drops rather sharply as one moves up the income scale. Except 3½% of the population who are the top income earners, a significant proportion of the households in the higher income groups rely upon fuelwood for water heating. This is not surprising if one notes that there are only two types of water heaters on the market - the electric boiler and the wood heater. The former is very expensive both by way of appliance cost and energy cost.

The analysis above shows that Bangalore, a city of 2.9 million people, has at best a market for 143,000 woodburning cookstoves of the type we are considering, while it needs 267,000 water heaters. Reddy and Reddy also estimated the number of households relying on woodfuels in urban Karnataka on the basis of their survey of Bangalore (which is the capital city of the state of Karnataka). These estimates are shown in table 7. It is seen that the total number of households using woodfuels is about

Annual per capita income 1982 US $	Number of households in range (x 10^3)	Cooking and water heating		Water heating only	
		Number of households (x 10^3)	Fire-wood use tons/HH/Yr	Number of households (x 10^3)	Fire-wood use tons/HH/Yr
≤ 133	190	87.7	1.713	42.6	0.920
134 - 199	75.5	24.0	1.666	14.7	0.932
200 - 265	92.8	16.9	1.675	16.6	0.890
266 - 332	105	10.4	1.883	22.4	0.820
333 - 399	51.1	1.28	1.890	19.6	0.832
400 - 465	59.5	.832	1.879	8.9	0.763
≥ 466	21.4	--	--	--	--
Total	595	143		124	

Table 6. Stove market stratification in Bangalore, India.

Notes: (a) The original data on incomes were in rupees. Conversion rate: US $1 = Rs. 9.
(b) Household numbers have been rounded to three significant figures; thus totals will not tally.
(c) Source: Reddy, A.K.N. & Reddy, B.S. (1983).

Type of city/town (Number)	Population ($\times 10^3$)*	Number of households ($\times 10^3$)*	Percent using fuelwood	Number of fuelwood users ($\times 10^3$)	Fuelwood consumption tons/day
Bangalore	2,913	595	45	267	970
Class I: ≥ 100,000 (17)	6,277	1,281	45	576	2,090
Class II: 50,000 - 99,999 (11)	692	141	60	85	308
Class III: 20,000 - 49,999 (64)	1,902	388	75	291	1,057
Class IV: 10,000 - 19,999 (100)	1,471	300	90	270	981
Class V: 5,000 - 9,999 (42)	308	62.8	100	62.8	228
Class VI: ≤ 5,000 (16)	61.8	12.6	100	12.6	46

Table 7. Estimates of urban stove market in the state of Karnataka.

Notes: (a) Original data rounded to 4 or 3 significant figures as the case may be.
(b) Total population of Karnataka: 47 million.
(c) Percent urban population: 28.91.
(d) Source: Reddy, A.K.N. & Reddy, B.S. (1983).

1.56 million in the state of Karnataka. At a rough guess, this means a market size of 1.56 million water heating devices and 1 million cookstoves.

The population of Karnataka is about 47 million corresponding to about 8 million households. It is probable that the rural areas of the state can provide an additional market for about 1 million mass-produced cookstoves.

There is yet another type of stratification that can be discerned in stove markets. Such a stratification is based on pan sizes. Pan sizes vary to suit the variation of quantities and types of food cooked by different households. Quite a number of tabulations of pan sizes available in different countries have been prepared in the recent past. We shall give one example from Rwanda in table 8 (Visser, 1985). Three different manufacturers make 31 different sizes of pans among them. All these pans are made out of pressed aluminium and wall thickness varies with the manufacturer. Stove theory says that the stove power should be matched to the pan size for maximum efficiency. Thus 31 different stove sizes are required, even though they may belong to the same family of designs. From the mass production point of view such a large amount of sizes is simply an invitation to disaster. A compromise is to state that the theory will not be obeyed to its last letter, but only in spirit. By adopting this, we can reduce the size variety to just 6. In fact even this variety is unnecessary as was shown by a household survey in Kigali, the capital city of Rwanda. The pan sizes used in the households followed a normal distribution with 95% of the households using pans in the range of 16 to 32 cm diameter and 68% using pans in the range of 20 to 28 cm diameter. For a start it appears useful to concentrate on stove sizes III and IV and when the market picks up move on to sizes II and V. Stove I and VI should be considered as special purpose stoves and custom built with obviously higher prices.

The detailed description above suggests that the total stove market reveals several levels of stratification. The first level of stratification occurs along national boundary lines in Africa and probably along state boundary lines in a large country like India. Even if one were to succeed in coming to a political arrangement that will permit stove marketing across national boundaries, the transport costs will put the prices up so that a centralized mass production system will find the market non-existent in the time-horizon we are considering. Thus we will be forced to live with national production systems and perforce smaller markets. On balance such a system - at least under the prevailing circumstances in developing countries - is likely to prove of benefit to a larger number of people.

Stove size	Cyangugu		Tanzanie		Kigali	
	Diameter	Height	Diameter	Height	Diameter	Height
I	14.1	5.5				
II	15.6 17.1 18.6	6.6 7.2 8.2	16.2 18.0 19.1	6.8 7.3 8.1	18.9	9.4
III	20.1 21.6 23.1	9.3 10.3 11.0	20.5 21.7 23.1	9.0 9.8 10.2	20.2 21.5 22.8	10.3 10.8 10.9
IV	24.6 26.1 27.6	11.6 12.3 13.6	24.2 25.6 26.8	11.3 11.8 12.7	24.0 26.0 27.2	12.2 13.1 13.5
V	30.1 33.1	14.5 15.1	28.8	12.9	28.5	14.4
VI	36.1	16.2				

Table 8. Pan sizes in Rwanda.

Notes: (a) All dimensions in cm.
(b) Cyangugu, Tanzanie and Kigali are trade marks of different manufacturers.
(c) Source: Visser (1985).

The second level of stratification is that between urban and rural markets. We advance the thesis here that large towns have faily strong commercial relations with villages surrounding them. Thus it is to be expected that a certain proportion of rural population will benefit from the technology. This proportion will probably not exceed the economic top-third of the rural population. Such a concentration on urban area will definitely be treated as anti-rural development. However, study after study has shown that the urban demands for fuelwood, charcoal and other timber products, rather than rural fuel use, have been responsible for much of the deforestation in the past two decades (see for example Beijer Institute, 1982 and Reddy & Reddy, 1984). Thus the mass production approach has something to commend for its adoption in terms of environmental protection.

The third type of stratification is based on the economic status of the households. Thus stoves manufactured exclusively for the poorest of the poor, who form 61% of the total number of households in Bangalore, might miss the 39% of the market. A better approach would be to design and market stoves for low, middle and high income groups. If an integrated production and marketing system could be designed, it is conceivable that the stoves for middle and high income groups could be sold at sizable profits while capturing the market for low income groups by selling stoves at low costs maybe incurring a small loss. This type of cross subsidy in a product line has not been a feature in the stove projects conceived so far.

The fourth level of stratification arises due to two distinct end uses - cooking and water heating. Hot water for most parts in the state of Karnataka is used for bathing. Thus hot water heaters need distinctly different designs than cookstoves. Cookstoves are small devices requiring rigorous standards of control while hot water heaters are large with pans of capacity 50 litres or more with no control requirements. Probably a majority of the water heaters are semi-open fires in this state. These heaters will receive less attention/ and will thus show poorer efficiencies. /While in operation/ Efficiency imrpovements in this application can come about through design of woodburning systems that require attention of an operator less frequently, and proper arrangement ot heat transfer surfaces. Of course the stratification of this type arises in many other situations. We mention two other examples. In north-west India, Pakistan, Afghanistan and many middle-eastern countries people bake a type of bread which goes by the name of 'Nan' in India and Pakistan. This bread is traditionally baked in clay ovens. These are reputed to be tremendously inefficient in their use of fuel (Micuta, 1984). In Ethiopia the staple diet resembles a large pancake known as injera baked on clay plates. The problem in connection with baking injera is its size - 60 cm in diameter. It is customarily baked in batches of 20. The size of a normal domestic metal cookstove - the preferred model in this study -

can rarely be expected to handle a frying pan larger than 30 cm. The reason for this is that the cost of a metal stove dramatically increases with its size. An alternative is to reduce the diameter of the injera, say from 60 to 30 cm. Such a reduction in the injera size will mean that one has to bake 80 injeras per batch against the present 20 injeras. Consequently the cooking time will increase from the present 100 minutes to something like 320 minutes. This is an unacceptable option. A different type of stove has to be designed for this task (Sielcken, 1985).

This discussion reveals that, while it is possible to conjure up visions of mass production on the basis of global markets, in reality the market is highly fragmented.

3.3. Market penetration rates

The design of a production system is strongly governed by its manufacturing capacity. The manufacturing capacity is governed by the estimates of the total market for the concerned stoves. In the previous section we have provided estimates for this for one-pan metal stoves. There is a second factor that governs the manufacturing capacity. It is the rate of market penetration. It is simply foolhardy to assume that the total market will be reached with the installation of the production system. It will take many years before the product reaches every potential user. It is this factor we shall address in this section.

Data on this subject and expertise as well, are in the hands of large multi-national corporations. Even in the well-developed information system of industrialized countries, it requires an enormous effort to put together a coherent picture of the market penetration rates of different classes of products. The only work that was easily accessible to the author was that of Marchetti on the automobile (1983). The work examines the evolution of the car population, i.e., the number of cars on the road. The latter is represented by three parameters describing the localization of the processes in time, the rate of the process and the saturation level. The results of his work are tabulated in table 9.

A shocking revelation of the analysis is that, to quote Marchetti, "the launching new models, introducing new tricks, and slashing prices, is of no consequence in the determination of owning a car, which seems to follow a perfect path, controlled perhaps by the usage values of the car that are not influenced greatly by a new shape or new bumpers". In essence Marchetti assumes that "there is a pool of good ideas in manufacturing, product design and advertising that are dormant and are picked up and used when (and only when!) there is a menace of falling behind the perceived path". And finally as far as the competition among the different companies is concerned, Marchetti quotes Red Queen saying to Alice, "Now <u>here</u>

Sl. no.	Country	Saturation level (x 10^6)	50% Penetration date	Time constant (years)
1.	United States	200	1977	79
2.	Canada	20	1979	58
3.	Sweden	4	1965	47
4.	Austria	3.2	1978	36
5.	United Kingdom	17	1965	30
6.	France	20	1967	30
7.	West Germany	19	1965	21
8.	Italy	20	1970	22
9.	Japan	21	1971	12

Table 9. Market penetration of automobiles in several industrial countries.

Notes: (a) Saturation level is calculated on the basis of extrapolation of time series data.

(b) 50% Penetration data implies that, for example, there were 100 million cars registered in 1977 in the United States.

(c) Time constant is the time for the car population to grow from 10% to 90% of the saturation level.

(d) Source: Marchetti (1983).

Sl. no.	Country	Refrigerator			Clothes washer			Dish-washer			Electric rice cooker		
		Level %	Number x 10^6	Year	Level %	Number x 10^6	Year	Level %	Number x 10^6	Year	Level %	Number x 10^6	Year
1.	France	95	17.7	1980	73	13.6	1980	22	4.1	1980	--	--	--
2.	Italy	94	15.5	1980	75	12.4	1980	10	1.6	1980	--	--	--
3.	Sweden	95	3.4	1979	80	2.9	1979	17	.61	1979	--	--	--
4.	U.S.A.	100	82	1978	80	66	1978	50	41	1978	--	--	--
5.	Taiwan	85	--	1978/9	--	--	--	--	--	--	90	--	1978/9
6.	Bangkok*	82	--	1980	--	--	--	--	--	--	84	--	1980

Table 10. Saturation levels of domestic appliances in some countries.

Notes: (a) Number correspondends to saturation level percentage (calculation by the author).
(b) Average family sizes in Taiwan and Bangkok was not available and hence number could not be calculated.
(c)
(d) Source: Schipper & Ketoff (1982).

you see, it takes all the running you can do to keep in the same place". (Emphasis from Marchetti's paper.)

I can hear loud protests against bringing in the automobile - such a large, complicated and expensive product - while discussing a small, simple and cheap product like a stove. I have tried to locate similar information for other products particularly at the household level, but the best I could come up with was the work of Schipper and Ketoff (1982). They provided information on the percentage saturation level and the date on which it was reached for several appliances used at the household level for six countries. The reference does not provide information on the absolute values of the saturation level nor does it provide the rate of growth of population of the appliances. The former can be inferred from the average number of people occupying a dwelling (the information on which is available from the Schipper - Ketoff paper) and the population figures (say from the World Bank). I have done this for three products, namely, the refrigerator, clothes washer and the dish-washer in common use in Western Europe, and the electric rice cooker. The information is tabulated in table 10. Several observations on this table are in order. The saturation limit in this work has been implicitly assumed to be equal to the total number of households. This is nearly true for refrigerators, plausible for clothes washers and to be doubted for dish-washers. For Bangkok the approach needs to be doubted; the survey was based on families that had children enrolled in secondary schools. If time-series data were available, then one could have obtained the three-parameter logistic of Marchetti. A second observation is connected with dates corresponding to the saturation levels. If we assume that before the second World War very few families had refrigerators and if we put 1947 as the approximate date of commencement of reconstruction, it has taken 33 years to approach the 95% level of saturation. The final observation is the size of the market for these products. They are at least an order of magnitude larger than the total expected stove markets in many African countries (see table 5).

While one can question the relevance of much of the information on mass-produced products in industrialized countries to the stove dissemination programmes in developing countries, it is the author's contention that one can draw a number of useful lessons from it. Firstly, the rate of market penetration of household appliances needs to be measured in decades (i.e. moving from 10 to 90% of saturation levels) and not in years. Moreover, the data in tables 9 and 10 pertain for most parts to the years after 1945 - a period in which the presently industrialized nations enjoyed an unprecedented growth. This growth was fueled by an industrial and commercial system that was nearly in place, the ubiquitous hire-purchase system that encouraged the population to use the technology and the last but not the least cheap energy. None of these factors have operated in the developing countries since 1977 - our date of commencement of the stove work on an international scale. Thus the critics of stove projects have not taken these into account and their criticisms should not be just considered premature but should be judged as ill-informed.

Secondly, the Marchetti ecologically deterministic model to be applicable for the present problem needs another parameter to be added to it - a parameter that accounts for the overall climate of economic growth. The biological example that supports this line of thinking is that it is not easy to imagine the duplication of the diversity and extent of species prevalent in a tropical rainforest, say in the region above the Arctic circle in a natural manner. This is the essence of the appropriate technologists' argument. However sound this argument may be, for greatest good to be achieved, it is imperative to achieve an integration of good ideas in manufacturing, product design and advertising. Moreover, the field of work is threatened with extinction if one restricts onself "to life at the lower levels" that have short life cycles. The whole business requires the support of some giant trees to retain its identity and perhaps even survival. Finally, we need to take serious note of Red Queen's advice to Alice: in order not to let the environmental degradation slip further, we not only have to explore other avenues but also do it rapidly.

This section brings forth the twin aspects associated with the adoption of a new technology like stoves. The market levels postulated in section 3.2 cannot be achieved instantaneously, but requires a finite time. To hold this time to modest levels one needs to avoid dogmatic beliefs and adopt a few of the practices of modern industrial technology.

3.4. The spin-off effect

We now turn to a totally different aspect of woodburning technology. Reddy and Reddy (1983) list in all 11 classes of wood users in Bangalore (see table 11). The domestic users consume the largest share in the total tally. But yet a significant 22.5% of wood is used in the institutional, commercial and industrial sectors. This is nothing special to Bangalore. Taken as a whole, 20% of all wood burnt in India is in the non-domestic sector (Guha Thakurtha, 1984). Similar situation is reported from African countries. Much of this wood is reputed to be burnt in highly inefficient installations.

The domestic and non-domestic users of wood pose different types of challenges as depicted in the diagram of figure 2. As we move down the diagram the per unit fuel consumption increases and along with this the technical complexity increases On the other hand as we move up the diagram, the complexity is seen mostly in terms of dissemination.

Consumer type	Number of units	Consumption tons/day	Percentage of total	Cumulative percentage
Households	267,134	970	77.5	77.5
Dyeing factories	175	62	5.0	82.5
Bakeries	1,850	55	4.4	86.9
Hotels	605	48	3.8	90.7
Industries	n.a.	47	3.8	94.5
Choultries*	297	24	1.9	96.4
Hostels	162	24	1.9	98.3
Cremation grounds	48	10	0.8	99.1
Canteens**	35	4.5	0.4	99.5
Road building	--	4.0	0.3	99.8
Soap factories	25	3.0	0.2	100

Table 11. Fuelwood users and their consumption in Bangalore, India.

Notes: (a) * Hall used for weddings and other social/religious functions.
(b) ** Fuelwood used in addition to gas and electricity.
(c) Source: Reddy, A.K.N. & Reddy, B.S. (1983).

The experience of the modern industrial system tells us that the technical innovations used in larger systems tend to creep into diverse household goods. One could expect a similar spin-off effect to be observed while working with large wood-burning installations. If one assumes that there is no genuine option to wood-burning devices in the foreseeable future in developing countries, the dissemination momentum can be maintained only through constant additional technical inputs. In view of the slowness of the dissemination process, it will be difficult to economically justify the technical interventions on a significant scale. Thus if we add the non-domestic sector to the picture, the use of the technical manpower will be more optimal. Moreover, the facts that there are stronger economic incentives, better managerial control and fewer numbers in the non-domestic sector than in the domestic sector, the total impact on the demand-side of the fuelwood could be expected to be of the same order as that obtained on the domestic stove front at least in the next ten years or so.

Thus there is a primafacie case to expand the activities of the woodburning stove movement to cover the non-domestic sector. It will provide an important boost to the whole business.

3.5. The fuel delivery system

The quality of the fuel controls not only the design of a stove but also its performance. The relationship between the two corresponds roughly to the relationship between the oil and automobile industries. If we note the fact that in urban areas wood is a commercial product, it is feasible to excercise some level of control on its quality. The quality comes in two levels. The first level is in terms of moisture content of the fuel. It should be feasible to decree to sell only air-dried wood. The enforcement of such decrees would be greatly assisted by actively forming consumer lobbies.

The second aspect concerns the increase in efficiency of stoves. Dramatic increases in efficiencies are feasible only with closed combustion chambers. The ASTRA stove approach is not feasible for the type of single-pan metal stove we are considering on account of high cost. Efficiency increases go hand in hand with decreases in combustion chamber sizes. Moreover, superior hardware will result in using smaller quantities of wood for similar tasks. These three factors imply that wood needs to be split into smaller sizes and cut into shorter lengths. There is little point in urging the consumers to do it. They simply do not have the appropriate tools for the job and it is unreasonable to expect them to invest scarce resources on tools. Thus this needs to be organized at the fuel sellers' end. In fact most of the existing stoves - without any new hardware or design principles - will show significant fuel savings with the use of air-dried wood cut into short, thin pieces. In particular if one is going in for mass-produced metal stoves with superior performance, it is imperative to organize the fuel delivery system with care. Assuming that for most parts the fuel markets exist only in urban areas, the splitting and cutting can be done either by machines or by paid labour equipped with much better tools like axes and saws. No doubt the fuel costs will go up. In the opinion of the present author, the resulting fuel savings will be more than adequate to compensate for the higher fuel costs.

The aspect of fuel delivery system has received very little attention in the total rhetoric that has been going on in the field of woodstoves in the 7 to 8 years. Needless to say, nothing has either been done or initiated on the ground as far as fuel delivery system is concerned. If mass-production of stoves is being considered as an option, then the installation of a fuel delivery system should receive priority attention.

3.5. The production system

The design of the production system is decided by two principal factors: (a) the design of the unit; and (b) the number of units to be made.

The design of the unit is characterised by:
(a) the material out of which the stove is to be made;
(b) whether the stove has a chimney or not; and
(c) the range of sizes required.
We will discuss the influence of each of these characteristics on the production system.

The heavy stove - be it made out of brick, cement or mud - has to be built in-situ in each home and does not qualify for mass-production. This leaves the two other contenders - ceramic and metal. The ceramic stove can be shaped out of hand, or be made using a potter's wheel and hitherto unconsidered process of a pressed design in the stove field. The last is the one used in Western Europe for large scale production of flower pots. This would be the one that comes near to a mass production system, but there is no experience as yet to adapt this technology to stove production. As per the state of play now, the first two are the choices. Most pottery work in developing countries at present takes place at the artisanal level. Dian Desa's work in Indonesia shows the set-up required to combine the work of several artisans under one roof to reach production levels of 1000 stoves/month. In principle there is no reason why this method could not be expanded to 50,000 stoves per year.

Metal stove manufacture provides a wide variety of possibilities. A popular approach is to use the informal sector and primarily rely upon waste metal like used oil drums. It is really an attempt to use the skills available now in making things like charcoal stoves in East Africa and woodstoves in West Africa. At the present moment there appears to be no documented information on the number of artisans involved, and the annual production level of these artisans. This method of production uses hand rivetting and seaming techniques. Generally speaking, it should be possible to mimic the work of Dian Desa with this sector. In fact according to Sielcken (1985) a co-operative of fifty metal workers is in place in Addis Abeba. A group of six from this fifty can be used to produce anywhere between ten and fifteen thousand stoves per year.

The other class of alternative is to use an industrial workshop as Bussmann (1984) reports. The capability of such a workshop was shown to be a minimum of 15,000 stoves per year. The system uses electric arc welding and new steel sheets.

There are three principal elements in any mass production system that need to be carefully worked out. These are: (a) raw material supply on an assured basis; (b) productivity of labour; and (c) quality control. None of these elements can be said to be in place in any of the experiences or ideas suggested above. Unless the size of the systems increases by factors of 3 to 5, these elements cannot be introduced in a cost effective manner. Assured material supply will prove to be a big bottle-neck for ceramic stoves and new steel sheet for metal stoves. Ceramic stove factories producing 25 - 50,000 stoves per year can only be located in regions where reasonable quality of clay is available. The best way to determine this is whether the region possesses brick and tile making industries. If they do, the job is much simpler. If not detailed estimation of the material quality, its extraction and supply becomes necessary.

With regard to metal, the question separates into two parts. The informal sector - recycled metal path can in principle be encouraged to adopt newer designs without affecting too seriously the material supply situation. Unless co-operatives along the lines of Addis Abeba are available, it is unlikely on the one hand that productivity increases will be registered (because of a lack of proper tools) and on the other hand quality will be maintained. The new metal path is beset with problems of import in most African countries. Since the import is under government control because of foreign exchange problems, a parallel trade exists in imported items in most developing countries. Thus steel sheets imported in the name of stoves might wind up being used for unintended purposes. One possible way out of this impasse is to import steel sheets that are all already cut to the sizes required by stoves. This will limit the adverse impact of parallel trade on stove manufacture.

We shall turn to the question of chimney stoves. At present levels of understanding of the combustion process of wood, it appears dangerous to work with chimneyless stoves. A chimney stove on the other hand will require special skills to instal in each household. A mass production system cannot safely assume that the buyer will carry out the installation with the necessary care. Thus the production system needs to organize for the installation of the stove as well. Another factor involved in chimney stoves will be connected with the periodic maintenance need to be done by a skilled person. These will inevitably push the cost up.

One of the major merits of the mass-production system lies in the area of quality control. Larger the unit, the process of quality control can be systematized. Quality control involves checking of the dimensions of the final product and conducting some simple tests for the performance of the product. At the initial stages probably almost every unit needs to be subjected to a quality control check. When the industry is working according to schedule, probably a sound statistical scheme of providing for quality control should be adequate.

The final set of observations we will make pertain to the size of the unit. In a situation with evolving designs and completely undeveloped marketing strategies (see next section), it is simply unthinkable to set up an industry completely devoted to making 100,000 stoves per year. Thus the [redacted] sizes would probably lie in the ranges of 25,000 units per year or less. Experimental units of this production capacity are certainly worth trying. It is to be noted that the manpower required for such an industry making metal stoves would probably be no more than 6 to 7 people if the experience in Ouagadougou (Bussmann, 1984) is taken as a guide. In such a case, the owner is supposed to provide inputs of management like material supply, quality control and sales.

A more worthwhile approach appears to use existing small industries - for example those making kerosene stoves in India and the jobbing workshops that exist in urban areas - and ask them to produce stoves according to specifications. An outside agency takes the responsibility for the supply of design drawings, material supply if necessary, quality control and marketing. This agency could be designed to run on commercial principles, for example through a system of franchising as described by Khosla (1985) for a spectrum of goods made according the precepts of appropriate technology and Krishna Prasad (1983) for forestry. Such an approach will permit production facilities to be located near the consumption centers while retaining the characteristics of large industrial systems that have in-house R & D and sales capacity. There is an urgent need for innovative thinking in organizational forms that are more suited to conditions in developing countries.

3.7. Marketing stoves

A mass-production system requires the support of a vigorous marketing system. The opinion at the moment is that the marketing is the weakest link in the chain of activities from the researcher dreaming up new ideas about better stoves and the end-user who is presumed to need these appliances. Whatever little marketing that has been done is by way of raising the consciousness of people towards the deteriorating environment. Most people will accept this exhortation up to a point. The point is reached when one is asked to pay for a piece of hardware. In essence the purpose of marketing strategy is to persuade and of course encourage people to invest in better stoves.

A fairly simple calculation could be made to demonstrate the financial advantage a family gains by buying a stove. We will use the Bangalore data again. An average wood using family paid a monthly bill of \$5.45 for their fuel in 1982. That is an annual bill of \$65.4, nearly half of which was spent on water heating. Gupta (1983) estimated that a stove like the Tamil Nadu stove, which would be ideal for water heating applications (Sulilatu et al., 1985) would cost about \$15.00 in India on the market. At the minimum this stove will save 50% fuel. In principle the stove pays itself in about a year. It is to be noted that the wood is not costed in terms of costs of raising it. And the stove is guaranteed to last a minumum of two years.

This simple calculation provides some important pointers for a marketing strategy. People have to be convinced in the first place that the stove will save fuel. One method is to set up demonstration centers for people to come and use the stove. If they are satisfied, presumably they will buy it. A second alternative - in my opinion, a better one - is to install the stoves in peoples' homes with the condition that if they are satisfied at the end of a month's use they have to pay for it. If they are not, then the stove designer has to work on the design a little more. If they cannot buy, the stove will be taken away. This approach was apparently employed in Kigali, Rwanda with success (Visser, 1985). This leads us to the second part of the strategy. People save only \$1.36 per month. They cannot afford to pay at one go the price of the stove. It is obvious that they should be allowed to pay in monthly in instalments. Without the backing of such a financing system, the mass-production system will not survive.

Third part of the strategy consists of sales outlets. In a city like Bangalore, there are any number of shopping centers in which such stoves could be sold. There is, however, an important class of outlets. They are fuel selling depots. People go there regularly and these are the best places to sell stoves. In Bangalore there are apparently 23 co-operative societies, and 1400 fuel depots (half of which are unregistered). One should start with the co-operative and registered fuel depots. There is an important issue here. The fuel sellers would not necessarily be enthusiastic about improved stoves. But making them stove dealers, their co-operation could be enlisted. Once this works the fuel preparation system as well could be incorporated into these depots. Moreover, the hire-purchase system could be made to work relatively easily with fuel depots being the sales outlets.

We have used the example of Bangalore here. The situation is roughly the same in many other cities of India. In many cities of West and East Africa there are sales outlets for pans and traditional metal stoves. These are potential sales points for cookstoves.

Such a strategy should be supported by an advertising campaign, demonstration sites, and training camps to tell people about how to use the stove most effectively. Its merits when compared to traditional stoves should be clearly explained in terms of convenience of operation and fuel saving capability. i.e. economic advantage.

This package of marketing strategies can hardly be carried out by the Government. It requires basically private entrepreneurship. This is where the concept of franchising comes in very handy. However, the whole business of marketing adds substantially to the cost of the product. It is obvious that most of these costs cannot be passed on to the consumer at the present levels of income. This is where the subsidy plays a powerful role. In principle such subsidies make good business sense. One saves the trees and planting trees and harvesting them is very expensive.

Such a marketing approach will have a salutary effect on the engineering fraternity. They need to prove that their product works under real life conditions. They need to pay attention to product design aspects so that the customer comfort is adequately taken into account. Such a dynamic interaction may even lead to much superior designs that will increase fuel savings to much higher levels than is possible with currently popular designs.

Finally, if the stove market is diversified to include commercial, institutional, and industrial stoves, these will provide their own informal channels of communication to the household market. Needless to say, this market segment can be used to generate neat advertisement copies for the stove idea.

A mass-production system for stoves can be conceived if and only if a sound marketing strategy is developed. The strategy needs to be deviced particularly with a sense of consumer appeal for the product.

4. CONCLUDING REMARKS

This paper considers the issues involved in designing, installing and operating a mass-production system for stoves. Mass-production here is interpreted in a very special sense. It is not mass-production when compared to the modern automobile industry. It is mass-production in the sense that it is a movement away from the productivity of 1 stove per person per day. Productivity of a minimum of 10 stoves per person per day is envisaged for the domestic market.

As I see the market now, there is no case for a factory making 100,000 stoves per year. But the possibility of a modest-sized industry branching off into stove manufacturing with a capacity of about 25,000 stoves per year is quite promising in many areas of the world. The main advantage of such a system is that it will take very little capital - a scarce commodity - to set up.

I am painfully aware that this paper does not touch upon the rural stove, if one were allowed to talk of such a breed. There are two reasons for this. It is my firm belief that the rural fuel-scarcity problem is closely associated with rural development. A possibility of dealing with the fuel-scarcity situation has been outlined in an earlier publication (Krishna Prasad, 1983). No useful purpose will be served in repeating the argument here. The second reason is that a certain proportion of the rural population will be reached by the production system considered here. While this will not be a majority, neither can it be assumed to be an insignificant minority.

Finally, the evidence presented in the review part of the paper clearly gives no room to sustain a propaganda of inefficient thermodynamic performance on the part of mud stoves. Successful programmes run by NGO's with a broad range of interest in rural development fill an important niche in the overall stove market. There is no doubt that many of the earlier designs could be vastly improved without necessarily changing either the method of construction or the mode of dissemination. There is no case whatsoever for abandoning these programmes at the present moment. It is my contention that their programmes will get a healthy input of a larger community participating in stove work with fresh ideas that could prove useful in their work.

ACKNOWLEDGEMENTS

This work has heavily relied upon many informal discussions with friends and colleagues actively engaged in woodstove work in the past few years.

APPENDIX

This appendix lists the formulas used in deriving the estimates of fuel consumption in table 1 with a few explanatory notes.

(a) We estimate the quantity of steam formed during the simmering period.

$$m_e = \frac{P_{min} \times \eta \times t_s}{L} \quad (1)$$

L is the specific heat of evaporation and is 2256.9 kJ/kg.

(b) The quantity of water we need to start with is

$$m_w = m_{w,f} + m_e \quad (2)$$

$m_{w,f}$ is the water content of the cooked food and is 3.7 kg for maize and beans of our example.

(c) The time to boil is calculated by

$$t_b = \frac{(m_m c_{p,m} + m_b c_{p,b} + m_w c_{p,w})\Delta T}{P_{max} \times \eta} \quad (3)$$

m = mass in kg
c_p = specific heat in kJ/kg°C
ΔT = temperature difference between boiling point and initial temperature ≡ 75°C
m, b & w are subscripts for maize, beans and water respectively.

c_p values for most third-world foods are not yet established. I take for maize and beans the value used for flour which is 1.8 kJ/kg°C. For water it is known and is 4.2 kJ/kg°C.

(d) The fuel consumption for boiling is

$$m_{f,b} = \frac{P_{max} \times t_b}{h} \text{ kg} \quad (4)$$

(e) The fuel consumption for simmering is

$$m_{f,s} = \frac{P_{min} \times t_s}{h} \text{ kg} \quad (5)$$

(f) The total fuel consumption for the cooking task is

$$m_f = m_{f,b} + m_{f,s} \text{ kg} \quad (6)$$

(g) The total cooking time is

$$t_c = t_b + t_s \quad (7)$$

(h) The Arlington test standards recommend the calculation of a specific fuel consumption and is given by

$$SFC = \frac{m_f}{m_b + m_m + m_{w,f}} \quad (8)$$

REFERENCES

Beijer Institute
Energy Development in Kenya: Problems and opportunities
The Royal Swedish Academy of Sciences, Stockholm
1982

Bol, W.
Personal communication
1985

Bussmann, P.
Personal communication
1984

Bussmann, P.
Field study on the performance, the production and the dissemination of woodburning cooking stoves in Upper Volta
in "Field studies: Woodburning cookstoves"
Ed. P. Bussmann
A report from the Woodburning Stove Group, Eindhoven
1984

Bussmann, P., Krishna Prasad, K. & Sulilatu, F.
On the testing of woodburning cookstoves
Third EC Conference on energy from biomass, Venice
1985

Căceres, A.
Personal communication
1984

Căceres, A.
Stoves and kilns: What has happened in the last decade
Paper presented at Bio Energy 1984, Gothenburg
1984

De Lepeleire, G., Krishna Prasad, K., Verhaart, P., Visser, P.
A woodstove compendium
Woodburning Stove Group, Eindhoven
1981

Eckholm, E.
The other energy crisis: firewood
World Watch Paper 1, World Watch Institute, Washington, D.C.
1975

Evans, I. & Wharton, D.
The Lorena mud stove, a wood-conserving cookstove
Appropriate Technology, Vol. 2, No. 3
1977

FAO
Map of the fuelwood situation in developing countries
Food and Agricultural Organization, Rome
1981

Foley, G. & Moss, P.
Stoves in developing countries
Earthscan Technical Report No. 2, London
1983

Guha Thakurtha, P.
Personal communication
1984

Gupta, C.L.
Personal communication
1984

Khosla, A.
Franchising system for appropriate technology products
Paper presented at the International Workshop on Woodstove Dissemination, Wolfheze
1983

Krishna Prasad, K.
Woodburning stoves: Their technology, economics and deployment
World Employment Programme Research, Working papers, ILO, Geneva
1983

Krishna Prasad, K.
Forestry and rural energy in developing countries
Paper prepared for DAC/OECD meeting, Paris
1983

Krishna Prasad, K., Sangen, E. & Visser, P.
Woodburning cookstoves
To appear in Vol. 17, Advances in Heat Transfer, Academic Press, New York
1985

Krist-Spit, C.
Personal communication
1984

Lokras, S.S., Sudhakar Bahu, D.S., Ms. [illegible] Bhogle, Jagadish, K.S; & Kumar, R.
Development of an improved three-pan cookstove
Proceedings of the ASTRA seminar, September 1983, Indian Institute of Science, Bangalore
1983

Makuria, G.
A case study from Ethicpia
Paper presented at the International Workshop on Woodstove Dissemination, Wolfheze
1983

Manibog, F.R.
Improved cooking stoves in developing countries: Problems and opportunities
Ann. Rev. Energy, Inc., U.S.A.
1984

Marchetti, C.
The automobile in a system context: The past 80 years and the next 20 years
Technological Forecasting and Social Change, 23, 3-23
1983

→ Micuta
A report on the visit to Afghan refugee camps
Bellerive Foundation
1984

Raju, S.P.
Smokeless kitchens for the millions
Revised edition
Christian Literature Society, Madras
1966

Reddy, A.K.N. & Reddy, B.S.
Energy in a stratified society: Case study of firewood in Bangalore
Economic and Political Weekly, Vol. XVIII, No. 41
1983

Sangen, E.
Personal communication
1985

Sarin, M.
Nada chula
Paper presented at the International Workshop on Woodstove Dissemination, Wolfheze
1983

Sudjarwo, A.
A case study from Indonesia
Paper presented at the International Workshop on Woodstove Dissemination, Wolfheze
1983

Schipper, L. & Ketoff, A.
Energy efficiency in homes: Progress in the industrialized world and encouraging signs for the less developed countries
Paper presented at the Workshop on End-Use Focussed Global Energy Strategy, Princeton
1982

Sielcken, M.
Personal communication
1985

Singer, H.
Improvement of fuelwood cooking stoves and economy in fuelwood consumption
FAO, Rome
1961

Skutsch, M.
Personal communication
1985

Sulilatu, F., Bussmann, P. & Krist-Spit, C.
The Tamil Nadu stove
in "From design to cooking"
Ed. Heeden, D. v.d. & Krist-Spit, C.
A report from the Woodburning Stove Group, Eindhven
1985

Visser, P.
Experiments on shielded fires
in "Some studies on open fires, shielded fires and heavy stoves"
Ed. Krishna Prasad, K.
A report from the Woodburning Stove Group, Eindhoven
1981

Visser, P.
Personal communication
1985

Wood, T.
A review of stovework in the Sahel
Paper presented at the seventh wood stove meeting, Leuven
1982

World Bank
World Development Report
Oxford University Press, New York
1984