What's Cooking?

A review of the health impacts of indoor air pollution and technical interventions for its reduction

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Executive Summary

Indoor air pollution is a serious environmental health problem in developing countries that has received relatively little attention in comparison to other issues. The most significant source of indoor air pollution is cooking smoke from low-grade fuels burnt using inefficient stoves. Indoor air pollution is strongly poverty-related, as it is the poor who predominantly rely on lower-grade fuels and have least access to clean technologies for cooking and heating. Furthermore, poor women and children are generally most exposed to indoor smoke, as women cook and simultaneously care for young children, and thus are also likely to be most at risk from the associated health effects.

There is now strong evidence to support a link between indoor air pollution and health, particularly respiratory disease, including acute respiratory infections, chronic obstructive lung disease and lung cancer. Increasing evidence also suggests links with cataracts, tuberculosis, asthma and possibly low birth weight, perinatal mortality and heart disease. There is some consensus that respirable particulates, especially those measuring less than 2.5 µg in diameter ($PM_{2.5}$) have the greatest health impact, as they penetrate furthest into the lungs. However, few studies have explored the health impacts of other pollutants.

Interventions to alleviate indoor air pollution in developing countries have tended to overtly focus on improved cooking stoves, despite the potential of other interventions such as smoke hoods, cleaner fuels or modified kitchen or house design to increase ventilation. There is a general lack of information on the effectiveness of these types of intervention in reducing indoor smoke, and studies published to date are both difficult to compare and have produced conflicting findings. There is much discussion around the most effective intervention(s) to reduce pollution levels, and the debate at present is inconclusive.

The promotional experience of improved technologies to reduce indoor air pollution in developing countries has been mixed, and has focused on the design and dissemination of improved stoves. Both large national-scale programmes and smaller independent initiatives have been implemented, each with instances of success and failure. Many initiatives have been designed according to the priorities of the implementers, or assumed priorities of intended beneficiaries, with little participation from users. As with other development projects, many initiatives have failed through failing to meet users' needs, which include both practical and socio-cultural factors. Many sources believe that a commercial focus is the optimal way to promote stoves, with government and international agencies playing a supporting role.

Very little work has been done to establish the necessary reductions in pollution levels for the health impacts to be significantly reduced. Although this is a priority for future research, the evidence supporting the health links suggests that the way forward is to work towards *any* attainable reduction, on the assumption that this will pose a reduced health risk.

List of Abbreviations

List of acronyms

ARI	Acute respiratory infection
COLD	Chronic obstructive lung disease
ESD	Energy for Sustainable Development
IAP	Indoor air pollution
ITDG	Intermediate Technology Development Group
LPG	Liquid (or liquefied) petroleum gas
NGO	Non-governmental organisation
ppm	parts per million
RWEDP	Regional Wood and Energy Development Program
TB	Tuberculosis
TERI	Tata Energy Research Institute
USAID	United States Agency for International Development
USEPA	United States Environmental Protection Agency
WHO	World Health Organization

List of pollutants and chemical symbols

BaP	Benzo(a)pyrene
CO	Carbon monoxide
H_2	Hydrogen
HCHO	Formaldehyde
NO_2	Nitrogen dioxide
$PM_{2.5}$	Particulates measuring less than or equal to 2.5 μm in diameter
PM_{10}	Particulates measuring less than or equal to 10 μm in diameter
SO_2	Sulphur dioxide
TSP	Total Suspended Particulates

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1. Background and justification for prioritising indoor air pollution

Since as early as 1968 (Cleary & Blackburn, 1968; Sofoluwe, 1968), claims have been made about the impact of indoor air pollution (IAP) on the health of people in developing countries. The primary source of IAP in the South has been identified as emissions from low-grade fuels - especially forms of biomass – used for cooking and heating on open fires or rudimentary cooking stoves with inadequate provision for smoke removal from the indoor environment. According to Bruce *et al* (2000), around half of the population in developing countries, and 90% of the rural population, rely on coal and biomass (wood, dung, crop residues) for domestic energy, often using simple stoves that produce incomplete combustion. According to Zhang & Smith (1999:2311):

> In developing countries, the primary source of indoor air pollution is often the combustion of dirty fuels used for cooking and/or heating, which has been found to be responsible for many indoor pollutants, including carbon monoxide, particulate matter, sulphur dioxide, nitrogen dioxide, and various organic compounds.

Bruce *et al* (2000) estimate that IAP from biomass and coal smoke is responsible for approximately 2 million annual deaths, representing around 4% of the global disease burden, with acute respiratory infections (ARIs) being the greatest cause of mortality in children under five.

1.1 Nature and scale of the problem

During the 1980s and 1990s, a number of studies in developing countries, including Bolivia, China, Gambia, Guatemala, India, Kenya, Mexico, Nepal and Papua New Guinea, investigated levels of emissions (especially particulates) from different fuels, and examined the links between these and health (particularly respiratory diseases, eye infections, adverse pregnancy outcomes and cancer) (Boy *et al*, 2000). These studies found consistent evidence of health impacts from biofuel and coal smoke emissions (Bruce *et al*, 2000). Much of the pioneering work to establish the links between IAP and health has been done by Professor Kirk Smith of the University of California at Berkeley. Based on these results, the Environmental Health Scoping Study identified IAP as a serious problem in the South; and, in 1992, the World Bank designated IAP in developing countries as one of the four most critical global environmental problems (TERI, 2001).

Despite this increasing focus, relatively little is known about IAP in comparison to ambient air pollution. More attention has been given to ambient air pollution from fossil fuel use (from industry, transport etc.) and its links with health and climate change. In its report, *Environment and Sustainable Development: Five Years After the Earth Summit*, the World Health Organization (WHO) states:

> Although the total amount of health-damaging pollution released from stoves worldwide is not high relative to that from large-scale use of fossil fuels, human exposures to a number of important pollutants are much larger than those created by outdoor pollution. As a result, the health effects can be expected to be higher as well (WHO, 1997).

However, it is increasingly recognised that levels of indoor pollution – particularly in the *home* environment – are often much higher than ambient levels, and exposure is often more prolonged, as often people spend longer periods indoors than outdoors. The United Nations Development Program (UNDP) World Energy Assessment states that:

> A relatively small amount of pollution can have a big health impact if it is released at the times and places where people are present, such that a large fraction is

breathed in. Thus it is necessary to look not only at where the pollution is, but also where the people are (Holdren & Smith, 2000:68).

Bruce (1999a) highlights that the revised WHO air quality guidelines for Europe have substituted particulate measurements with exposure-response data, reflecting growing evidence that there appears to be no safe lower limit for particulate exposure and demonstrating an increasingly cautious attitude towards particulate air pollution in the developed world. However, people in developing countries using open fires are exposed to 20 times or more the previously recommended particulate levels. The WHO estimates that the global burden of disease from exposure to particulate air pollution is experienced *indoors* in developing countries, contributing to approximately 50% of disease among rural and 25% among urban dwellers respectively (Boy *et al*, 2000). The difference between the rural and urban levels is accounted for by the fact that lower-grade fuels, in particular biomass, are used more widely in rural homes.

1.2 Those most affected: poor children, women and men

IAP is a problem that is strongly *poverty-related*, as it is the poor who both rely on lower-grade fuels and have least access to clean technologies for cooking and heating (Bruce *et al*, 2000). Many studies emphasise that *poor women and children* are at greatest risk from the health effects of IAP (Boy *et al*, 2000). In poor households in the South, women typically do most of the cooking and spend most time indoors, thus they are subject to high levels of pollution both from being close to the fire, and spending longer periods of exposure in the indoor environment. Young children (especially infants under five years) are also greatly exposed as they are placed close to where the mother is working – in some countries strapped to the mother's back as she cooks - so are also exposed to long periods in the polluted environment. Infants and young children are also physiologically more susceptible to the health impacts (Boy *et al*, 2000; Bruce *et al*, 2000). Children's lungs are only fully developed in their late teens and their breathing is faster, thus they absorb pollutants more readily than adults and retain them in their systems for longer (Banerjee, 2000). The elderly and expectant women are also more susceptible (WHO, 2000). Susceptibility is exacerbated by malnutrition, poor living standards, overcrowding and exposure to disease through poor sanitation, as well as a low standard of medical care (WHO, 2000).

1.3 The importance of interventions

IAP, like unsafe drinking water, can be considered a 'traditional hazard' associated with a lack of development (Schirnding, 2000). The 1992 United Nations Conference on Environment and Development (Earth Summit) stressed the importance of investing in improvements to people's health and their environment as a prerequisite for sustainable development (UNCED, 1992). The WHO (1997) regards a safe environment as a basic human need. Bruce *et al* (2000:78) believe that: "the goal of interventions should be to reduce IAP, while meeting domestic energy and cultural needs and improving safety, fuel efficiency and environmental protection".

The health impacts from IAP have repercussions on the productivity of the poor, which in turn negatively affect both their livelihoods and quality of life. The WHO recognises the costs of poor health in terms of expenditure on healthcare and loss of productivity, emphasising the "staggering economic losses" that result (WHO, 1997:15). Ashley (1993) believes that improved stoves have the potential to address wider development issues, as, by improving health, they simultaneously free up poor people's time that can be used to increase their productivity. She regards stove projects to have multiple aspects that are beneficial to development in general, for instance, health improvement, better safety, more time for productive activities, beneficial environmental impacts in terms of reduced emissions, and hence the potential to alleviate poverty.

Interventions for IAP in the past have focused on improved cooking technology, with the design and dissemination of various improved cookstoves in developing countries, mainly in Africa and Asia. Although the initial impetus for improved stoves in the 1950s was the reduction of smoke in the home environment, from the 1970s the focus shifted to fuelwood conservation to curb deforestation (RWEDP, 1993c), and reduction or removal of smoke was no longer a priority. A notable example of an improved stove is the 'smokeless *chulha* [stove]' in India, which was the focus of both NGO programmes (for instance UNICEF within its Total Sanitation Concept) and a large-scale government initiative from the early 1980s, but with little evidence of large-scale uptake. Many problems arose from aspects of the *chulhas*' design that did not meet user needs or expectations. However, a similar programme in China was more successful (Barnes *et al*, 1993). There are many initiatives promoting improved cookstoves in developing countries, and a systematic review is needed to determine their development impacts. In addition to improved cooking technologies, interventions that focus on increased ventilation in housing design, cleaner fuels, access to higher-grade fuels, and educational activities also have the potential to alleviate IAP.

1.4 The need for attention from international agencies

The need for international attention and action is clearly defined in Chapter 6 on human health and environmental pollution of Agenda 21:

> […] nationally determined action programmes in this area, with international assistance, support and coordination where necessary, should include:
>
> (a) urban air pollution
>
> (b) indoor air pollution
>
> - support research and develop programmes for applying prevention and control methods to reducing IAP, including the provision of economic incentives for the installation of appropriate technology
> - develop and implement health education campaigns, particularly in developing countries, to reduce the health impact of domestic use of biomass and coal (UNCED, 1992).

In its recent Health Target Strategy Paper, DFID (2000a) emphasises the need to reduce the disease burden of the poor by focusing on priority health problems, including communicable diseases, such as TB, and infectious diseases of childhood, such as ARIs. DFID recognises and stresses the strong links between poor health and poverty, and aims to prevent people from falling into poverty through catastrophic or chronic illness. As such, DFID regards infant mortality as a poverty-sensitive measure, and uses it as an indicator of the state of health of the poor population as a whole. This goal of improved health is expressed by means of an international development target of reducing the rate of infant and child mortality by two thirds by 2015.

International attention has been slow to mobilise due to concerns that the links between IAP and health have not been adequately proven, and that too little is known about both the problem and the possible solutions to permit large-scale household level interventions. The topic has been confounded by conflicting claims, for instance, regarding the degree to which improved cookstoves reduce harmful emissions. However, Smith (2000) argues that there is now enough evidence to support claims of health impacts, and it is time to decide how to intervene.

2. Links between indoor air pollution and health

2.1 Methodological issues and definitions

2.1.1 Risk ratio (relative risk) and odds ratio

The risk ratio (also known as the relative risk) is an estimate of the strength of an association between an exposure and a health outcome. It is the ratio of the incidence of disease in an exposed population to that in a non-exposed population. A risk ratio of 1 indicates that there is no difference in the disease incidence of the two populations. A value of greater than 1 indicates an increased risk among the exposed population while a value of less than one indicates a decreased risk among the exposed population. For example, if a study reports a relative risk of 2 for asthma amongst women who cook with biomass fuel compared with those using electricity, this is analogous to saying that, in the study, the women using biomass fuel appeared twice as likely to suffer from asthma as those using electricity.

In a case control study the risk of developing a health outcome cannot be calculated since one group of subjects (the cases) have already developed this outcome. The calculation is therefore based on the relative probability of cases having been exposed. The resulting measure, the odds ratio, is equivalent to the risk ratio explained above. A more comprehensive discussion of this topic can be found in Hennekens and Buring (1987).

2.1.2 Confounding

The problem of confounding arises when one exposure is associated with one or more additional exposures in such a way that their effects cannot be separated. An association between yellow fingers and lung cancer may thus be confounded by the fact that individuals with yellow fingers are more likely to be heavy smokers (Giesecke, 1994). Potential confounders in the study of the health impact of IAP from biomass fuels include poverty, nutrition, breast-feeding, birth weight, housing type and other features of the home environment (Bruce *et al,* 1998). It is often possible to control for the effects of confounders by using multi-variable statistics for data analysis, assuming they have been correctly identified and appropriate data have been collected. Few of the studies to date have dealt adequately with confounding (Bruce *et al,* 2000).

2.1.3 Outcome characterisation

Disease outcomes have been defined in a number of ways. There are no universally accepted criteria defining many of the outcomes of interest. In addition the studies have used a variety of methods to ascertain cases. These have included self-report, report of symptoms by carers and confirmation by radiology.

2.1.4 Exposure assessment

Few studies have made direct measurements of exposure. This raises the possibility that exposure has been mis-classified and means that data are not available with which to assess the health impact of different exposure levels. Measurement of exposure is complicated. There are a number of components of smoke that are of potential interest which no single instrument is capable of measuring. Also it is not clear which measurements of exposure are most appropriate (for example whether to use peak levels or 24-hour means). The concentrations of different pollutants are not constant throughout the indoor environment (Ezzati *et al,* 2000b). Measurements of CO, SO_2 and NO_2 in one study were reported to decline rapidly with distance from the stove, while the concentration of particles was found to be higher in areas adjacent to the kitchen than in the kitchen itself. In addition to measurements of pollutants, calculation of exposure requires data on the time spent in polluted environments by the population of interest. Ezzati *et al* (2000b) suggest that the use of mean pollution levels fails to take account of activity patterns and the spatial distribution of pollutants and can lead to an underestimate of exposure by up to 71%.

Cooks are exposed to frequent, short bursts of high pollution concentrations during activities such as lighting fires and moving cooking pots. The health implications of these exposures have received little attention. Ezzati and Kammen (in press, a) found that these exposures have no effect over and above their contribution to the total exposure of an individual. However, their work relates solely to the relationship between PM_{10} and ARIs.

2.1.5 The need for intervention studies

The number of studies examining the health effects of IAP from biomass cooking stoves in developing countries is small and the sample sizes used in these studies are generally small. Evidence for the health impact of IAP is therefore limited and imprecise. The studies reported are observational and have the attendant problems of confounding and bias. Households which have adopted cleaner technologies or fuels, may consistently differ from those that have not, in other ways that may be beneficial to health (e.g. higher socio-economic status or healthier behaviours). Also the sequence of events is difficult or impossible to establish from observational studies. The strongest evidence for causal associations comes from intervention studies and there is a clear need for studies of this sort in the field of IAP.

2.2 The proposed link between indoor air pollution and health

2.2.1 The content of smoke

The incomplete combustion of biomass fuels in simple stoves releases smoke containing a complex and unstable mixture of hundreds of chemicals. The precise nature of the mixture can vary with minor changes in the characteristics of the stove or the fuel. The mixture is also dependent on the time since combustion. Work on the characteristics of smoke has focussed on the wood-burning, metal stoves used in developed countries (Larson & Koenig, 1994). The arguments linking IAP from cooking stoves in developing countries with health impacts are therefore based on generalisations and are not mixture specific.

The main components of smoke thought to be of potential importance in their effect on health are:

- Suspended particles
- Nitrogen oxides
- Carbon monoxide
- Sulphur oxides (particularly from the burning of coal)
- Carcinogens (e.g. formaldehyde, benzene and polyaromatic hydrocarbons)

The suspended particles in smoke from biomass fuels are a mixture of solids and liquids of varying size and composition. Particle size is important in determining deposition within the airways. Smaller particles are able to penetrate deeper into the respiratory system. Particles having a diameter of ≤10 μm (PM_{10}) are able to reach the upper airways and the larger of the lower airways. Particles with a diameter of ≤2.5 μm ($PM_{2.5}$) are able to penetrate the small airways of the bronchioles and alveoli. Penetration of these airways increases the health threat because it allows easy absorption of toxins into the blood stream. It also avoids the mucocilliary apparatus, meaning that removal of these particles from the body will be a lengthy process if it occurs.

Comparison of studies of particulate pollution is complicated by the use of different measures. Some have used the density of total suspended particles while others specify the size of particles measured. The importance of PM_{10} as a health risk *per se* as opposed to an indicator of pollution is questionable and it has been suggested that future monitoring and regulation should concentrate on smaller particles (WHO, 2000).

There is a lack of established biological mechanisms to account for the associations observed between suspended particles and health impacts (Lippman & Maynard, 1999). The effects of particles may depend on their physical and chemical characteristics. The composition of particles within the smoke mix has received little attention and may be highly variable. In studies of outdoor (ambient) air pollution, levels of particle pollution are often highly correlated with SO_2 concentration and their effects are difficult to separate. However, studies of ambient air pollution in the US have found consistent results across a variety of locations suggesting that the overall concentration of particles (in $\mu g/m^3$) may be more important than the precise chemical make up. Raiyani *et al* (1993) report that, while the SO_2 content of IAP from stoves depends on the sulphur content of the fuel used, the concentrations of particles, NO_2 and formaldehyde are correlated and depend on the efficiency of the combustion process.

2.2.2 Levels of exposure in the home

Personal exposure to pollutants within the home depends on the concentration of pollutants in the environment and the length of time spent in this environment. Estimates from developing countries where simple biomass stoves are used for cooking suggest that exposure is between 3 and 7 hours daily. Exposure can be longer in climates where these stoves are also used for space heating. Few data have been collected on the concentration of individual pollutants within households. The concentrations of many pollutants have not been recorded in the domestic setting. Those that have vary between studies. However, reported concentrations are high when compared with the guidelines established for ambient air pollution.

There are no standards for indoor exposure to biomass smoke (Smith *et al,* 2000). Air quality standards and guidelines have been developed in response to ambient air pollution in urban areas of developed countries. The characteristics of suspended particles in these areas may differ from those found within houses in developing countries. Also the guidelines are based on dose/response relationships for lower exposure concentrations than those found in many indoor environments in developing countries.

Unlike national standards, the WHO guidelines are non-binding recommendations. They are intended to assist in evaluating the extent and nature of health risks associated with exposure to pollutants. It is recognised that environmental, social, economic and cultural conditions may, in some circumstances, result in policies allowing concentrations above the guidelines (Lippman & Maynard, 1999).

The United States Environmental Protection Agency (USEPA, 1997) standards for ambient air pollution allow a 24-hour mean for $PM_{10} \leq 150\ \mu g/m^3$. This mean should be exceeded no more than once in 100 days. The 24-hour means recorded within houses in developing countries range from 300 to 3,000 $\mu g/m^3$. Maximum levels of 30,000 $\mu g/m^3$ have been reported during cooking.

The USEPA (1997) standards for ambient air pollution allow an 8-hour mean for CO = 9ppm. The mean recorded levels reported from studies in houses in developing countries range from 2 to 50 ppm, with levels during cooking varying from 10 to 500 ppm.

The USEPA (1997) standards for ambient air pollution allow a 24-hour mean for SO_2 of 365 µg/m^3. Using the conversion factor of 0.25 (Dockery & Pope, 1994) the reported PM_{10} levels equate to 24-hour means for SO_2 of 75 – 750 µg/m^3. The conversion factor is based on studies of ambient air quality. Its applicability to indoor air quality is not known.

A study from Tamil Nadu (Balakrisna, 2000) found that the WHO guidelines for short-term exposure to CO, NO_2 and SO_2 were exceeded in 40%, 63% and 67% of households respectively.

WHO guidelines recommend that SO_2 should not exceed a 24 –hour mean of 150 µg/m^3. This figure resulted from the application of a safety factor of 2 to the lowest 24-hour mean at which an exacerbation of symptoms was consistently found in sensitised patients (WHO, 2000).

The WHO guidelines for NO_2 recommend that means should not exceed 200 µg/m^3 over 1 hour or 40 µg/m^3 over a year. At a level of double these, there is consistent evidence of reduced lung function in asthmatics.

WHO guidelines for CO_2 recommend that mean exposure should not exceed 30,000 µg/m^3 over 1 hour or 10,000 µg/m^3 over 8 hours. These standards are set so that carboxyhemoglobin levels will not exceed 2.5% in order to protect middle aged and elderly, non-smoking, coronary heart disease patients and the foetuses carried by non-smoking pregnant mothers.

No WHO guidelines have been set for suspended particles. The WHO finds that, although increasing exposure to PM_{10} and $PM_{2.5}$ are associated with increasing risk of adverse health effects, the available evidence does not allow a clear judgement to be made of a level below which no adverse effects would be expected.

2.2.3 The mechanisms by which indoor air pollution could affect health

- The mucociliary apparatus, responsible for the mechanical removal of particles from the bronchi and alveoli, can be adversely affected by nitrogen dioxide and by the mix of sulphur dioxide and particles.
- The operation of the immune system can be reduced by exposure to nitrogen dioxide and by exposure to the mix of sulphur dioxide and particles.
- Chronic inflammation of the airways or damage to the physical structure of the lungs may also increase the likelihood and severity of infection.
- Smoke from biomass fuels is known to contain a number of carcinogens
- Absorption of toxins from smoke condensates by the lens has been found to cause cataracts in animal studies.
- Carbon monoxide can retard foetal development by reducing oxygen delivery to the foetus.

Broadly speaking there are two ways in which IAP can affect health. Substances in the smoke can themselves be responsible for a health impact, as is the case with carcinogens or the toxins that cause cataracts. Alternatively these substances can pave the way for infection by bacteria or viruses by damaging the respiratory system's mechanical and immune defences. It seems likely that the biggest health impact (in terms of morbidity, mortality or an aggregate measure such as the disability adjusted life years lost - DALY) comes about through the latter process.

2.2.4 The health problems for which indoor air pollution may be a risk factor

Toxicology, animal studies and epidemiological studies suggest a number of health problems that could result from exposure to smoke from biomass stoves (ambient air pollution and environmental tobacco smoke share many of the constituents of biomass smoke and can serve as models for exposure to biomass smoke. However, the health effects of these different types of pollution may differ because of differences in the relative concentrations of their constituents and because of differences in exposure patterns.

The potential health risk which have been identified include:

- ARIs
- Chronic obstructive lung disease
- Cancer (of the lung, mouth, nasopharynx or larynx)
- Asthma
- TB
- Cataract
- Low birth weight
- Infant mortality
- Heart disease

2.2.5 The people most at risk

ARI (see definition below) is the most common cause of illness in children and is thought to cause over 3 million deaths amongst under fives each year (Smith *et al,* 2000). Young children are particularly at risk from the effects of IAP for a number of reasons (Satterthwaite *et al,* 1996). They often spend long periods of time in polluted environments in the company of their mothers. Their immune systems are not fully developed, (a process which may be further delayed through the effects of malnutrition), and their small airways may be more susceptible to the effects of inflammation. Adult women are at risk of chronic conditions resulting from frequent and long periods of exposure to polluted environments while preparing food. The poor are at greater risk than the rich because of their greater reliance on biomass fuels in addition to the effects of poor nutrition and, possibly, poor housing.

2.3 Evidence for an adverse effect of indoor air pollution on health

2.3.1 Acute respiratory infections (ARIs)

ARIs include a variety of conditions that vary in severity and aetiology (Smith *et al,* 2000). They can be divided into infections of the upper respiratory tract and those of the lower respiratory tract. However, there are no globally accepted criteria for these definitions. WHO defines upper respiratory tract infections to include any combination of cough with or without fever, blocked or runny nose, sore throat, and/or ear-discharge. Upper respiratory tract infections tend to be viral and self-limiting. Symptoms for acute lower respiratory tract infections include any of those for upper respiratory tract infections plus rapid breathing and/or chest in-drawing and/or stridor. Acute lower respiratory tract infections tend to be more severe, involving infection of the lungs, with pneumonia being the most serious. ARIs are the leading cause of death in children under 5 years in developing countries. Seventy-five percent of these deaths are from pneumonia (Smith *et al,* 2000).

Fifteen published studies examined the association between indoor pollution from biomass fuels and ARI in children. Five of these studies found no association, but suffer from methodological problems associated with poor definitions of exposure or small exposed samples. The majority of the remainder found relative risks/odds ratios in the range 2-5 (Bruce *et al,* 2000, Smith *et al,* 2000). These findings are supported by those of studies of outdoor air pollution and exposure to environmental tobacco smoke (Smith *et al,* 2000).

2.3.2 Chronic obstructive lung disease (COLD)

Chronic lung disease (and a number of similar terms including chronic non-specific lung disease, chronic airways obstruction, chronic pulmonary disorder and chronic airflow limitation) is used to describe the common problem of patients with a number of underlying abnormalities (Florey & Leeder, 1982). These include chronic bronchitis, emphysema, chronic asthma and other progressive, incompletely reversible obstructions of the airways. Four studies in developing countries have examined the relationship between COLD and use of biomass fuels with sufficient rigour to allow the calculation of odds ratios and confidence intervals (Smith, 1998 cited in Smith & Mehta, 2000). These studies find odds ratios in the range 2-4 for adult women who have habitually cooked using biomass fuels. These findings are similar to those reported for ambient air pollution and for exposure to tobacco smoke (Smith *et al,* 2000). However, studies of lung function in developing countries have found only small differences associated with exposure to wood smoke (Bruce *et al,* 2000).

2.3.3 Cancer

An association between lung cancer in women and the use of open coal fires for cooking has been demonstrated in over 20 studies in China (Smith & Liu, 1993). Although wood smoke is also known to contain a number of carcinogens no association has yet been shown between biomass fuels and lung cancer (Bruce *et al,* 2000). Biomass fuels have been linked to cancers of the mouth, nasopharynx and larynx but findings have been inconsistent (Bruce *et al,* 2000).

2.3.4 Tuberculosis (TB)

Two studies from India report an association between TB and biomass fuels. One finds a significant odds ratio of 2.58 after adjusting for socio-economic factors. (Mishra *et al,* 1999 cited in Bruce *et al,* 2000). The other reports similar findings but only controlled for age (Gupta & Mathur, 1997 cited in Bruce *et al,* 2000). This link may result from physical damage to the lungs rendering them susceptible to infection, or from suppression of the immune system.

2.3.5 Cataract

Two studies from India report odds ratios of around 1.3 (which though small are statistically significant) for cataract associated with the use of biomass fuels. These findings are supported by the results of animal studies and studies of the effects of tobacco smoke (Bruce *et al,* 2000).

2.3.6 Asthma

Asthma in developed countries has been linked to ambient air pollution and environmental tobacco smoke, amongst other factors. Few studies have been carried out in developing countries and the results linking asthma to biomass smoke are mixed. An odds ratio of 2.3 has been reported from Nepal, but other studies have found no evidence and non-significant protective effects have also been reported (Bruce *et al,* 2000).

2.3.7 Low birth weight and perinatal mortality

One Indian study reports a significant association between still births and IAP, with an odds ratio of 1.5. Ambient air pollution and tobacco smoke have been linked to low birth weight, but links with perinatal mortality are inconsistent (Bruce *et al,* 2000).

2.3.8 Heart disease

Although heart disease has been linked to tobacco smoke and outdoor air pollution there are no studies in developing countries linking heart disease to the use of biomass fuels (Smith, 2000).

2.3.9 Summary of the evidence

Smith and Mehta (2000) summarise the available evidence as follows.

1. Strong evidence
    - ARIs
    - Chronic obstructive lung disease
    - Lung cancer
2. Moderate evidence
    - Cataract
    - TB
3. Limited evidence
    - Asthma
4. Insufficient evidence
    - Low birth weight and perinatal deaths
    - Heart disease

In spite of the small total number of studies reported, lack of evidence of an association between IAP and a disease outcome should not be interpreted as a lack of risk. In view of the strong evidence suggesting a link between IAP and ARIs, and the fact that these are the leading cause of mortality in infants under 5 years (Bruce *et al*, 2000), the reduction of ARIs should be the focus of interventions to reduce the health impacts of IAP.

3. Technical interventions to reduce indoor air pollution

Technical interventions to reduce IAP have strongly concentrated on improved cookstoves. This is probably because there is a relatively long history of stove development. The earliest stove projects in the 1950s were a response to indoor smoke; however, from the 1970s onwards the emphasis changed to addressing fuelwood shortages and deforestation (RWEDP, 1993c). The emphasis in recent years has refocused on reducing IAP, thus stoves are the obvious intervention. A lesser amount of attention has focused on improved fuels, possibly because it is deemed more feasible to change the design of stoves than fuels. The use of hoods and modifying house design to increase ventilation are also possible interventions for reducing IAP.

However, relatively little research has been done on technical interventions to reduce IAP in relation to studies investigating the links between IAP and health (e.g. work by Professor Kirk Smith and Dr Nigel Bruce). This section aims to review the literature and practice relating to technical interventions to reduce IAP in developing countries, and examine the reductions in emissions that have been observed from them.

3.1 Technical options

According to Bruce *et al* (2000), three factors determine the extent to which IAP impacts health:

- the degree of *pollution*, that is, the emission levels;
- the degree of *exposure*, that is, the amount of time spent in a polluted environment;
- personal *susceptibility* to the effects of IAP, that is, physiological factors that make some individuals more prone to the effects than others, such as children and asthmatics.

Technical interventions can thus reduce IAP in three ways (Ballard-Tremeer & Mathee, 2000):

1. *by producing less smoke*: improved stoves, improved fuels and fuel switching;
2. *by removing smoke* from the indoor environment: chimneys, flues, hoods and ventilation;
3. *by reducing exposure to smoke*: reducing cooking time, behaviour, kitchen design.

3.1.1 Improved stoves

Improved stoves are the most obvious and popular technical response to reducing IAP. Many different versions of improved stove have resulted from both the *purpose* and the *local context* for which they were designed. The following have been major drivers for improved stove design:

- smoke reduction
- better fuel and/or thermal efficiency
- flexibility to use different fuels

Variations in design have also arisen from local contexts. For example, in colder regions stoves are also used for heating, thus heat radiation must be maximised, whereas in hotter regions it would be minimised. The above drivers will have implications for the performance of different stoves in terms of efficiency and emissions.

Well-known types of improved stove are: improved *chulha* (India), *plancha* (Central America), bucket stove (Thailand), *upesi* (Kenya); *mirte* (Ethiopia) and *anagi* (Nepal). RWEDP (1993a; 1993b) give detailed descriptions of stove models in China and India respectively. Box 1 gives three examples of improved stoves from different regions.

Box 1. Examples of Improved Stoves from Developing Countries

'Mina' Stove, Lucknow, India

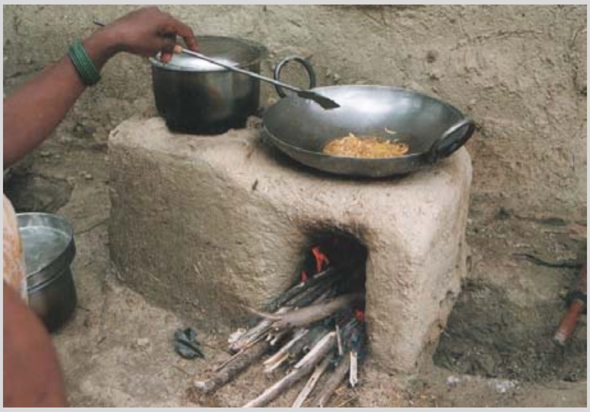
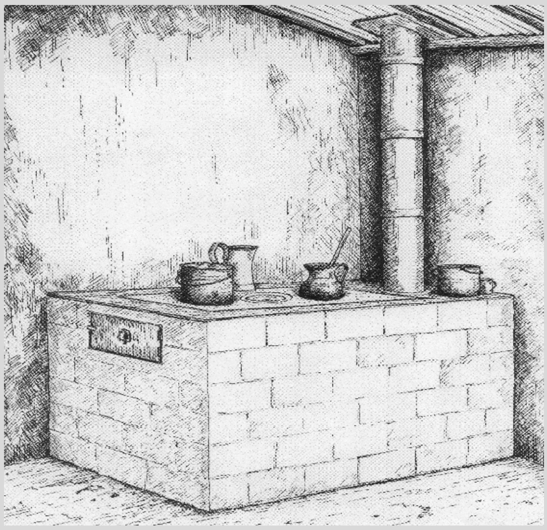


Photo: Jonathan Rouse (WEDC)

The Mina Stove is a simple two-pot mud stove with no chimney. The first pot-hole is situated directly above the firebox and is flat to produce a smokeless seal between the stove and pot. The second pot-hole is displaced from the firebox and also acts as an exit for the hot gasses from the fire. A sloping tunnel connects the second pot hole to the firebox. A grate provides primary air to the fuel from below. Around the firebox, air holes provide secondary air to the hot, flammable gases in the firebox. The firebox opening is shaped to minimise heat loss while allowing easy refuelling and traditional baking of *chapattis*.

Plancha Stove, Central America

This improved stove is built with bricks or cement blocks with a flat metal sheet which is used as the burner (the '*plancha*'). The stove has a metal or brick flue to remove smoke from the kitchen. The *plancha* stove is more durable and is designed to last longer than a traditional stove.



Drawing: Nigel Bruce (University of Liverpool/WHO)

Upesi Stove, Kenya

The Upesi is a simple, improved single-pot stove with a fired ceramic liner installed in the home using mud mortar. The flames are enclosed in the fire area, directing more energy from the fire to cooking, and also producing less smoke and better fuel efficiency. This example has been built into the house using mud.

Photo: Liz Bates (ITDG)

Sources: Bates (1999); Rouse (2000)

Improved stoves without flues or chimneys

Simple design steps can be taken to improve the burning efficiency of a stove, which can achieve more complete combustion and reduce emissions. Adding a grate allows a steady source of primary air to the fire, and holes in the firebox, above the level of the fire, improve the flow of secondary air to the fire (Ballard-Tremeer, 1998; Rouse, 1999; Rouse, 2000) Insulating the firebox can also improve combustion efficiency (Rouse, 1999; Sulpya, 1998).

There has been much debate and many experiments on whether improved stoves significantly reduce emissions. Most improved stoves were designed to use less fuel, with emphasis on more efficient combustion but not smoke reduction. Improved combustion is usually expected to reduce emissions, however, where increased fuel efficiency is not achieved through more complete combustion, but through enclosing the firebox and reducing airflow, emissions will be higher (Ahuja *et al*, 1987 cited in Smith, 1989). Some improved stoves have been found to significantly reduce emissions of total suspended particulates (TSP) and carbon monoxide (CO), while others have shown no improvement or even higher emissions (see table 2).

Several other factors influence emissions levels from stoves. Low-cost stoves tend to deteriorate through use of poor quality materials, poor construction and poor maintenance, leading to higher emissions with time, as observed with *plancha* stoves (Naeher *et al,* 2000; WHO, 2000).

Improved stoves with flues and chimneys

The addition of a mechanism to *remove* smoke from the kitchen will reduce indoor pollution. Chimneys and flues are an integrated design feature of many improved stoves. Flues work by providing an extraction mechanism to remove smoke directly from the combustion chamber through a vertical vessel. Chimneys are defined here as structures that allow smoke to exit the building (Bates, 2001b). A further advantage of flues is that, as hot air moves upwards to the outside, it draws primary air into the firebox from below to replace it, which can make combustion more efficient and thus cleaner (Rouse, 1999). Some stoves have been designed for better efficiency based on this principle (Khan, 1998).

There are also several drawbacks with stoves with flues and chimneys. Flues may not perform well if not installed properly, are difficult to design and are fragile when made of asbestos or ceramic (RWEDP, 1993c). Chimneys are expensive and may be difficult to obtain, as illustrated in Box 8, making their feasibility in practice questionable (RWEDP, 1993c). Chimneys may be ineffective if smoke returns through windows and doors (Goldemberg, 2000).

3.1.2 Hoods

Hoods work on the same principle as flues and chimneys, but are free-standing and independent of the stove. This is advantageous, as they can be used with both open fires and all types of improved stove, and still remove the majority of smoke from the indoor environment (Bates & Doig, 2001). Hoods are widely used in the North over cookers and heating stoves where they are considered effective. However, there are very few interventions involving hoods. They may present problems of integration into traditional homes, especially small houses (Bates & Doig, 2001). Box 2 illustrates an intervention that is using hoods specifically as an intervention to reduce IAP.

Box 2. Use of Hoods in Kenya

ITDG is working to introduce technical interventions to alleviate IAP in two poor, rural areas of Kenya: a Maasai area in Kajiado, and Nyamira and Mumias in West Kenya. In Kajiado, ITDG is working with the Maasai community to improve housing design, and is building on its *upesi* stove programme in West Kenya. The projects give local people the option of installing smoke hoods in their homes. The metal hoods incorporate flues with chimneys to remove smoke from the house. The main advantage is that they can be used with both open fires and *upesi* stoves, and remove the majority of smoke.

In the Maasai community, half of the project participants have already adopted hoods. Among the benefits cited were reduction of smoke inside the house, increased ventilation, and keeping young goats from falling into the fire. Unlike windows, hoods do not allow too much heat to escape from the house during cold periods, and cannot be blocked by householders, ensuring that smoke can always escape. Initial drawbacks reported included the hood taking up too much space, getting in the way while cooking, and women hitting their heads on it. Hoods have not as yet been as widely adopted in West Kenya due to problems of integrating them into houses with thatched roofs.

Smoke hood used with upesi *stove*

Photo: ITDG Kenya

Sources: Bates (2001a), Bates & Doig (2001), Gitonga (2001)

3.1.3 Cleaner fuels

Interventions that seek to produce less smoke also focus on cleaner fuels. Studies show very different emission levels from different types of fuel when burnt using the same technologies (see table 3). Cleaner fuels are also usually designed for both fuel efficiency and smoke reduction. Most cleaner fuels for developing countries are derived from biomass, because this is the only fuel available to most poor people. This section will look at those fuels that have been specifically engineered to be cleaner.

Briquettes

Briquettes are simply units of fuel – usually biomass, charcoal or coal – compressed into a more compact form to produce more efficient and cleaner combustion due to their higher density. Advantages of briquettes is that they are very simple to make and can be produced locally.

Biogas

Biogas is produced from the anaerobic digestion of biomass. The resulting gas is rich in methane and burns very cleanly with very low TSP and CO emissions. Although it can be made from locally-available resources, such as animal dung and crop residues, the technology and process is more complex than that for briquettes, and requires specific equipment (Ballard-Tremeer & Mathee, 2000).

Limitations to biogas are that its production requires a reasonable supply of biomass and water (Ballard-Tremeer, 1998). Also, people may not be amenable to cooking with gas produced from animal dung (Joshi, 1999). At present, biogas is not widely used, with reports of it being used only when wood is unavailable (Goldemberg, 2000; Joshi, 1999). However, several initiatives are installing biogas digestors in China, India and Nepal, with some smaller initiatives in Africa (Ballard-Tremeer & Mathee, 2000; Goldemberg, 2000; Malhotra, 1999).

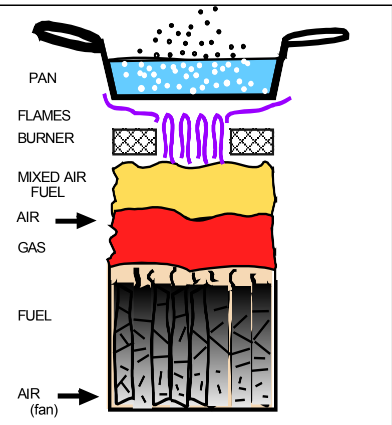
Producer gas

Although burning wood produces smoky emissions, it can be burned cleanly. During gasification, wood is heated in an inadequate oxygen supply and the volatile portion is released as a gas. This gas is called a 'producer gas' and in the presence of sufficient oxygen it will burn with a smoke-free blue flame. A unit designed to combust wood in this manner is a *gasifier*. Gasifiers were used during the Second World War to power modified car engines. Producer fuel consists largely of CO and H_2, meaning that equipment (including stoves) need to be designed carefully and used correctly in order to avoid the risk of CO poisoning. (Ballard-Tremeer, 1998). Producer gas is simple to produce, the gasifier for a truck being the size of a hot water heater. It was produced centrally from coal and distributed to homes from about 1850-1950, but it is also possible to make on a small scale (Ballard-Tremeer & Mathee, 2000).

Box 3. The Turbo Stove: a Domestic Producer Gas Stove

A number of small gasifier units have been designed for domestic use in the developing world. One such example is the Turbo stove which produces a smoke-free controllable flame for cooking. This gasifier is charged with small pieces of wood which are lit from the top. A small fan pushes air up through the wood chips which, under the heating from the burning layer, liberate their volatiles as producer gas.

This gas is mixed with more air above the wood where it burns with a clean blue flame. The size of the flame, and hence cooking temperature, can be controlled by increasing or decreasing the speed of the fan. The fan is usually driven by a 12V electric motor, but could be powered by photovoltaic power or a wind-up mechanism. The higher the density of fuel used the better the combustion process and cleaner the burning.



Simple Diagram of Turbo (Gasifier) Stove

Prototype CPC Turbo (Wood-Gas) Stove Under Test

Source: Tom Reed (Community Power Corporation, USA)

Other improved fuels

Other improved fuels are torrified wood, low-smoke coal, ethanol and biodiesel. Ethanol and biodiesel can be produced from biomass energy crops such as sugarcane, and burn as cleanly as fossil fuels, but ethanol may be socially unacceptable in certain regions due to alcohol taboos (Ballard-Tremeer & Mathee, 2000). No interventions that focus on these fuels have been identified, although a study of low-smoke coal in South Africa found equal or higher TSP levels than normal coal (Ballard-Tremeer & Mathee, 2000).

A few solar-powered stoves have been produced, but are very much at the development stage (see for example D'Sena, 1999). Although they produce no emissions from the fuel source, they cook slowly and only work in sunshine, meaning that they cannot be operated in cloudy weather or in the evening, and cooks must stand in the hot sunshine (Ballard-Tremeer & Mathee, 2000).

3.1.4 Fuel switching

Fuel switching, that is, changing to a cleaner fuel (or "moving up the energy ladder" – see Figure 1) is one of the simplest and most effective ways of reducing IAP. Simply changing from biomass to kerosene or LPG will produce a very significant reduction in harmful pollutants, especially TSP (see Table 3). The general theory of the 'energy ladder' is that people use 'better' fuel alternatives when they are able (Holdren & Smith, 2000). Needless to say, the transition is much simpler in theory than in practice, as there are many barriers to adopting different fuels, as discussed in Section 5. Some authors dispute the 'energy ladder', and some evidence suggests that household fuel use is more complex than a result of rising income levels (see for instance Saatkamp *et al*, 1998). People may also not *want* to change fuels, as discussed in Section 5. Hulscher (1998) refers to a process of "fuel complementation", by which households have a greater *choice* of energy sources and may use different fuels for different tasks without abandoning lower-grade fuels. An argument for discouraging the use of dung is that it is a missed opportunity for use as fertiliser, in addition to being a dirty fuel (TERI, 1998).

Despite the potential of fuel switching to reduce IAP, it is widely accepted that biomass and coal will continue to be used by a large proportion of low-income households in developing countries for the foreseeable future (USAID, 2000). Unlike improved stoves and fuels, fuel switching is not usually carried out as a *technical intervention*, but as a policy intervention, as described in Box 4.

Figure 1. The Energy Ladder

Most polluting

↓

Biomass:
- dung
- crop residues
- wood

Charcoal
Coal
Kerosene
Liquid Petroleum Gas (LPG)
Electricity

Least polluting

Sources: Saatkamp et al *(1998), Smith (2000)*

Charcoal and coal

Several studies show that charcoal is much cleaner than raw wood or biomass, and advocate its use as a preferable alternative to biomass (Ezzati *et al,* 2000a; Oanh *et al,* 1999). Other opinions indicate that, while charcoal produces lower TSP emissions, it produces substantially more CO, described by Smith (2001) as “substituting an acute hazard for a chronic one” (Ballard-Tremeer & Mathee, 2000; Goldemberg, 2000). Although charcoal used as fuel produces lower emissions, its production requires great amounts of wood. This raises concerns over ambient air pollution as the *overall* efficiency of using charcoal as fuel (Rouse, 1999).

Coal is used widely in some regions, notably China, but is not available everywhere. A shift from biomass to coal can raise levels of harmful sulphur dioxide and carcinogens. The energy ladder is a general guide to emissions levels, without assessing levels of individual pollutants.

Kerosene, liquid petroleum gas (LPG) and electricity

Kerosene is a liquid fossil fuel derived from oil. It can be burned very cleanly in a pressurised burner, but is often used in wick burners for cooking or lighting which are very sooty and smoky. When burned well, kerosene produces only negligible levels of TSP and less CO than wood (Ballard-Tremeer & Mathee, 2000). There is some concern over its emissions, particularly when burned with wicks, but little research has been undertaken. Unlike the fuels mentioned thus far, kerosene cannot be produced informally, and has to be purchased, thus implying costs, and it is not always easily available. This will be discussed in section 5.

LPG, or household cooking gas, is a fossil fuel that also achieves combustion that is nearly 100% complete, making emissions hard to detect from background levels (Ballard-Tremeer & Mathee, 2000). Like kerosene, the main drawbacks of LPG are cost and availability. Like solar power, electricity as a fuel produces no IAP emissions. Switching to electricity also implies both monetary costs and access to infrastructure and supply.

3.1.5 Housing design

Improved ventilation

It is believed that inadequate household ventilation seriously exacerbates the concentration of pollutants in homes through the low exchange of indoor air with outdoor air (RWEDP, 1993c). The air exchange rate depends on the number and placement of window and door openings. Modifying housing to increase ventilation is another way of dispersing smoke from indoors.

Modified housing design is an intervention to control IAP that is used widely in the North, yet is seldom adopted in the South. Only one initiative focusing on modified housing design to alleviate IAP was identified (see Box 4). This could be because it is considered more difficult to modify house structures than to improve stove or fuel design. However, it is also argued that relatively cheap and simple changes can be made to housing in developing countries, for instance enlarging windows, opening eaves or raising roof height (Bruce, 1999b; RWEDP, 1993c).

The WHO emphasises the particular lack of information on ventilation rates in housing in developing countries (WHO, 2000). Furthermore, no information exists on the effectiveness of ventilation in comparison to improved stoves and fuels (RWEDP, 1993c). Its effectiveness is likely to depend on the specific changes made. This is simpler in warmer regions, as in cold regions ventilation tends to be minimised due to the cold, as noted in Box 4.

Kitchen design

The kitchen or cooking area can also be designed to reduce IAP (Smith *et al*, 1983; RWEDP, 1993c). If a stove is close to doors or windows, emissions will disperse. The stove at waist height will reduce the emissions inhaled by the user (Ballard-Tremeer, 1998). A further option is to have a separate kitchen. However, it may be difficult to change kitchen design, because cultural factors may determine the position of the stove within the house, and often little priority and few resources are given to the place in which women work (Saatkamp *et al*, 1998). This problem would first need to be overcome, as mentioned in Box 4. Ballard-Tremeer & Mathee (2000) and RWEDP (1993c) note that few household energy projects pay attention to the kitchen.

Box 4. Modified Housing Design to Reduce Indoor Air Pollution in Kenya

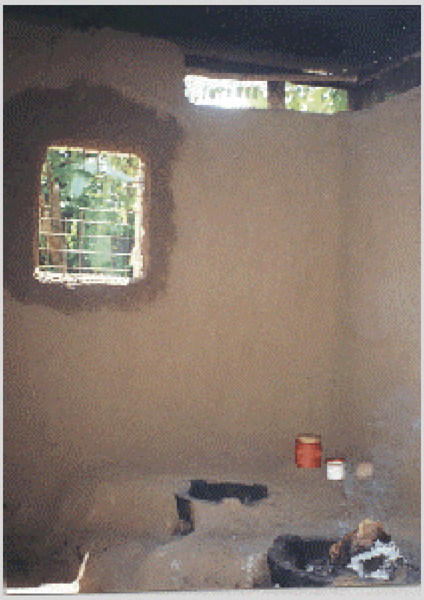
Alongside its smoke hoods project (see Box 2), ITDG is also working with modified housing design to increase ventilation and alleviate IAP in Kajiado and West Kenya. In Kajiado, the traditional Maasai houses, *bomas*, are small and low with tiny windows. Cooking is done inside the house using biomass on an open fire. Fires are left smouldering during the night for warmth. In West Kenya, houses have bigger windows, but these are still small and poorly positioned. Cooking is done in the main house or in a small and unventilated kitchen, using biomass on an open fire or a *upesi* stove. In both areas, women are responsible for cooking.

The present initiative developed from two previous ITDG participatory community development initiatives working with women: a housing improvement project in Kajiado, and the *upesi* stove programme in West Kenya. The housing design interventions comprise larger and better-positioned windows, and eaves spaces between the walls and roofs. Women participated in the choice and design of interventions, for example, deciding the number and position of windows. Although they wanted more light and air inside their homes, they also wanted to be able to close windows for privacy, security, warmth at night and to keep animals out.

Initial discussions with women were very positive. Reduction in smoke levels gave them more light, more convenience and less discomfort. Specific benefits were: better visibility in homes (children being able to do their homework, finding lost objects, spotting snakes and scorpions, easier to do housework, fewer accidents); kerosene saving (not having to light lamps during the day), better health (less fatigue and fewer headaches), and general satisfaction. Husbands also spent more time in the *bomas* due to the improved environment. However, it was also observed that women were reluctant to open all windows for reasons of security, privacy and warmth.

The project works with women because they are responsible for housing design and construction. However, in the communities, the kitchen has low status and men control financial resources. In once case, however, a husband was persuaded to finance kitchen improvements when he was convinced that his children's health would benefit.

Addition of windows and eaves spaces (in conjunction with smoke hood and associated flue and chimney)



Photos: ITDG Kenya

Sources: Bates (2001a), Bates & Doig (2001), Gitonga (2001)

3.1.6 Behavioural changes

Behavioural changes, although not wholly a *technical* response, can be important for reducing IAP by seeking to modify the behaviour of those affected by IAP to reduce their exposure. Behavioural interventions often *complement*, rather than form the *core* of, interventions.

Education

Education about the impacts of smoke on health is an essential component of IAP interventions, as often people are unaware or have lay beliefs about the risks. McGranahan (1994) found that women in Accra, Ghana generally did not view exposure to air pollution as a major problem. In Kenya, women had little notion of the health impacts of IAP; although they associated sore eyes with indoor smoke, they did not regard coughing as a problem, probably because it was so habitual and widespread (Bruce & Doig, 2000). Educational interventions may be underestimated, as Crewe (1992:107 cited in Rouse, 1999:31) asserts: “in wood burning stove use, the user is a more influential variable on fuel consumption than the equipment”.

Reducing exposure to smoke

Keeping children away from the fire and smoke is a practical way to reduce children’s exposure (Bruce & Doig, 2000). However, it may be harder in practice if women need to mind their children while cooking, and placing them out of sight may expose them to other dangers.

Reducing emissions from stoves

Drying wood prior to burning, cutting wood into smaller pieces, and extinguishing the fire immediately after use can also reduce emissions (Rouse, 1999). Although apparently simple, these measures may not be practical: drying wood requires both a covered drying area, and building up a stock, while cutting wood smaller increases the time needed to prepare the fire.

Modified cooking practices

Cooking outdoors maximises ventilation, but is unlikely to be practical in areas where it is very hot, very cold, rainy or windy. Furthermore, Bates (2001a) notes, it may also be impractical due to the presence of animals ready to steal food, and culturally unacceptable where the fire is spiritually significant or where privacy is needed for eating.

Cooking time can be reduced by pre-soaking food, preparing food before lighting the fire and using lids (Rouse, 1999). Again, these measures may meet with barriers: soaking food may not be an acceptable cooking practice, and lids may be unavailable or unsuitable for food requiring frequent stirring. A ‘hay box’ – an insulated container in which a hot pot can be placed to continue cooking after being removed from the fire – is a good idea, but was not widely adopted as it required a significant change in cooking practice (Ballard-Tremeer, 1998; Rouse, 1999).

3.2 Effectiveness of interventions for reducing indoor air pollution

Several studies have measured the reduction of IAP levels for interventions in the South. The majority have focused on different stoves and fuels, concentrating on biomass. Studies have been undertaken in laboratories, simulated field conditions and in the field. Laboratory or simulated field studies have been able to eliminate confounding variables. However, they are also criticised for having little relevance to field conditions (Rouse, 1999; Smith, 1989). Smith (1989) asserts that field tests are necessary because laboratory and simulated tests only impart limited ability to predict actual exposures. This is because in the field, stoves are often not built, operated or maintained as intended by designers, and the many household variations in kitchen design, stove location and user behaviour will influence pollution and exposure levels.

Studies have focused on different pollutants and different technologies, and have used different methodologies, thus making comparison difficult. Many studies test for TSP and CO, because these are the most significant emissions, those considered most harmful to health, and those easiest to measure. While these studies can be considered useful, many have presented widely varying and conflicting results, and hence quite varied and inconsistent conclusions. Therefore, implications for recommended interventions remain unclear. This section will examine these studies and present their findings and note inconsistencies. Table 1 outlines the most recent WHO guidelines for pollutant levels to enable comparison.

Table 1. Recommended emissions levels for pollutants applicable to IAP

Pollutant	Guideline (limit not to be exceeded)
Sulphur dioxide (SO_2)	500 μg/m^3 for 10 minutes
Carbon monoxide (CO)	100 mg/m^3 = 90 ppm for 15 minutes 60 mg/m^3 = 50 ppm for 30 minutes 30 mg/m^3 = 25 ppm for 1 hour 10 mg/m^3 = 10 ppm for 8 hours
Nitrogen dioxide (NO_2)	200 μg/m^3 for 1 hour
Particulates (PM_{10} and $PM_{2.5}$)	No guidelines given (no safe limit can be identified)
Formaldehyde (HCHO)	100 g/m^3 for 30 minutes

Source: WHO (2000)

3.2.1 Studies investigating emissions reductions from improved stoves

The studies' results are difficult to compare due to the different measurements used, but clearly present conflicting findings. They show that, in general, improved stoves are less polluting than traditional stoves, with some exceptions, such as Joshi *et al* (1989), and also Ballard-Tremeer & Jawurek (1996), who found that improved stoves had higher CO and SO_2 emissions – although they do not give results for TSP. It could be argued that any improvements are due to flues, however Ezzati *et al* (2000a) found lower TSP levels in six types of improved stove without flues.

RWEDP (1993c:13) argues that "many stoves concentrate on increasing thermal efficiency at the expense of combustion efficiency, thus creating more pollution, especially with flueless stoves". Bruce *et al* (2000:1087) assert that improved stoves are usually better, but not substantially: "although improved stoves are usually capable of reducing ambient pollution and personal exposure, the residual levels for stoves in regular use are still high, mostly in the range 500 to several thousand μg/m^3 TSP or PM_{10}". This is reflected in the results of Smith *et al* (1983). It is difficult to determine the specific improvement made by flues, but the results suggest that the greatest reductions are from improved stoves with flues, such as Reid *et al* (1986), Joshi *et al* (1991) and Naeher *et al* (2000), where significant reductions of TSP and CO were recorded.

Although it is difficult to determine the difference that is specifically attributed to the presence of a flue, the results seem to suggest that the highest reductions observed are from those studies that tested improved stoves with flues, such as Reid *et al* (1986), Joshi *et al* (1991) and Naeher *et al* (2000), where significant reductions in TSP and CO were recorded.

Goldemberg (2000:372) argues that flues make a significant difference: "even the best biomass stoves available today do not greatly reduce the health-damaging pollution from biomass combustion, although they may put it outside through well-operating chimneys or hoods"; as does RWEDP (1993c:13): "improved cookstoves with a chimney are environmentally safe as far as the kitchen atmosphere is concerned".

Table 2. Summary of findings from studies investigating emissions from different stoves

Reference	Stoves studied	Results
Ballard-Tremeer & Jawurek (1996)	Laboratory test: Open fire Open fire with grate One-pot metal stove (no flue) Two-pot ceramic stove (no flue) Two-pot metal stove (with flue)	Average smoke emissions lowest for fire on grate and 2-pot ceramic stove; others higher by factor of 1.5–3. CO and SO_2 higher from 3 stoves than 2 fires; stoves higher by factor of 2-3 (CO) and 3–10 (SO_2).
Ezzati *et al* (2000a)	Field test (Kenya): Open fire 3 improved wood stoves (no flue) 3 improved charcoal stoves (no flue)	- Improved wood stove reduced TSP by 48% (1822 μg/m^3) (burning) and 77% (1034 μg/m^3) (smouldering). - Improved charcoal stove reduced TSP by 63-65% (559-578 μg/m^3) during burning. - Transition from wood to charcoal reduces TSP by 87% (3035 μg/m^3) (burning); 92% (1121 μg/m^3) (smouldering).
Joshi *et al* (1989)	Simulated field test (India): 1 traditional stove (no flue) 3 improved stoves (no flue) wood (w) crop residue (c) dung (d)	- Both TSP and CO emissions were higher from the 2 more efficient improved stoves: - Traditional stoves (mean - g/kg of fuel): TSP = 1.9 (w); 2.7 (c); 52.5 (d) CO = 17.0 (w); 26.0 (c); 42.0 (d) - Improved stoves (mean - g/kg of fuel): TSP = 2.4 (w); 9.4 (c); n/a (d) CO = 47.5 (w); 91.0 (c); n/a (d)
Joshi *et al* (1991)	Simulated field test (India): 2 heavy stoves with flues – 'thapoli' (bricks and clay) 'sahyog' (clay) wood (w) crop residue (c) dung (d)	- Flue can remove 80% CO and 60% TSP from indoors. - Chimeys emitting emissions indoors lead to higher CO than stoves without chimneys. - TSP rose by up to 1100% with dung. - Sahyog vented outside [4m flue] - g/kg of fuel: TSP = 0.5 (w); CO = 5.0 g/kg (w) Sahyog vented inside [1.8 m flue] - g/kg of fuel: TSP = 1.3 (w); CO = 25.0 g/kg (w)
McCracken & Smith (1998)	Field test (Guatemala): open fire *plancha* stove water boiling test (W) standard cooking test (C)	Plancha reduced $PM_{2.5}$ by 87-99% and CO by 91-96% for water-boiling and cooking tests respectively. Open fire: $PM_{2.5}$ = 14,800 μg/m^3 (W); 27,200 (C) CO = 86,400 μg/m^3 (W); 118,000 (C) *Plancha:* $PM_{2.5}$ = 1,170 μg/m^3 (W); 450 (C) CO = 2,040 μg/m^3 (W); 14,900 (C)
Naeher *et al* (2000)	Field test (Guatemala): background (B) open fire using (wood) (O) *plancha* stove (wood) (P) LPG stove (L) Test area – kitchen, bedroom, outdoors	Plancha and LPG reduce CO and TSP by 10-20% compared to open fire; *plancha* deteriorates with age. Kitchen values: $PM_{2.5}$ = 56 μg/m^3 (B) 528 (O) 96 (P) 57 (L) PM_{10} = 173 μg/m^3 (B) 717 (O) 210 (P) 186 (L) TSP = 174 μg/m^3 (B) 836 (O) 276 (P) 218 (L) CO = 0.2 ppm (B) 5.9 (O) 1.4 (P) 1.2 (L)
Ramakrishna *et al* (1989)	Field test (India): open fire (half) 7 types of improved stove – with and without flues (half)	CO significantly lower for improved stoves (except one), irrespective of flue. No significant improvement in TSP or conclusions could not be reached. In one case where traditional stove had hood, TSP was significantly lower.
Reid *et al* (1986)	traditional stove w/out flue improved stove with flue	Improved stove reduced CO by ¾ and TSP by $^2/_3$. Traditional *chulhas*: TSP = 2200-2900 μg/m^3; CO = 220-230 ppm Improved *chulhas*: TSP = 710-1300 μg/m^3; CO = 35-39 ppm
RWEDP (1993b)	Laboratory testing (India): 29 types of improved *chulha*	TSP values range from 50 to 3800 μg/m^3, although median value approximately 1500 – 1800 μg/m^3.
Smith *et al* (1983)	Field test (Nepal): traditional *chulha* (no flue) pit *chulha* (no flue) smokeless *chulha* (with flue) test areas: main room veranda separate kitchen	- TSP and benzo(a)pyrene (BaP) – higher for traditional *chulhas,* but smokeless *chulha* performed poorly. - Traditional *chulha*: TSP = 6400 μg/m^3; BaP = 4100 ng/m^3 - Pit *chulha*: TSP = 6600 μg/m^3; BaP = 2700 ng/m^3 - Smokeless *chulha*: TSP = 4600 μg/m^3;BaP = 2400 ng/m^3

Note: where appropriate, TSP emissions have been changed to μg/m^3 for ease of comparison

3.2.2 Studies investigating emissions reductions through use of hoods

Although no studies specifically measured emission reductions using hoods, Ramakrishna *et al* (1989) found significantly reduced TSP from one house using an open fire under a hood in India. Similarly, a field study in Kenya observed that houses with both hoods and windows had lower levels compared with houses with just windows, illustrating that hoods are very effective in the extraction of smoke compared with ventilation (Gitonga, 2001).

3.2.3 Studies investigating emissions reductions from improved fuels and fuel switching

Studies have also examined emissions levels from different fuels (see Table 3); however, no studies measuring emissions from cleaner fuels, such as biogas or producer gas, were identified.

Studies comparing emissions from fuels show that biomass fuels are generally more polluting than fossil fuels. An interesting finding from Brauer *et al* (1996) and Ballard-Tremeer & Jawurek (1996) is the significant difference made by adding a grate to an open fire. The studies by Brauer *et al* (1996) and Zhang & Smith (1999) show that emissions from biomass may not be higher per *unit* of fuel, but can be higher per cooking task as biomass cooking typically takes *longer*. Brauer *et al* (1996) also mention that studies focus on emissions from *fuels* and not from *foods* being cooked. Harrison (2000) notes that emissions from cooking with fat are particularly high in TSP.

3.2.4 Studies investigating emissions reductions through improved ventilation

Very few studies look at the effect of improved ventilation in reducing IAP. Benefits were found with ‘cooking window’ constructions in Vietnam, and it was asserted that cross draft from windows could decrease CO by 50% in kitchens (Nyström, 1994 cited in Ballard-Tremeer & Mathee, 2000). Bruce (1999b) also believes that improving ventilation will have a significant impact on air exchange rates and indoor pollutant concentrations. Albalak *et al* (1998) measured PM_{10} in two Bolivian villages, one in which cooking was done indoors and the other outdoors. They found that mean PM_{10} levels were 1830 μg/m^3 for indoors and 280 μg/m^3 outdoors, over six times lower.

3.2.5 Studies investigating emissions reductions through behavioural changes

Information on behavioural changes and IAP reduction is very scarce. McGranahan (1994) believes that information shortages could be combated with health campaigns. Ballard-Tremeer & Mathee (2000) stress the potential of behaviour in contributing towards a reduction, but note that it is unlikely to bring about decreases as large as those achieved by hoods or fuel switching.

3.2.6 Indications of the most effective intervention to alleviate IAP

In addition to the mixed and conflicting results from the above studies, there is intense debate over which intervention is the most effective in reducing IAP. Table 4 presents a comparison of the effectiveness of the main types of intervention.

A number of sources argue that improved stoves are the way forward. Brauer *et al* (1996:109) argue that “control efforts should focus on improvements in cooking stoves and/or fuel substitution rather than alteration to the design of kitchens”. DFID (1999:3) agree: “it would not be realistic to encourage the abandonment of traditional fuels. In most poor countries biomass is the only significant indigenous source of energy. Important opportunities exist to assist with improving the efficiency with which biomass is used”. RWEDP (1993c) and Goldemberg (2000) also agree, but indicate that improved stoves should be a short-term response (5 years). Conversely, Hulscher (1998) believes that there is no such thing as a dirty fuel, only dirty technology. He disagrees that biomass should be considered as a ‘traditional’ or ‘dirty’ fuel, and points out that it is used widely in the North, and can burn very cleanly given the right technology (compare an old, inefficient engine to a modern, clean one).

Table 3. Summary of findings from studies investigating emissions from different fuels

Reference	Focus	Results
Brauer *et al* (1996)	Field test (Mexico): TSP - biomass (B) - biomass + LPG (M) - LPG (L) - ventilated biomass (V) - outdoors (control) (O)	- PM_{10} and $PM_{2.5}$ concentrations were highest in kitchens burning biomass only: Concentrations in rank order, highest first: biomass > biomass + LPG > ventilated biomass > LPG > outdoors - Mean $PM_{2.5}$ (μg/m^3) (cooking period) = 554.7 (B) 203.6 (M) 69.4 (L) 132.4 (V) 37.4 (O) - Mean PM_{10} (μg/m^3) (cooking period) = 767.9 (B) 311.2 (M) 225.5 (L) 282.9 (V) 68.3 (O)
Oanh *et al* (1999)	Laboratory test (SE Asia): TSP + polycyclic aromatic hydrocarbons (PAH) - wood (W) - charcoal (C) - coal briquette (B)	PAH – wood highest; charcoal lowest. TSP – wood highest; briquettes lowest. TSP (μg/kg fuel) (concentration sample) = 5100 (W) 3600 (C) 700 (B)
Raiyani *et al* (1993)	Field test (India): TSP + CO + NO_2 + SO_2 +HCHO (formaldehyde) + PAH - dung (D) - wood (W) - coal (C) - kerosene (K) - LPG (L) [= control]	- Majority TSP and PAH emissions less than $PM_{2.5}$ size. - Dung and wood had highest emissions for all pollutants, except SO_2, for which coal was the highest. - TSP (μg/m^3) (cooking period) = 3470 (D) 2630 (W) 1190 (C) 520 (K) 500 (L) - CO (mg/m^3) (cooking period) = 174 (D) 189 (W) 110 (C) 137 (K) 24 (L) - NO_2 (μg/m^3) (cooking period) = 348 (D) 344 (W) 165 (C) 184 (K) 183 (L) - HCHO (μg/m^3) (cooking period) = 1002 (D) 916 (W) 165 (C) 164 (K) 87 (L) - SO_2 (μg/m^3) (cooking period) = 188 (D) 187 (W) 258 (C) 121 (K) 65 (L)
Zhang & Smith (1999)	Mixed simulated field and field test (China): Carbonyl emissions from - kerosene - biomass - LPG - coal - coal gas - natural gas	Carbonyls were rarely emitted by coal, coal gas and natural gas. - Kerosene and LPG emissions were higher, but biomass stoves were the highest. - Coal is lower in carbonyls than other fossil fuels, by may producer higher levels of other emissions (TSP, CO, SO_2).
Nyström (1994), Wang & Smith (1999), Hong (1992) [in Ballard-Tremeer & Mathee (2000)]	coal briquettes	High levels of CO at beginning of cooking (70 ppm), then falls to 20 ppm. TSP = 1.2 kg/GJ compared with 1.1 kg for traditional stove using biomass or 5kg on coal stove TSP 60% of those for firewood, but CO 240% of that for firewood.

Note: where appropriate, TSP emissions have been changed to μg/m^3 for ease of comparison

As outlined above, some sources believe that mechanisms to remove smoke from the indoor environment are the best way to reduce IAP, such as Zhang & Smith (1999:2319): "a simple but relatively effective way to reduce the exposure is to use cookstoves with flues, chimneys, or hoods instead of releasing pollutants directly into the kitchen". Bates & Doig (2001) believe that hoods are the key to removing emissions from the kitchen environment, because they do not depend on improved stoves, and provide constant ventilation for smoke to escape. Ballard-Tremeer & Mathee (2000) also believe that hoods have potential. Like improved stoves, WHO (2000) regards chimneys as a short-term solution, while Goldemberg (2000) regards technologies that can potentially achieve dramatic improvements to be medium-term goals (5-15 years).

Conversely, there is little support for increased ventilation, for instance, Brauer *et al* (1996) believe that IAP is best reduced through better stoves rather than modified kitchen design.

Table 4. Assessment of exposure reduction of different types of intervention

Intervention	Exposure as % of open fire [open fire = 100%]
Improved biomass stove – no chimney	50 to 150
Improved stove – with chimney	33 to 100
Briquettes / pellets	75 to 100
Charcoal	10 – 30
Kerosene / LPG / biogas / producer gas	0 – 2
Other low smoke fuels (ethanol, biodiesel)	0 - 150
Solar cookers / electricity	0
Hoods	50
Ventilation / windows	15
Separate kitchen	10 – 100
Use of lids	50 – 100
Keeping children out of smoke	?
Stove at waist height	?
Sound operation and good maintenance	50 - 100

Adapted from Ballard-Tremeer & Mathee (2000)

Many sources identify fuel switching as the best response for IAP reduction. Ballard-Tremeer & Mathee (2000), Ellegard (1996) and DFID (1999) believe that a switch from wood to charcoal is beneficial, and advocate better charcoal production techniques. Some sources, including Bruce (1999b), believe that fuel-switching is a long-term response. Goldemberg (2000) points out that kerosene and LPG have replaced biomass in countries that have achieved successful rural development, namely Brazil and South Korea. He asserts that transition to modern energy is the appropriate long-term (15-30 years) goal.

3.3 Final Remarks

In the debate over the most effective interventions, there is little recognition that interventions should be context-specific and that different interventions may be more or less appropriate in certain contexts. Section 5 discusses the socio-cultural and practical aspects of interventions and barriers to their adoption. A further important aspect of IAP interventions is government policy responses, which are not within the remit of this report. Policy is important for IAP as it is both able to address the structural framework in which IAP is produced and persists, and play a key role in the promotion of interventions. As Bruce *et al* (2000:1088) note, “it is necessary to keep in mind the close interrelationship between poverty and dependence on pollution fuels, and consequently the importance of socio-economic development, which should be at the core of efforts to achieve healthier household environments”.

4. Health outcomes of technical interventions

The greatest health benefits to be gained from technical interventions or changes in behaviour are likely to occur as a result of decreasing exposure to suspended particles. There is still much to be learned about the components of particulate pollution and the biological mechanisms through which exposure to particles impacts on health. However, it seems that acute and chronic respiratory diseases represent the greatest health impact of IAP, and that exposure to high levels of suspended particles is an important risk factor for these diseases. In addition it is likely that suspended particles contain carcinogens that can cause cancers of the respiratory system.

Dockery and Pope (1994) estimate that mortality will increase by 1% for every 10 $\mu g/m^3$ rise in PM_{10} concentration. This estimate is based on studies of ambient air pollution. The only detailed work to date on an exposure-response relationship is that of Ezzati and Kammen (in press, a; in press, b) who examined the relationship between ARIs and exposure to PM_{10} from domestic stoves in Kenya. They found that the relationship is non-linear. Once PM_{10} levels reach 2000 $\mu g/m^3$, additional units of PM_{10} lead to smaller increases in the probability of ARI than at levels below 2000 $\mu g/m^3$. For this reason they recommend that efforts be concentrated on interventions that bring PM_{10} exposure to levels below 2000 $\mu g/m^3$ (and if possible below 1000 $\mu g/m^3$).

The switch from biomass to charcoal, kerosene or gas is one intervention that consistently lowers particulate pollution within the range recommended by Ezzati and Kammen (in press, a; in press, b), and can bring levels down to those established as standards for ambient air. However, such changes are likely to be beyond the reach of the majority of poor, biomass users. Improved wood burning stoves have not been universally successful in reducing particulate pollution. Those reductions that have been achieved have been more modest. Nevertheless, some of these stoves have brought PM_{10} levels down below 2000 $\mu g/m^3$. Ezzati and Kammen (submitted) have reported that lower probabilities of being diagnosed with ARIs are associated with the use of improved wood burning stoves. Among children below four years of age they report a decrease of 24% in the probability of ARI when comparing households with improved wood stoves and traditional three-stone hearths. Although this result was not statistically significant in their sample, if it could be replicated on a large scale it would represent a considerable public health benefit.

The benefits of an improved stove depend on many factors. These can include fuel type, local climate, acceptability, and behaviour patterns (especially of cooks and children). Therefore there is no single intervention for which the degree of health impact can be universally predicted. The comparison of different options is also hampered by a lack of accurate data on the resulting exposures across the range of pollutants. The health benefits to be gained from an intervention will depend not only on the scale of the reduction in emissions but also on which emissions are reduced. An intervention that reduces exposure to particulates but not to toxic condensates may reduce ARI but not cataracts. A dilemma would arise if an intervention achieved substantial reductions in exposure to one pollutant but substantially increased the exposure to another.

No studies have simultaneously measured all possible pollutants and data on emissions other than particulates and carbon monoxide are particularly scarce. Comparisons based on the available data are difficult. On the data available it seems that, in most cases, when stove technology is changed or a flue or chimney introduced, all emissions are affected in a similar direction, albeit to different extents. Changes in fuel type, however, can change the nature of the exposure. Thus a switch to charcoal can reduce exposure to particles but increase the exposure to carbon monoxide, while a switch to kerosene introduces the risk of kerosene poisoning. This argues for careful testing of all potential interventions and consideration of the full range of potential health risks, prior to attempts at widespread introduction.

5. Promotional and marketing experience of improved technologies

Most studies and projects on technical interventions have focused on their design and effectiveness, with relatively little attention being devoted to their marketing and promotion processes. The dissemination of technical interventions are fundamental to their effectiveness, as solutions will make no difference to the lives of intended beneficiaries if they are not used.

Although the interventions being discussed here are *technical* responses to IAP, the context into which they will be integrated is social and cultural. Therefore, interventions must also meet other needs of users, as well as meeting technical criteria of smoke reduction and fuel efficiency. In the words of Bates (2001a:1): “it is incumbent on development organisations to recognise that technologies should be appropriate to people’s needs, rather than trying to change people’s behaviour to suit the technological option”. Many examples of improved technologies have failed through not meeting user needs. This section will look at the marketing and promotion experiences of technical interventions, and the various factors influencing their levels of uptake.

5.1 Experiences of marketing, promotion and dissemination

The marketing and dissemination experiences described in the literature focus on improved stoves and, to a lesser extent, improved fuels and fuel switching. The lack of emphasis on promotion may be because many technical interventions are still at an experimental stage, and are not yet ready for wide dissemination, or because they are designed for a specific local context. Smith (1989) and Bruce (1999b) believe that lessons of improved dissemination need to be applied to current programmes, and further case studies should examine the production, distribution and maintenance of improved technologies.

Promotion and dissemination of technical interventions fall into two groups: large-scale centralised efforts and small-scale independent efforts. These are characterised by national programmes, such as in China and India; and small-scale NGO-led efforts, of which there are many in Asia and Africa (Goldemberg, 2000; Smith, 1989). The experiences of both types have been erratic, each with instances of success and failure (Ballard-Tremeer & Mathee, 2000).

Smith (1989) describes how large-scale and small-scale initiatives usually involve a trade-off between quality and quantity. National programmes tend to result in a greater number of stoves being built and distributed, but also suffer from high rejection rates. National programmes may also pay little attention to monitoring, as this diverts time and costs from distribution. Local projects, on the other hand, are more likely to be participatory and promote technologies through a bottom-up approach. However, a disadvantage of small initiatives is that they can lead to fragmented efforts, meaning that lessons are unlikely to be widely disseminated, and research and field testing will be repeated (Barnes *et al*, 1993). The following sections compare some experiences of large-scale and small-scale programmes.

5.1.1 Large-scale programmes

China

The ongoing Chinese National Improved Cookstove Programme was initiated in 1980 to develop and widely disseminate stoves with flues primarily for biomass conservation (Bruce, 1999b; RWEDP, 1993a). The programme is co-ordinated by several central government authorities which delegate to county level, thus is not overly bureaucratic in practice (Smith *et al*, 1993). The counties select stoves appropriate to the local context and delegate implementation, training and monitoring to local rural energy offices (RWEDP, 1993a; Smith *et al,* 1993).

By 1992, more than 140 million rural farming households had received improved stoves, a very impressive coverage of approximately 70% of the rural population, and representing 90% of stoves installed worldwide at that time (Barnes *et al,* 1993; RWEDP, 1993a). The programme adopted a policy of first concentrating on areas of greatest need hence the emphasis on farm households (Smith *et al,* 1993). The programme promotes some 20 different stove models, most for biomass and some for coal use. The stoves are aimed at different contexts, with some for heating, in different sizes, and a few industrial models (RWEDP, 1993a). All parts are made from prefabricated cast iron, or ceramic or concrete slabs to help to maintain stoves' critical dimensions and durability (RWEDP, 1993a). Latterly, the production of complete stoves was replaced by the local manufacture of durable inserts that could be used with a variety of stove structures (Smith *et al*, 1993).

A distinctive feature of the Chinese programme, and one to which its success is often attributed, is the design of stoves for commercial marketing. The quality and durability of stoves enables them to be sold on the market like other household commodities (RWEDP, 1993a). From the outset, the government has encouraged local energy manufacturing and retail companies to produce stoves, and has provided both loans and technical and management support (Smith *et al*, 1993). The stoves are also affordable, priced at around US$ 10 in 1993, with a very low government subsidy of US$ 0.84 paid to producers, meaning that users pay the full material and labour costs (Barnes *et al*, 1993; Smith *et al,* 1993). However, Smith *et al,* (1993) stress that, in terms of purchasing power, China is a middle-income country, and most people can afford to pay for stoves.

Other distinctive elements of the Chinese programme that contribute towards its success include women's involvement at the design and field-testing stages, and incorporating their needs (ESMAP, 2001). More recent stoves are designed to better meet user needs of convenience and attractiveness: "the importance of convenience to the household cannot be overemphasised" (Smith *et al*, 1993:955). The programme also comprises regular and systematic monitoring and evaluation (Smith *et al*, 1993). The programme's success is also due to the innovative well-publicised national competitions for improved stove design (Goldemberg, 2000).

India

The Indian National Programme of Improved *Chulhas*, initiated in 1983 and still underway, has been far less successful than the Chinese programme (ESMAP, 2000; RWEDP, 1993b). Although operating nationwide, it had distributed only 8 million stoves by 1993 (Barnes *et al*, 1993) and 32 million by 2000, purportedly reaching 25% of households (ESMAP, 2000). The programme's drivers are biomass conservation, smoke reduction and alleviation of women's drudgery (RWEDP, 1993b). The programme is centrally co-ordinated by the Ministry for Non-Conventional Energy Sources through six regional offices which then delegate to state, district, and local levels. In practice, this approach is somewhat bureaucratic (Ramakrishna, 1991 cited in Barnes *et al*, 1993; RWEDP, 1993b).

The programme comprises about 30 different stoves, from simple improved mud stoves for the very poor to metal stoves with flues (ESMAP, 2000; RWEDP, 1993b). The average cost of a stove in 1993 was US$ 4.50, with a 50% government subsidy on the basis that the poorest cannot afford to pay (Barnes *et al*, 1993). Barnes *et al* (1993) note that this provides little incentive for producers to construct stoves, as they are only responsible for production and not subsequent marketing.

Experience shows mixed perceptions from users and at least one third of stoves no longer in use (Barnes *et al*, 1993; Bates & Doig, 2001; Goldemberg, 2000). The high failure rate is due to many stoves soon breaking down, the programme's top-down approach preventing user involvement in the design process, and inadequate monitoring to detect problems at an early stage. As a result, the programme has since concentrated efforts on developing stoves with lifespans of over 5 years, training self-employed workers - especially women - as stove producers, and encouraging potters, blacksmiths and rural technicians to become entrepreneurs in stove production and marketing, as in China (ESMAP, 2000). The programme is also trying to integrate stove efficiency, women's participation and user convenience, and improve monitoring (Barnes *et al*, 1993; ESMAP, 2000).

5.1.2 Small-scale programmes

Kenya

In Africa, Kenya has experienced the highest level of improved stove distribution, although only reaching 10% of households, with 700,000 stoves being distributed primarily in urban areas, compared with only 50,000 stoves in other countries (Goldemberg, 2000; Smith *et al*, 1993).

Kenya has experienced both successful and failed projects. A successful intervention is the Kenyan ceramic *jiko*, an improved charcoal stove produced by small businesses and artisans, which has been widely distributed and adopted. However, to illustrate the context-specificity of a stove, when exported to other countries, such as Tanzania, the *jiko* was rejected until the design was modified to suit local needs (Barnes *et al,* 1993; Goldemberg, 2000).

Ethiopia

Energy for Sustainable Development (ESD) has been working with improved stoves for several years in East Africa, including the *lakech* and *mirte* stoves in Ethiopia. A previous project on the commercialisation of the *mirte* stove aimed to develop and test a methodology for the successful and sustainable marketing and dissemination of the *mirte* through private sector producers. The research entailed full-scale commercialisation trials that included radio and television advertising, market demonstrations in urban areas and training and assistance to regional and local energy officials. As a result, over 15,000 stoves were sold at market price, illustrating that stoves can be successfully marketed without subsidies when producers receive the necessary training, technical assistance and commercial guidance (DFID, 1997; ETSU, 2001).

A current research project is examining the poverty impact of such improved stoves programmes on producers and users. Initial results from Ethiopia show that poverty alleviation is most apparent for stove producers, and indicates that the long-term sustainable success of stove distribution rests upon a totally commercial focus. In contrast, Uganda's stove programmes have had little success because the programmes were driven by donors and NGOs with little attention to marketing techniques or market dynamics (DFID, 2000b).

5.2 Barriers to effective marketing

As indicated by the success and failures of the above initiatives, successful promotion of technical interventions is much more complex than the simple production and distribution of improved technologies. The goal of interventions to reduce IAP will only be achieved if they are *used* by the intended beneficiaries. The most important barriers to user adoption of new technologies are acceptability, access and availability, and affordability. There is nothing new in this; the same factors have been found to be crucial for development initiatives in other sectors, such as water and sanitation. This section will look at the principal factors that determine the potential effectiveness of technical interventions in terms of user adoption.

5.2.1 Practical needs of users

The drivers for most technical interventions, notably improved stove and fuel initiatives, are fuel efficiency and smoke reduction. Factors considered as priorities of the poor by project implementers include savings in fuel collection, less expenditure on fuel and health benefits resulting from smoke reduction (Hulscher, 1998; USAID, 2000). However, these are rarely the *principal* reasons for which people use improved stoves (RWEDP, 1993c). This does not mean that such goals are not relevant to the poor, or that they would not improve their lives, but they are often not the most important aspects of energy interventions for poor people themselves. There is therefore a strong consensus that *perceived user needs* are the appropriate starting point for technical interventions, and will lead to a higher level of uptake (Ashley, 1993; Barnes *et al,* 1993; Hulscher, 1998). Hulscher (1998) suggests kitchen design, convenience and income generation as better starting points, as these are often user priorities.

In terms of technology design, all aspects must be compatible with user needs. These can range from cultural needs, such as the need for a slow heat for warming milk in the Punjab, or a very high heat for stir-frying in China, or priorities of individual users, such as convenience or attractiveness (Barnes *et al,* 1993). The following have all been suggested as important user features of improved stoves: fuel efficiency, heat control, power output, smoke, safety features, convenience, attractiveness, low cost, maintenance, compatibility with existing kitchen utensils, fuel and cooking practices, construction material, skills for production and distribution (Barnes *et al,* 1993; RWEDP, 1993c). Table 5 outlines the main factors that will be important to users.

Table 5. Factors important in stove design

Factor	Detail
Fuel efficiency	Burns less fuel – less to collect and/or buy
Cleanliness	Chimney directs smoke outside Burns fuel with little smoke Easy to clean ash from stove Does not blacken pots
Time saving	Cooks food fast Easy to light and keep alight
Fuel	Flexible: can use different fuels Fuel easy to prepare and does not need to be cut small
Cooking	Easy to control heat output Adaptable – able to cook traditional foods Flexible regarding different and local kitchen utensils Can keep second pot warm, simmering, cooking or boiling
Comfort	Comfortable to use Can be installed at waist height Simple to use with little or no training or new skills
Safety	Outside surfaces of stove cooler Stable
Cost	Low initial cost Durable design
Portability	Portable for indoor and outdoor use Lightweight with comfortable handles for easy transportation
Space	Occupies little space
Other	Looks good, modern or of adequate status Produces smoke to repel insects, seal or preserve roof thatch, preserve food Produces heat for drying clothes Provides heating and/or emits light Provides social focus Improves household division of labour

Reproduced from Rouse (1999)

User convenience is often underestimated. Giving a parallel example of the success of microwaves in the North, Ashley (1993) stresses that the main benefit and reason for their wide usage is *convenience*. She points out that the benefits are determined by the user, and not those who invent, sell or promote microwaves; therefore, in the South, it must be recognised that women like stoves for different reasons from energy planners. This is illustrated by a Kenyan stove with a tiny firebox for maximum efficiency. Women did not have time to cut fuel into small pieces, so they enlarged the firebox, gladly sacrificing some of the efficiency for more convenience (Barnes *et al,* 1993). Box 5 outlines how a participatory approach with local women was used to develop an improved stove.

Box 5. Participatory Stove Development and Promotion: Village Laboratory in Lucknow

Jonathan Rouse (WEDC) is involved in the co-ordination of a participatory stove project with the Indian NGO, Institute of People's Action and Development Systems (IPADS), in Uttar Pradesh, Northern India. The project has entailed the participatory design and testing of the 'Mina' Stove (see Box 1) in the rural village of Chibau Khera, 25 km from Lucknow.

The design, promotion and testing were all carried out in the 'village laboratory'. This comprised an area of land lent to IPADS by a local potter, whose interest lay in manufacturing and selling components for the stove. The land was situated in the centre of the village, enabling villagers to participate in the process of developing the stove. They helped in construction and testing, posed questions, made suggestions, criticised and even made new models themselves.

The improved stove was developed for mostly illiterate, low-income, female domestic cooks in a rural setting. The project team sought to devise tests which were both relevant to these users, and tests which would serve to promote the stove in the village. As such, a cooking competition was organised in the 'village laboratory'. This comprised two female domestic cooks preparing typical family meals of vegetables, lentils, rice and bread, one on a traditional stove, the other on the improved stove. The same type of wood was provided to both women and the amount used by each was weighed. The women were left to cook without interference from the fieldworkers.

The tests revealed that the Mina stove saved time, used less wood than the traditional stove and emitted considerably less smoke during use. The woman using it also commented on the convenience of having two pot holes. Many women, men and children attended the tests which did much to raise the profile and popularity of the stove and gave the villagers further opportunity to air comments and hopefully allay their concerns.

Since the field trials, villagers who have adopted the stoves have made modifications to the design to suit their needs, that were not previously foreseen. For instance one family had blocked the ash-removal hole under the grate because they feared being bitten by poisonous insects during ash removal, and others had blocked the air vents, seeing no use for them.

Village laboratory *Woman using traditional stove during competition*


Photos: Jonathan Rouse (WEDC)

Source: Jonathan Rouse (WEDC)

Like water and sanitation initiatives, improved technologies to address IAP also have a very strong *gender* element. In developing countries, almost without exception, it is the role of women to prepare food, therefore women must be recognised as the end users of technologies (Ashley, 1993). The need for women's active participation in interventions needs to be widely recognised if technologies are to be adopted and used (Ashley, 1993; Barnes *et al,* 1993; ESMAP, 2001). Some initiatives have either ignored gender aspects, or made assumptions about the needs and perspectives of women; for instance, assuming fuel efficiency to be their top priority due to time spent collecting fuel that could be spent on other activities (ESMAP, 2001). It is particularly important that interventions obtain women's perspectives, because it is often men who decide which cooking device will be purchased (McGranahan, 1994). Hulscher (1998) believes the acceptance of improved stoves is closely related to women's opportunities for paid labour, an aspect that is seldom integrated into stoves programmes, which focus on male artisans and entrepreneurs.

It is also assumed that households will adopt new technologies if the perceived benefits are greater than the costs. However, this assumes that benefits are recognised by users, and also that the interests of all household members are considered by those who decide (Barnes *et al,* 1993; USAID, 2000). Smith (1989) argues that factors such as economy, efficiency, and to some extent, safety, are fairly easily perceived by the users themselves, thus they are best qualified to choose the option that suits their needs. The most effective way of gauging user priorities is to consult them. This can be done by undertaking surveys and engaging participation in interventions so people - especially women - can express their opinions and priorities for factors that determine stove design, fuel use and appearance (Barnes *et al,* 1993). According to Barnes *et al* (1993:126) "an improved stove design should be tried out in households early in the programme and monitored at the development stage to make sure that it is acceptable to the prospective consumers, especially women who are the principal users". This is illustrated by the project in Lucknow described in Box 5. However, other aspects, such as health-damaging contaminants are not detectable to users, and besides, health may not be their foremost priority (Smith, 1989). In this case, education would be essential for the initiative (McGranahan, 1994).

5.2.2 Lay perceptions of users

Alongside the practical needs of users, their perceptions can play a significant role in whether a technology is actually used.

McGranahan (1994) believes that people generally dislike smoke, thus making it difficult to say that people choose to be exposed to high levels of IAP. In Kenya and India, householders generally did not like a smoky indoor environment, due to discomfort and soiling of the house interior; however, on the other hand, it was observed that householders were reluctant to open windows due to cultural needs for privacy (Bates & Doig, 2001; Gitonga, 2001). There are some reports of smoke being used as protection from insects and to preserve thatched roofs (Barnes *et al,* 1993; Gitonga, 2001; Smith, 1989). Box 6 describes lay perceptions of both the status of the improved technology, and its suitability to users' cultural needs.

It is also assumed that the poor want stoves that are as low-cost as possible. Very low-cost improved stoves use low-grade materials, such as mud. However, the poor may consider such rudimentary technology as inferior, leading to concerns of stigmatism, as described in Box 7. This issue has also arisen with very simple and low-cost sanitation. A challenge is therefore to reconcile affordability with user perceptions of adequate quality and status.

Box 6. User perspectives in Lucknow: Prestige and Smoked *Chapattis*

In the stove project in Chibau Khera, a number of issues arose relating to users' perspectives, attitudes and special needs. The first related to the name of the stove. The 'Mina stove' was originally named after a girl in a nearby village who gave instruction in making mud stoves. Some members of the project team, however, insisted that the stove be referred to and promoted in the villages as the 'Jon Stove'. It was explained that the foreign associations were very positive and that such a name in itself would constitute a strong selling point.

Some cooking techniques create specific needs in the design of a stove. One such need relates to the cooking of *chapattis*. These are a round flat bread which form a part of most meals in Chibau Khera. *Chapattis* are partially cooked on a steel plate heated on a stove then baked next to the fire itself (as shown).

The baking in the fire imparts a smoky flavour to the bread. The Mina stove had to be designed with a large firebox opening to allow *chapattis* to be admitted. Ignoring this need could result in a stove not being used, as with an improved stove introduced in Chibau Khera in early 1999 by another NGO. This had a small firebox opening – too low for *chapattis* which resulted in the stove never being used, as it was not culturally acceptable for cooks to omit this stage of cooking.

Photo: Jonathan Rouse (WEDC)

Source: Jonathan Rouse (WEDC)

Box 7. Reconciling Affordability and Status: Cheap Grates in Lucknow

A clay grate (see photo) was promoted in Chibau Khera as a cheap alternative to steel. However, despite reassurances from the project team about its strength and longevity, it did not prove popular. In addition to these practical concerns, there were likely to be deeper attitudes influencing people.

The grate was promoted as a low cost alternative, and this may have been a problem. It is possible people began to view the grate as a poverty indicator because it was so cheap, and a steel grate (often referred to as more expensive) as an indication of wealth.

Photo: Jonathan Rouse (WEDC)

To compound this there are two words in Hindi which indicate deeply held views about certain materials. *Pucka* means permanent, engenders good quality and would be used to describe, for example, a house made of bricks with a tin roof. By contrast *katcha* means temporary, engenders poor quality and would be used to describe, for example, clay objects or houses made from mud and straw. The clay grate is *katcha*, while the steel grate is *pucka*. These may have affected people's attitude towards the grates.

Source: Jonathan Rouse (WEDC)

5.2.3 Affordability, availability and accessibility

In addition to user needs and perceptions, other barriers that impede the adoption of alternatives are access and affordability.

Access to new technologies will depend on the availability of local materials and expertise for production and maintenance. As noted above with low-cost stoves, there is often emphasis on the use of locally-available materials precisely for this reason; however, issues of user acceptance arise if the materials are seen as low quality, as outlined in Box 7. These parts and materials must also be available to produce improved technologies, and barriers may exist to prevent this, as Box 8 describes in relation to chimney stoves. Interventions will not be sustainable if poor users acquire a stove for which they cannot get replacement parts, and some interventions may result in irreparable stoves if the project ends without provision for the supply of parts and skills for maintenance.

Box 8. Embracing Reality: Unobtainable Chimneys in Lucknow

In certain circumstances, technical ideals need to be compromised due to the reality of people's wealth or inadequate supply of materials. Incorporating a chimney on a stove is one such ideal. It can lead to the total removal of smoke from the kitchen area, but this example shows how prices and supply meant that it was better to design a stove for villagers without a chimney.

Fieldworkers approached the Block Division Office (BDO), a local administrative body 5 km from the village. There was a large store of chimneys that were on offer at a substantially subsidised cost to villagers. The BDO was also obliged to support NGO energy-related activities in the area.

After a number of visits, the fieldworkers were unable to procure the chimneys. The main difficulty was that, apparently, no-one had a key to the storeroom in which they were kept. It is likely however, that other more complex reasons existed. The villagers of Chibau Khera had no motor-transport to reach the office and would probably find it difficult to meet the officer.

Given this, it was decided that the stove would have no chimney. Villagers could not afford to pay the full market price and no subsidised chimneys were available. A chimneyless stove cannot eradicate smoke emissions, but at least parts are available locally.

Source: Jonathan Rouse (WEDC)

Technical interventions must be readily available to poor groups who are expected to use them. The most common examples of inadequate availability are with improved fuels. As noted in Boxes 9 and 10, kerosene and LPG are often affordable, but severely restricted local supplies make them infeasible in practice. Young (1989) also notes that cooking devices designed to be used with kerosene and LPG are usually designed for recreational use by the affluent and not subsistence use by the poor, and electric cookers have also not been designed for the poor.

Switching to kerosene represents a greater ‘step’ up the energy ladder than other fuels. Unlike charcoal, it cannot be produced informally, and has to be purchased. Unlike biomass, charcoal and coal it requires a specialised (and expensive) stove for burning, implying additional cost. There are also often transport problems, particularly for rural, inaccessible and isolated areas. Kerosene could be seen as a more practical solution for the urban poor who are more likely to purchase fuel and whose access to biomass is limited. Box 9 outlines the practicalities of obtaining – or being unable to obtain – kerosene in a rural village in India.

As with kerosene, the main drawbacks with LPG are availability and cost. However, the increased availability of these fuels is likely to call for a *policy* response rather than a technical intervention to promote their use. The complexities of promoting a transition to LPG is illustrated with reference to two contrasting experiences in Brazil and India in Box 10.

Box 9. Access to Kerosene in Lucknow

This example illustrates the reality of switching to kerosene for people in Chibau Khera. A number of villagers in Chibau Khera said they used kerosene for cooking and lighting in their homes, but none used it as a replacement for wood. They considered it to be a cleaner fuel, but also considered its use to be labour intensive (having to keep the burner pressure high) and noisy (some burners hiss during operation). It is probable that traditional cooking methods, such as *chapatti* baking (see Box 6) would not be possible using a kerosene cooker.

Subsidised kerosene is available at 8.50 Rupees/litre through ration shops in India. It is also available on the black market for between 10 and Rs12/litre. A single family has a quota of 5 litres per month, but according to one villager, this is sufficient only for lighting needs. This villager also described how the ration shop will sell just 3-4 litres legitimately and withhold the remainder for sale on the black market, forcing people to pay more or use alternative fuels.

While kerosene is available to villagers in Chibau Khera it is not available in sufficient quantities at the subsidised price, and corruption restricts people’s access. In more remote locations, distance, transport and supply problems could compound such restrictions.

Source: Jonathan Rouse (WEDC)

Electricity is the cleanest household fuel in terms of indoor emissions. However, it may not be the best solution for low-income groups in developing countries. Firstly, electricity is rarely used for principal cooking tasks, but for lighting and running electrical appliances such as radios and televisions (Ballard-Tremeer & Mathee 2000). Secondly, it may not be affordable. In China, a rural electrification programme brought electricity to many poor rural homes, but less than 50% of households could afford it, and despite a similar programme in South Africa, poor households continued to use wood for cooking and heating (Bruce *et al,* 2000; Goldemberg, 2000). Like kerosene and LPG, electricity use also necessitates the purchase of alternative cooking devices, which may be more expensive than their simpler counterparts (Bruce *et al,* 2000).

Box 10. Transition from Biomass to LPG in Brazil and India

Brazil

In Brazil, a government programme to encourage domestic LPG use successfully enabled many poor households to switch from biomass to LPG, even in remote rural areas. In 1997, the government deregulated LPG to encourage competition in distribution and retail, reversing previous state control over the commercialisation process. The market was opened up to other distributors and retailers, and fixed tariffs were abolished. The success of the LPG programme is due to easy transportation of gas bottles, high safety standards, better convenience, affordability and an excellent distribution network. The substitution of LPG has contributed greatly to the decline in firewood use, as 88% of homes now use LPG.

India

In India, several government initiatives have encouraged LPG use, such as a government program in Andhra Pradesh to support the cost of LPG cylinders and stoves through very low-cost loans. However, there are several policy and institutional barriers to LPG adoption. The LPG market consists of a two–tier system, in which state-owned Public Distribution System suppliers sell at government subsidised prices to (primarily urban) domestic users, and to private sector distributors at market prices. However, in practice, subsidised LPG intended for domestic use is often diverted to commercial users, meaning that subsidies to not reach those for whom they are intended. Furthermore, there is a waiting list of urban residents who want to switch to LPG, and the poor with no fixed address are unable to obtain subsidised LPG. The reaction of the government, whose budgets are being drained by the untargeted subsidies, has been to freeze the amount of LPG available to the market.

Sources: Brazil (1997), Goldemberg (2000), Storck & Yoffe (1998), USAID (2000), World Bank (2000)

LPG, being a fossil fuel, is subject to price fluctuations which makes it a less accessible option for the poor (Goldemberg, 2000). However, Bates & Doig (2001) disagree, asserting that even the poorest groups will go to very great lengths to make gradual savings to make improvements to their lives when they are convinced that these improvements are priorities for them, thus asserting that the issue is not making improved technologies more *affordable,* but making them *priorities* for low-income groups.

Many technical interventions, principally by governments, are subsidised to make them affordable to the poor and thus achieve a higher level of distribution. Subsidies are also often used as a means of dissemination, with initial subsidies being provided for new technologies to persuade users of their effectiveness before making a financial commitment (Barnes *et al,* 1993). It is assumed that, in the absence of subsidies, poor groups will be unlikely to spend money on improved technologies as they may have other, more pressing priorities, such as the purchase of food and fuel. As noted above by Bates and Doig (2001), this argument will depend on whether such groups regard improved technologies or basic needs as higher priorities. Subsidies may help promote interventions, but do not necessarily guarantee that the new technologies will be used. Evidence shows that most programmes offering stoves at little or no cost have experienced very low use and maintenance rates (Barnes *et al,* 1993; Smith, 1989).

The provision of subsidies may also mean that the poor receive a poor quality stove, or that better stoves are bought by middle-income families, meaning that subsidies do not target the intended beneficiaries (Barnes *et al,* 1993). People often do not value items received at no cost, a lesson learnt from many past development projects (Smith, 1989). Barnes *et al* (1993) assert that government support is better directed by gathering and disseminating information, providing technical and managerial inputs and monitoring implementation, as in the Chinese programme.

5.3 Social marketing

Effective, acceptable technologies will only bring health benefits if populations are sufficiently motivated to buy or build, and use them. Experience of health education suggests that knowledge of a health risk is often a poor motivator. Commercial enterprises make widespread use of marketing techniques to motivate consumer behaviour. Social marketing uses these techniques to achieve socially desirable ends such as improvements in health. The promotion of improved stoves as a means of addressing a major public health problem is likely to benefit from the use of social marketing.

The principle underlying social marketing is to identify the precise needs and interests of a particular audience and to use this knowledge as the basis for motivational messages. It is a structured approach that begins with a short period of formative research to answer a basic set of questions. These questions can be summarised as follows:

- Who are the important audience or audiences at whom the motivational messages will be directed?
- What do they value in the desired behaviour outcome?
- What constraints do they face?
- What channels of communication do they use?
- Which people have an influence on their behaviour?

The answers to these questions are used to design attractive, motivating messages that are delivered to a defined audience through appropriate channels of communication. Characteristics of the audience, and hence of the messages, will vary according to the local context. The approach can help target resources effectively and allows planners to make precise statements about how many people will be reached with what message, through what channels and at what cost.

5.4 Final Remarks

The paramount importance of marketing and dissemination as a component of interventions to promote improved technologies to reduce IAP has been underestimated. The marketing and promotion experiences of improved technologies to alleviate IAP have been mixed, with apparent difficulty of both large and small scale initiatives achieving a balance between quality and coverage. Problems result from interventions that quite simply have not met users' needs and preferences. Integrating a participatory approach into household energy interventions and incorporating field testing to understand and address user needs can reduce these barriers.

Similarly, in many cases lack of access and affordability have prevented the adoption of improved technologies. One of the goals of technical interventions is to achieve sustained production and distribution of improved technologies. Many approaches have adopted a commercial approach oriented towards the local small-scale private sector. A strong commercial focus using existing distribution and marketing channels seems to have been more successful, as observed with the Chinese stove programme. The involvement of producers is also paramount in the design process, as they will ultimately build and produce the stoves. Such approaches have focused predominantly on income-generating activities for (mostly male) artisans and entrepreneurs, with little attention to livelihood opportunities for local people, especially women.

6. Conclusions and directions for action and research

It is estimated that indoor biomass and coal smoke in developing countries is responsible annually for approximately two million deaths, representing around 4% of the global burden of disease. ARIs are the greatest cause of mortality in children under five. Strong evidence now links ARIs with exposure to cooking smoke, therefore women and young children are most likely to be at risk. There is also evidence to support a link with other health problems including chronic obstructive lung disease, cataracts and TB. The greatest health threat from indoor air pollution appears to be due to particulate matter. Therefore, interventions should specifically prioritise the reduction of cooking smoke.

This evidence comes from observational studies, which could be strengthened by intervention studies if exposure and outcome are accurately measured and confounding variables controlled. Research comparing different technologies under different conditions and using the same parameters is also necessary. Data are also needed on exposure to emissions which take into account human behaviour and features of the indoor environment. Health impacts also depend on personal susceptibility, which is influenced by factors such as age and nutritional status.

Data on the effectiveness of technologies in reducing emissions are incomplete and often contradictory; nevertheless, a number of important points emerge from the literature. Fuel switching has the greatest potential to reduce indoor smoke in the long term, although this is likely to remain beyond the means of the majority of the poor for the foreseeable future. Improved stoves with flues and chimneys and the use of hoods appear to be the most effective short-term interventions.

However, the emissions from different improved stoves vary greatly, and stoves that are more efficient do not necessarily reduce emissions levels. The effectiveness of stoves and hoods is also determined by factors such as ventilation, climate and mode of operation. Furthermore, the emissions from many stoves and hoods still result in exposures well above the maximum recommended WHO guidelines. In adopting a more people-centred approach, greater emphasis needs to be placed on emissions per cooking task rather than emissions per unit of fuel burnt, as levels of indoor smoke may not be reduced if less polluting stoves are used for longer periods.

Too little attention has been paid to ascertaining users' perceptions and needs with regard to improved stoves, in contrast to the more extensive scientific studies, that have been undertaken outside the local context. Top-down solutions that do not incorporate the needs or views of intended users, or the particularly important gender dimension, are destined to failure. Aside from national programmes in China and India, little attention has been given to the promotion of improved technologies. The promotion and marketing of stoves has had mixed success. It is unlikely that there is a single, universally acceptable and effective intervention. Therefore it is crucial to design and field-test improved technologies in the specific local context at which they are targeted. For this process to be effective, detailed surveys of user needs, desires and perceptions will be necessary at all stages of an intervention. In this respect, lessons learned from other sectors, such as water and sanitation, are relevant to interventions for reducing indoor air pollution. Interventions that have adopted a commercially-oriented approach to the production and distribution of improved technologies appear to be more successful.

Appropriate policy responses also have an important role. Fuel-switching, in particular, needs a comprehensive policy framework in order to make it an option for the poor. Policies that foster income-generating activities or create access to microcredit will also increase the capacity of the poor to address indoor air pollution.

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