Addressing the Impact of Household Energy and Indoor Air Pollution on the Health of the Poor – Implications for Policy Action and Intervention Measures

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ABSTRACT

More than 2 billion of the world's poorest people still rely on biomass (wood, charcoal, animal dung, crop wastes) and coal-burning for household energy needs. Use of these fuels indoors leads to levels of indoor air pollution many times higher than international ambient air quality standards allow for, exposing poor women and children on a daily basis to a major public health hazard. This exposure increases the risk of important diseases including pneumonia, chronic respiratory disease and lung cancer (coal only), and is estimated to account for a substantial proportion of the global burden of disease in developing countries. Other important health impacts from household energy use among the poor include burns to children and injuries to women from carrying wood. Furthermore, a range of inter-related quality of life, economic and environmental consequences of household energy use impact on health through such factors as the time women spend collecting scarce fuel, and restrictions on educational and economic activity. A wide range of interventions can reduce the impact of indoor air pollution. These include changes to the source (improved stoves, cleaner fuels), living environment (better ventilation) and user behaviour (keeping children away from smoke during peak cooking times). These can be delivered through policies operating at national level (supply and distribution of improved stoves/cleaner fuels) and local level (through community development). Experience to date shows that successful implementation requires participation by local people (particularly women), collaboration between 'sectors' with responsibility for health, energy, environment, housing, planning etc., and with an emphasis on market sustainability. Initial studies suggest that indoor air pollution interventions perform favourably in terms of cost-effectiveness, with, for example, an improved stove programme costing $50-100 per DALY saved. Although evidence is in need of strengthening, concerted global action is needed to implement cost-effective interventions which can deliver substantial health benefits to the poor, and contribute to sustainable development.

INTRODUCTION

Exposure to indoor air pollution from the combustion of traditional biomass fuels (wood, charcoal, animal dung, and crop wastes) and coal is a significant public health hazard predominantly affecting poor rural and urban communities in developing countries. Large numbers of people are exposed on a daily basis to harmful emissions and other health risks from biomass and coal-burning, which typically takes place in open fires or low-efficiency stoves with inadequate venting. It is estimated that globally 2.5 to 3 billion people rely on these (solid) fuels for everyday household energy needs (1). The majority of those exposed are women, who are normally responsible for food preparation and cooking, and infants/young children who spend time near the cooking area.

Although the fraction of global energy from biofuels has fallen from 50 percent in 1900 to around 13 percent currently, this trend has levelled off and there is evidence that biofuel use is increasing among the poor in some parts of the world (1,2). It is estimated that daily fuelwood consumption in Africa, for example, is approximately 500,000 tonnes per day. The efficiency of the three-stone open fire used in many developing countries is only about 10-15 % however, thus most of the energy content of the fuel is wasted (3,4).

While the majority of people at risk of exposure live in rural areas of the world's poorest countries, this is increasingly becoming a problem of poor urban dwellers, a trend likely to increase with the urban transition. It should be noted too that the impacts on health of domestic fuel use go beyond indoor air pollution and affect the household economy, women's time and activities, gender roles and relations, safety and hygiene, as well as the global environment. For example, it is estimated that half of the worldwide wood harvest is used as fuel. Further, in some settings, poor families expend more than 20% of disposable household income to purchase biofuels, or devote more than 25% of total household labour to wood collection (5).

Biomass smoke contains a large number of pollutants that, at varying concentration levels, pose substantial risks to human health. Among hundreds of harmful pollutants and irritant gases, some of the most important include particulate matter, carbon monoxide, nitrogen dioxide, sulphur dioxide (mainly from coal), formaldehyde, and carcinogens such as benzo[a]pyrene and benzene. Studies from Asia, Africa and the Americas (see recent reviews 6,7,8,9) have shown that indoor air pollution levels from combustion of biofuels are extremely high – often many times the standards in industrialized countries such as those set by the U.S. Environmental Protection Agency (US-EPA) for ambient levels of these pollutants (10).

Whereas cities in industrialised countries infrequently exceed the US-EPA 24-hour standard for PM_{10} (small particles of diameter less than 10 microns) in rural homes in developing countries, the standard may be exceeded on a regular basis by a factor of 10, 20, and sometimes up to 50, exceeding even the high levels found outdoors in such cities as in coal-burning northern China (11). Typical 24-hour mean levels of PM_{10} in homes using biofuels may range from 300 to 3,000+ $\mu g/m^3$ depending on the type of fuel, stove, and housing (9,12). Concentration levels measured depend on where and when monitoring takes place, given that significant temporal and spatial variations (within a house, including from room to room), may occur (8,9,13). Ezzati et al. (8) for example have recorded concentrations of 50,000 ug/m^3 or more in the immediate vicinity of the fire, with concentration levels falling significantly with increasing distance from the fire. These small particles are able to penetrate deep into the lungs and appear to have the greatest potential to damage health (14). Levels of carbon monoxide and other health-damaging pollutants also often exceed international guidelines (see Annex A).

REVIEW OF THE EVIDENCE FOR HEALTH EFFECTS

There is consistent evidence that exposure to biomass smoke increases the risk of a range of common and serious diseases of both children and adults. Chief amongst these are acute lower respiratory infections (ALRI) in childhood, particularly pneumonia (6,15,16). Association of exposure with chronic bronchitis [assessed by symptoms] and chronic obstructive pulmonary disease [COPD - progressive and incompletely reversible airways obstruction] (assessed by spirometry and clinical assessment) is also quite well established, particularly among women (7). In addition there is evidence (mainly from China), that exposure to coal smoke in the home markedly increases the risk of lung cancer, particularly in women (17-19).

In recent years, new evidence has emerged which suggests that indoor air pollution (IAP) in developing countries may also increase the risk of other important child and adult health problems, although this evidence is more tentative, being based on fewer studies. It includes conditions such as low birthweight, perinatal mortality (still births and deaths in the first four week of life) asthma and middle ear infection for children, tuberculosis, nasopharyngeal and laryngeal cancer, and cataract in adults (6,7).

A summary of the evidence for each of these conditions is given in the section below, based on a recent review by Bruce et al (7). The main emphasis is given here to acute (lower) respiratory infections (ALRI), COPD, and lung cancer (due to coal) for which the evidence is most robust. The high incidence and mortality of childhood ALRI, together with the fact that it predominantly affects young children, means that this condition makes up by far the greatest proportion of the burden of disease attributable to indoor air pollution.

Key Health Outcomes

- **Childhood acute lower respiratory infections (ALRI)**

Acute lower respiratory infections (ALRI) remain the single most important cause of death globally in children under 5 years, and account for at least 2 million deaths annually in this age group. There are more than fifteen studies in developing countries which have reported on the association between indoor air pollution exposure and ALRI, and two further studies among Navajo Indians in the US (see Annex B). Discussion is restricted here to studies that have used definitions of ALRI which conform reasonably closely to current WHO criteria (or other definitions that were accepted at the time the study was carried out) and/or include radiographic evidence.

This includes 10 case-control designs (two mortality studies), 5 cohort studies (all morbidity), and one case-fatality study. In contrast to the relatively robust definitions of ALRI, the measurement of exposure in the majority of these studies has relied on proxies, including the type of fuel used, stove type, exposure of the child to smoke during peak cooking times, reported hours spent near the stove, and whether the child is carried on the mother's back during cooking. One study made direct measurements of pollution (particulates) and exposure (COHb) in a subsample (20). In that study, respirable particulates in the kitchens of cases were substantially higher than for controls (1998 $\mu g/m^3$ vs. 546 $\mu g/m^3$; $p<0.01$), but there was no significant difference in COHb levels. In a recent cohort study in Central Kenya, individual exposures were estimated by repeated area monitoring and time-activity budgets coupled with longitudinal monitoring of ARI/ALRI episodes (8,15,16).

Five studies reported no significant association between ALRI incidence and exposure (21-25). In several of these only relatively small proportions of the samples were exposed. Thus, in urban Brazil only 6% of children were exposed to indoor smoke (22) and in another south American study 97% of homes used gas for cooking, although 81% used polluting fuels (kerosene, wood, coal) for heating (25). This study also excluded neonates with birthweight <2,500 gms – the group most vulnerable to ALRI. In the study reported by Shah (23), a so-called 'smokeless chullah' was used as an indicator of lower exposure, but such stoves often perform little better than traditional ones in terms of smoke emissions (26).

The remaining studies reported significantly elevated odds ratios (ORs) (for incidence or deaths) in the range 2-8. Not all studies however, have dealt adequately with confounding factors (20,21,27-29). The Navajo studies used case-control designs, reported fuel type (wood vs. cleaner fuel) as a proxy for exposure and adjusted for confounding (30-31). Both reported elevated ORs of approximately 5, although this was not statistically-significant in one study (31). This latter study also carried out 15 hour PM_{10} measurements, but found minimal differences between cases and controls, while the actual levels (median 15 hr PM_{10} 22.4 $\mu g/m^3$, range 3.2 - 186.5) were relatively low. However, children living in homes with $PM_{10} \geq 65$ $\mu g/m^3$ had an OR of 7.0 (95% CI 0.9-56.9) times that for children with levels < 65 $\mu g/m^3$ (31). The recent study in Central Kenya, which controlled for a number of confounding covariates, obtained an exposure-response relationship for PM_{10} exposure and childhood ALRI, with those in higher exposure categories being 2-3 times as likely as the baseline group to be diagnosed with ALRI (15,16).

- **Chronic obstructive pulmonary disease (COPD)**

There are about 20 community- and hospital-based studies with various outcomes that include chronic bronchitis (by assessment of symptoms) and chronic obstructive pulmonary disease (COPD – by clinical examination and lung function measurement) (7). Some patients also go on to develop emphysema [overinflation of the air sacs in the lung] or cor pulmonale [right heart failure]. The majority of studies found associations between exposure and COPD, although these are not reported in a consistent manner. As with studies of acute lower respiratory infections in children, very few carried out exposure assessments, and confounding was inadequately dealt with in some. Overall, the studies indicate that exposure to indoor air pollution increases the risk of chronic bronchitis, but, as with ALRI, the relative risks in some instances may be poorly estimated.

- **Lung Cancer**

Smoke from both coal and biomass contains substantial amounts of carcinogens, including benzo[a]pyrene, 1,2 butadiene and benzene. A consistent body of evidence, particularly from China, has shown that women exposed to smoke from coal fires in the home have an elevated risk of lung cancer (17-19), in the range 2-6. This effect has not been demonstrated among populations using biomass, but the presence of carcinogens in the smoke suggests that the risk may be present. Synergistic health impact between use of coal for domestic heating and passive smoking from environmental tobacco smoke has also been noted (32). The vapours of some cooking oils may also have toxic and potentially carcinogenic effects.

Other Health Outcomes

♦ Upper respiratory infection, and otitis media

Several studies have reported an association between biofuel smoke exposure and general acute respiratory illness in children, mostly upper respiratory illness (URI). The Kenyan cohort study included ALRI as well as total ARI as outcome measures, finding an association for both (15,16).

Evidence from developing countries regarding middle ear infection (otitis media) - a condition which causes a considerable amount of morbidity - is limited, but there is reason to expect an association. There is now strong evidence that environmental tobacco smoke (ETS) exposure causes middle ear disease: a recent meta-analysis reported an OR of 1.48 (1.08-2.04) for recurrent otitis media if either parent smoked, and 1.38 (1.23-1.55) for middle-ear effusion (33). A clinic-based case-control study of children in rural New York State, reported an adjusted OR for otitis media (two or more separate episodes) of 1.73 (1.03-2.89) for exposure to woodburning stoves (34). The actual exposure to smoke in these industrialized country situations is much lower than those found in developing country households burning solid fuels.

♦ Asthma

Fewer than 10 studies from developing countries examining the association between biomass fuel smoke and asthma (mainly in children) have been published (7). Again, outcome definitions have not been well standardised, exposure has not been measured and confounding has not been dealt with in some studies. Evidence so far is inconsistent in both industrialized and developing countries; however, taken together with studies of environmental tobacco smoke and ambient pollution, the evidence is suggestive that wood smoke pollution may exacerbate and/or trigger asthma in sensitised people.

- **Cancer of the nasopharynx and larynx**

Several studies have found an increased risk of nasopharyngeal and laryngeal cancer, although this is not a consistent finding. The most recent study, from South America, reported an adjusted odds ratio of 2.7 (95% CI: 2.2-3.3), and estimated that exposure to wood smoke accounted for around one third of such cancers in the region (35).

- **Tuberculosis**

There have been three studies to date examining the association with tuberculosis (two published from India; one unpublished from Mexico) (7). An analysis of data from 200,000 Indian adults as part of the Indian National Family Health Survey (1992-93) found that persons living in households burning biomass reported tuberculosis more frequently compared to persons using cleaner fuels, with an adjusted odds ratio of 2.58 (36). Although large, this study relied on self-reported tuberculosis. The other studies used clinically defined tuberculosis and found consistent results. More research is needed to fully understand the nature of this relationship. Such an association, if proven, may be due to reduced resistance to infection as shown in laboratory experiments with animals exposed to wood smoke.

- **Perinatal mortality**

Only one study has been reported from a developing country (37). This found an association between perinatal mortality and exposure to indoor air pollution, with an odds ratio of 1.5 ($p=0.05$) adjusted for a wide range of factors, although exposure was not assessed directly. There is also some supportive evidence from outdoor air pollution studies.

- **Low birth weight**

Currently only one study of the effects of fuel use on birth weight in human populations is known to have been completed in a developing country (38). This study, conducted in Guatemala, found that birth weight was 63 grams (95% CI: 0.4-127) lower for babies born in households using wood versus those using cleaner fuels. This estimate was adjusted for confounding but exposure was not assessed directly. This result is, however, consistent with a meta-analysis of the effects of environmental tobacco smoke and several outdoor air pollution studies (39).

- **Eye irritation and cataract**

Eye irritation (sore, red eyes and tears) is widely reported in the literature. In addition, a hospital-based case-control study in Delhi comparing liquid petroleum gas (LPG) with biomass fuel use found adjusted odds ratio of 0.62 (95% CI: 0.4-0.98) for cataracts (LPG use had lower risk) (40). Animal studies report that biomass smoke damages the lens and evidence from environmental tobacco smoke is also supportive.

The box below summarises the nature and extent of the evidence available for health effects of IAP exposure in developing countries.

Condition	**Nature and extent of evidence**
• ALRI (young children) • Chronic bronchitis and COPD • Lung Cancer (coal only)	15-20+ studies; fairly consistent across studies, but confounding not dealt with in a substantial minority; supported by studies of ambient air pollution and ETS and to some extent by animal studies
• Cancer of nasopharynx and larynx • Cataract	Few (2-3) studies; consistent across studies; supported by evidence from

• TB	smoking and animal studies
• Acute otitis media • Cardiovascular disease	No studies, but an association may be expected from studies of ambient air pollution and/or studies of wood smoke in developed countries
• Asthma	Several studies, but inconsistent. Support from studies of ambient air pollution

Shortcomings in studies

Most existing studies on indoor air pollution and health effects, while providing important evidence of associations with a range of serious and common health problems, suffer from a number of methodological limitations, namely (a) the lack of detailed and systematic pollution exposure determination, (b) the fact that all studies to date have been observational (no intervention studies) and (c) that some have dealt inadequately with confounding.

Exposure Characterisation

Very few of the studies conducted to date have measured pollutant concentrations or exposure directly. Indeed characterisation of exposures is one of the most challenging aspects of the work needed (8,41). Apart from biomass, a number of other sources of indoor air pollution may be associated with adverse health outcomes, making it difficult to assess the independent contributions of various fuel sources to ill-health. It is important to note that in many countries and settings today, a mixture of fuels is used, including biomass fuel, liquefied petroleum gas (LPG), and kerosene (42-44).

Concentration levels of pollutants may vary significantly over time and space. For example large variations in exposure may result in the course of a day, month, season, or year. Significant variations may also occur from room to room in a house. In urban/industrialised areas, exposure to other sources of air pollution need to be taken into account, and in low-income, high density housing areas (formal or informal), indoor air pollution may also impact on outdoor air pollution. In Soweto, South Africa for example, indoor coal-burning has a profound impact on ambient air pollution, exacerbated by adverse meteorological circumstances (13). As mentioned, few studies have conducted personal monitoring of exposures; relying instead on proxies such as frequency, duration and magnitude of contact with known concentrations of pollutants, or indicators such as type of fuel used, regular carriage of child on mother's back, cooking indoors versus outdoors etc.

Study design and confounding

The observational nature of the studies presents a particular problem in terms of confounding. Some studies do not control adequately for confounding factors such as malnutrition, low birthweight, housing type, or other features of the child's environment which are closely associated with poverty. Intervention studies may ultimately result in more robust evidence on the nature of the relationship between indoor air pollution and health, nevertheless they may also cause a variety of altered states and behaviours, which may not be directly related to the impact of indoor air pollution on health. With improved and more efficient stoves for example, people may cook food for longer periods of time, thus exposure levels may not be reduced to the extent expected. Or, changes in cooking practices may result in altered nutrition patterns, also likely to impact on ARI. Impacts on ARI may be mediated also by changes in birthweight, itself a well documented risk factor, independent of air pollution (43).

Despite these limitations of epidemiological studies, the evidence on ALRI and chronic bronchitis (for biomass) and lung cancer (for coal) is consistent, especially when viewed in conjunction with what is known about the effects of environmental tobacco smoke and urban outdoor air pollution (notwithstanding their differing pollutant mixtures), and the evidence from animal studies. The major weakness is the uncertainty about the exact nature of the exposure-response relationship, that results from the lack of direct exposure measurement and inadequate control of confounding factors in some studies. For the other conditions described the evidence must be seen as more tentative, but plausible given the overall body of research on the effects of air pollution on human and animal health.

Strengthening evidence, monitoring and evaluation

New studies are needed to help strengthen evidence on health effects, with emphasis on quantifying the patterns of exposure and risk estimates, and extending knowledge on potentially important health effects (e.g. TB and low birthweight) for which few studies currently exist. A variety of studies using different designs need to be conducted in a range of settings throughout the world. Different populations with varying socio-economic characteristics and fuel-use patterns should be included. The role of potential confounding and interactive factors such as nutrition status, breast-feeding practices, level of crowding in homes, chilling, low birth-weight, environmental tobacco smoke, and other factors need to be carefully assessed in these studies. Additional well conducted case-control studies, as well as cohort (longitudinal, follow-up) studies and intervention studies, including randomised controlled trials, are needed (43).

Also required is strengthening of the tools needed for monitoring and evaluation, including exposure assessment, indicators and systems for data collection at national level and for poor rural and urban communities where the need for information and action is greatest.

THE GLOBAL BURDEN OF DISEASE FROM INDOOR AIR POLLUTION

The foregoing review provides information on the risk to individuals associated with exposure to IAP from biomass fuels, and coal. It has been emphasised that very large numbers of people, mainly women and young children, are exposed to this pollution in a wide range of rural and urban settings, and that the overall public health impact could be substantial. While acknowledging the uncertainty that exists in estimates of relative risk, levels of personal exposure, numbers of people exposed and disease rates, it is nevertheless possible to combine this existing information to quantify the 'public health burden'. This approach is encapsulated in the global burden of disease methodology, the application of which to IAP has been described for India (45) and globally (46). A summary of the results of the assessment is presented here, based on a recent paper by Smith and Mehta (46).

Methods for estimating the burden of disease

Four basic methods for estimating the burden of disease from the use of solid fuels in developing countries have been described by Smith and Mehta (46). Each has advantages and disadvantages, but given that their results are fairly similar, taken together they provide credibility for the approaches taken. Summarised here are results from what has been termed the fuel-based method (drawing on studies of risk associated with use of different fuels/stoves and/or reported exposure to them), which tends towards underestimation of burden compared with other approaches. This method involves applying the results of epidemiological studies done solely in developing country households using solid fuel to estimate the impact by disease and age group. Using this method, conservative assumptions of relative risks for the diseases included are applied to data on the number of people exposed and the disease rates, to calculate the population attributable fraction, by region. In practice, adequate estimates of relative risk are only available for women and children under 5 years. Known relationships between mortality and morbidity for specific diseases in each age group are then used to calculate years of life lost and DALYs.

Estimates of global mortality and DALYs lost

Table 1 shows the deaths, illness incidence and DALYs lost calculated using the fuel-based method.

Table 1. Annual burden of disease attributable to solid fuel use, early 1990s

Region	Deaths	Illness Incidence	DALYs
India	496,059	448,351,369	15,954,430
China	516,475	209,727,474	9,335,387
Other Asia & Pacific Islands	210,721	306,356,582	6,599,471
Sub-Saharan Africa	429,027	350,703,204	14,323,188
Latin America	29,020	58,246,497	918,236
Mid-East and North Africa	165,761	64,150,732	5,633,022
LDC Total	**1,800,000**	**1,400,000,000**	**53,000,000**

Excess significant figures retained to reduce rounding errors

The total DALYs (53 million) amounts to slightly more than 4% of the global total for developing countries. Table 2 shows the total burden of disease from solid fuel use as a proportion of the total burden of disease experienced in each region. Compared to China, a larger percentage of India's DALYs compared to deaths can be attributable to solid fuel use because young children account for a larger proportion of the deaths in India, while women in China experience a larger burden of COPD and lung cancer, which occur at older ages. The table also shows the percentage in each category due to ARI, which correspondingly form a much smaller fraction of the burden due to solid fuels in China than in the rest of developing countries.

Table 2 Percentage of Total LDC Burden Attributable to Solid Fuel Use

Region	Deaths	Percent ARI	DALYs	Percent ARI
India	**5.3%**	81	**5.5%**	87
China	**5.8%**	25	**4.5%**	50
Other Asia & Pacific Islands	**3.8%**	75	**3.7%**	85
Sub-Saharan Africa	**5.2%**	85	**4.9%**	90
Latin America	**1.0%**	71	**0.9%**	82
Mid-East and North Africa	**3.6%**	89	**3.7%**	93
LDC Total	**4.7%**	**67**	**4.3%**	**81**

Based on Smith and Mehta(46)

Burden of disease from IAP and development

Figure 1 shows total burden of disease and burden of disease due to indoor and ambient air pollution in different regions of the world. Although cross-sectional, this suggests that on this global scale, as a region's income grows the disease burden from IAP falls – and does so more consistently than the total burden of disease or the burden from outdoor air pollution. The latter shows a more complex relationship with income, peaking at the interim stages of development due to the growth of transport and industry and decreasing again in wealthier countries. High-income countries have the lowest levels of all three burdens.

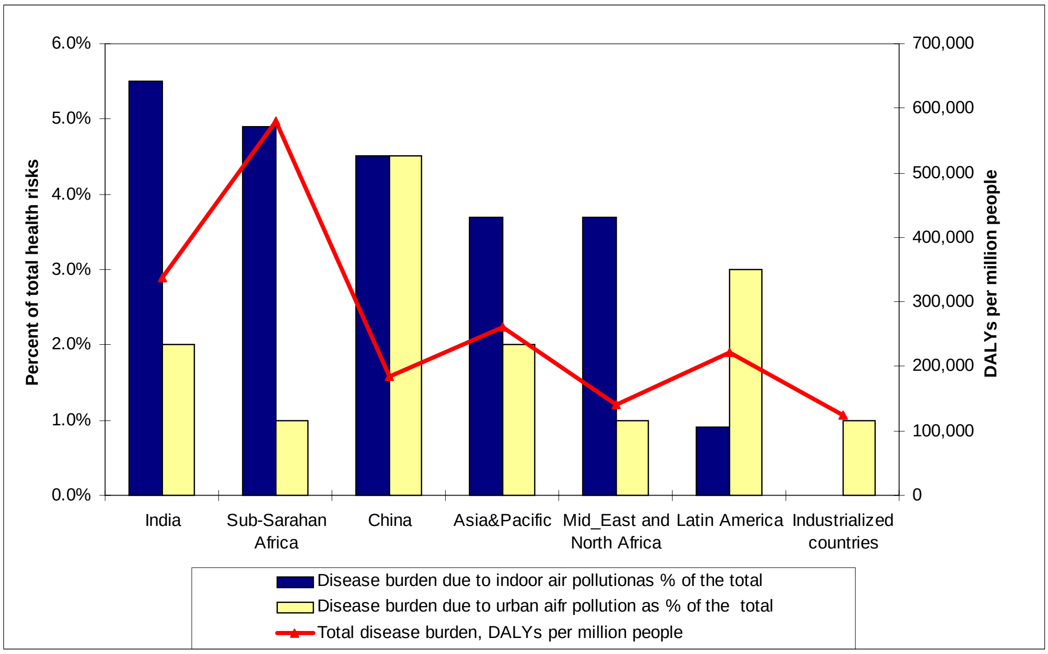

Figure 1: Total disease burden and disease burden arising from indoor and urban air pollution.

Source: World Bank (47)

The health consequences of IAP exposure from biomass and other solid fuels in developing countries should not be ignored for three over-riding reasons. Firstly, the health burden is high, even though there is uncertainty associated with the exact risk estimates. Secondly, biomass and coal will continue to be used by a large number of households for the foreseeable future. The World Energy Council has carried out projections under a variety of scenarios which indicate that biomass energy use may increase by between 1.1 to 1.3 Gtoe[1] by 2020 (48). Thirdly, the burden of disease due to indoor air pollution is highly concentrated among the society's most vulnerable groups: women and children in poor households.

[1] Gtoe: gigatonnes of oil equivalent – the amount of oil that would have supplied the same amount of energy.

POLICY AND INTERVENTION MEASURES THAT COULD IMPROVE HEALTH OF THE POOR

In considering strategies to reduce disease due to exposure to indoor air pollution, it is important to distinguish between interventions such as changes in energy technology (fuel, stoves), behaviour, etc., and policy for implementing and sustaining those changes. These are discussed in the following section.

Interventions

A wide range of interventions can contribute to reducing exposure to indoor air pollution. These can be classified under three headings (49): source (fuel, type of stove); living environment (housing, ventilation); and user behaviour (fuel drying, protection of child) – see Table 3.

Table 3: Potential interventions for reducing IAP exposure in developing countries (49)

Source	Living Environment	User behaviour
Improved cooking devices • Chimneyless improved biomass stoves. • Improved stoves with chimneys. ***Alternative fuel-cooker combinations*** • Briquettes and pellets • Charcoal, Kerosene • Liquid petroleum gas (LPG) • Biogas, Producer gas • Solar cookers (thermal) • Other low smoke fuels • Electricity ***Reduced need for the fire***	***Improved ventilation*** • Hoods / fireplaces • Windows /ventilation holes ***Kitchen design and placement of the stove*** • Shelters / cooking huts • Stove at waist height	***Reduced exposure through operation of source*** • Fuel drying • Use of pot lids • Good maintenance • Sound operation ***Reductions by avoiding smoke*** • Keeping children out of smoke ***Food preparation*** • Partially pre-cooked food.

• Efficient housing • Solar water heating		

There has to date been little in the way of systematic evaluation of the direct (e.g. reduction of IAP exposure, safety) and indirect (e.g. opportunity costs of women's time, environmental impacts, etc.) effects of these potential interventions on health, and in particular their distribution within the household (women, men, children for example, may be differentially impacted by various types of interventions). Some of the information available relates to the impact on fuel consumption and on direct emission levels. Therefore current knowledge is almost entirely restricted to source interventions, and mainly for various types of improved stove.

The initial emphasis from the 1970s on fuel efficiency brought with it a somewhat narrow focus on technological solutions that included primarily improved biomass stoves. These stoves include enclosed mud devices, often with chimneys, which on the whole were unsuccessful due to low efficiency and rapid deterioration. A large-scale stove programme in India appears to be suffering from these problems, although a thorough evaluation has not been conducted yet. Further, initial work on the benefits of improved stoves was often marked by a lack of detailed data on stove performance. Efficiencies and emissions, for example, were often measured in controlled environments as the stoves were used by technical experts under conditions very dissimilar to those in the field (50,51).

Recent surveys have identified several hundred improved stoves programmes (not counting larger changes in household energy technology such as electrification or biogas) in over 50 countries (52) ranging from entirely local, non-governmental advocacy to national initiatives reaching millions of households - as has been achieved in rural China (53). The implication of such a variety of programmes has been that the quality and efficiency of individual stoves has varied greatly, as has the success of individual programmes. The lack of success with some of the initial technologies and programmes shifted focus to the factors that can result in successful technical design and dissemination of improved stoves (54). In programmatic terms, a more successful approach has been with ceramic chimney-less stoves which are cheap, relatively durable, and more fuel-efficient. Such stoves have been quite popular, especially where sustainable markets have developed – for example in Kenya (54,55) and China (53). These stoves can reduce indoor air pollution because of better combustion, with lower emissions and potentially also shorter cooking times.

One of the reasons for the lack of systematic studies may have been that, with the central role of energy technology in household livelihoods, the adoption of interventions are more likely to vary from setting to setting and even household to household (44). For this reason, a more appropriate and realistic approach to evaluating the health benefits of interventions would be to consider the set of possible scenarios that may take place with the introduction of any intervention, as well as the corresponding health benefits. Recently, the reduction in emissions and exposure as a result of improved stoves has been considered in Guatemala and Kenya (8,56), as well as health benefits using a range of intervention scenarios (57). This analysis shows that transition from wood to charcoal can reduce exposure to indoor PM_{10} by more than 80%, although wider environmental impacts of charcoal production must be considered (58). The corresponding reductions for improved ceramic woodstoves are between 35% and 50% . The estimated reductions in the incidence of childhood ALRI are between 21% and 44%.

Despite these recent advances, three key questions in design of programmes for reducing the health impacts of indoor air pollution from biofuels remain: first, although the benefits of adopted interventions are known, it is not entirely clear what set of factors would motivate households to adopt any intervention or suite of interventions. Second, the performance of interventions in exposure reduction have not been monitored over long time periods. Third, knowledge is scarce about the wider implications and sustainability of many of the proposed interventions within certain environmental and socio-economic contexts. For example, encouraging a shift to charcoal could lead to even more severe environmental degradation and fuel scarcity, as more wood is needed per meal using charcoal compared to wood (58,59).

Other impacts on health and quality of life

As mentioned earlier there are a wide range of other factors associated with the supply and use of household energy in poor countries that can be expected to impact on health. This includes direct health consequences such as burns to children falling into open fires, as well as the less direct health impacts associated with a range of other energy-related socio-economic factors. The total evidence available on the health consequences is of variable extent and quality, partly due to a paucity of research attention in this field, but also due to the methodological challenges of demonstrating cause and effect where a range of social, environmental and other factors interact. This is an important area for further review and investigation. Some of the key factors which should be considered are summarised below:

Key Health and Development-related Factors

- The opportunity cost of women's (and children's) time spent collecting fuel, estimated at 0.5-2 hours per day (60).

- Vulnerability of women to injury and violence when collecting fuel, especially when supplies are scarce and in areas of civil unrest and war (60).

- Burns to children falling into fires (61,62).

- Accidental poisoning of children drinking kerosene (paraffin) stored in soft drink containers (63-65).

- Restrictions on economic and educational activity in the home due to poor air quality, lack of adequate light, and the inflexibility in use of available fuels and appliances (60).

- Opportunities for income generation through involvement of the poor in the production and distribution of stoves and energy services, and associated activities such as forest management (60).

- Degradation of the local environment: although it is recognised that the use of wood as a fuel is not a primary cause of deforestation and land erosion (as most is collected rather than cut), it does contribute. Perhaps more important is that poor people who are dependent on wood in areas where the environment is under stress will have more difficulty in meeting their energy needs, and women may have to spend more time collecting wood or alternative biomass (60).

KEY ISSUES AND CONSTRAINTS TO IMPLEMENTATION

As discussed earlier, the complexity of household energy technology implies that solutions to the various health and environmental problems associated with biofuel use in poor countries are highly dependent on the local context and the specific needs of a particular household energy system. Consequently, if policies are to be successful they must be sensitive to local conditions and build on the particular ways in which the people exposed to high levels of pollution in the home respond to the problems they face and the opportunities they have for change. Such experience as exists suggests that the key to success is to broaden the range of secure and sustainable choices available to the local actors in devising solutions (49, 57).

Criteria for Successful Implementation

In order for household energy projects to be successfully implemented they should:

- Be needs-oriented, i.e. solutions developed should meet the wishes and needs of consumers
- Be participatory, i.e. the users and producers should be involved in the planning and implementation of activities
- Be holistic in design, i.e. they should be treated as a complex system which addresses issues such as energy saving measures, resource conservation measures, lighter workloads, improved health and higher incomes
- Be tailored to the situation at hand, ie be carefully designed to ensure they are appropriate to the respective local socio-cultural and economic circumstances
- Be sustainable, i.e. local production should be reinforced to secure a sustainable supply of stoves, ovens and accessories by local stove fitters, potters or smithies (promotion of local artisans, self –help measures)
- Promote demand, i.e. by awareness-raising, sensitization, advertising, education

Adapted from GTZ (4), in von Schirnding (43)

The key issues and constraints that need to be considered in implementation of intervention measures are discussed below. Some are more readily actionable within the health sector, while the other more distal constraints related to poverty and distortions in the energy sector are actionable outside the health sector.

Energy Sector Policies and Financial Support Measures

Among the factors that have led to distortions in the supply and demand of cleaner petroleum-derived cooking fuels (Kerosene, LPG) at national level in some countries have been government price controls, particularly subsidies on domestic kerosene and LPG, and protection of state oil monopolies, for example through import restrictions and discrimination against the private sector. Although introduced with a view to making cleaner fuels more accessible to the poor, universal fuel subsidies have often tended to be counter-productive, with wealthier people, who have better access to these fuels, gaining most advantage.

To reduce the adverse fiscal impact of such policies, some governments have supplemented a heavy kerosene subsidy with a ration system that made subsidised kerosene available in small amounts, but not sufficient for cooking. In addition, a price differential between domestic kerosene and LPG on one hand and other petroleum products that are close substitutes (e.g. commercial kerosene and LPG, and diesel) have led to illegal diversion of domestic fuels to the commercial and transport sector; thus further reducing their availability for the poor.

Lack of incentives and enabling environments for the private sector may also slow growth in supply, removal of infrastructure bottlenecks and development of effective marketing strategies. Although in some countries, recent removal of subsidies on kerosene is believed to have pushed poor families back to reliance on biofuels, "across-the board" subsidies are neither a sustainable nor an efficient tool for addressing the needs of the poor. Subsidy schemes should always be carefully assessed and designed to target households in greatest need. In particular, carefully targeted financial support for technical development and production of appliances, and for infrastructure for marketing and transport may be justified. For example in the case of the improved stoves programme in China, support to initiate the project beyond a critical threshold of design and distribution allowed longer-term sustainability (53). In another successful program, financial incentives were used in a biogas project in Nepal, where meeting of quality standards and durability of the biogas system were rewarded in the form of an additional bonus. A mechanism that is receiving growing attention is the provision of affordable micro-credit to households: if used to support the purchase of efficient appliances that reduce fuel (and health) costs in the long term, this could be a powerful instrument for change.

Thus well-targeted and locally relevant interventions that include financial support measures (through income generation and/or micro-credit), where appropriate, will to some extent allow change in the face of continuing high levels of poverty. It should be recognised however that in rural areas where wood and other biomass are cash free, cleaner fuels are seen as expensive. This, together with the unreliability of supply due to insufficient distribution infrastructure and markets in rural areas is a major factor, meaning that for the rural poor - even if up-front costs are reduced and there is a willingness to pay - barriers to accessing cleaner fuels remain.

Intersectoral Action

The fact that indoor air pollution and household energy impacts on such a wide range of inter-related issues including health, women's lives, the environment and socio-economic development, demands that a collaborative approach be taken if implementation is to be effective and sustainable. Unfortunately, this collaborative action has by and large been lacking, also in donor programmes.

Overall, there has been a lack of awareness among all sectors, including national governments, of the health consequences of household energy use among the poor, both in terms of the direct consequences of IAP such as ALRI, COPD, cancer, burns, etc., as well as broader impacts on health, the environment, and development. This is despite the fact that over the last twenty years, a number of prominent scientists, agencies and institutions such as WHO, World Bank, World Resources Institute have sought to draw attention to these issues (1,2,12,66,67). Governments and aid agencies have associated energy aid with large-scale infrastructure rather than small-scale household energy which requires smaller scale operations. It should be recognised however, that some energy and development organisations including bilaterals and NGOs, have given household energy considerable attention over this period, although the focus has been on reducing fuel costs and environmental protection.

Institutional framework for technological solutions

Apart from the relatively isolated and partial success of examples such as the ceramic chimney-less stoves (and the Chinese rural stove programme – see below), the main problem with the technology driven approach has been the failure to fully involve the community, and in particular women and those involved in production and marketing, in understanding the issues and developing solutions appropriate to local needs and circumstances. In fact many technologies have been developed and tested in laboratories, with inadequate testing under real-life field conditions where actual conditions of use can be critical to the eventual success of the technology. Even in these circumstances, the set of complex technical requirements for stove design were at times ignored, equating appropriate technology with simple technology (57). In addition, the circumstances required for sustainable marketing of these interventions have not usually been addressed. A component of this is the resources available to the household for purchasing and operating the stoves and/or other changes, and the part that income-generation or local credit can play (see earlier discussion). The integration of credit into energy development, particularly for primary cooking and space-heating tasks, has received little attention.

Variations in national capacity and will

Countries vary greatly in their capacity to make cleaner fuels available to the poor. South Africa, for example, is a country with large coal reserves, and well-established infrastructure for electrical power generation, distribution planning and financial management through the utility company Eskom. Whilst many other countries with large, poor rural and urban populations do not have this capacity, an important aspect of this is the will, or otherwise, of governments to address the problem. The political commitment in South Africa to make electricity available to the poor is one example. Another important example is the rural stove programme developed by the Chinese government, which by the end of 1995 had resulted in the installation of over 172 million chimney stoves (68). Although centrally-led, the programme involved the setting up of a large number of local enterprises for the production and installation of the stoves. Whilst evaluation of durability, acceptability and effects on pollution is so far lacking, it does seem that this massive government-led programme has been more successful than many. Another aspect of capacity is the level of technical (e.g. in energy, stoves, monitoring and evaluation, etc.) and programme (collaborative working, community development, developing markets) skills available to draw on in the country. Experience suggests that this needs to be built on, and linked up.

It is clear from the above discussion that, while many challenges remain for the widespread implementation of effective and sustainable interventions, there have been some successes and important experiences to learn from. Thus, there are interventions that substantially reduce IAP, and models of good practice involving community participation and market development. China and South Africa offer valuable experience in terms of national initiatives regarding solid fuel stoves and electrification respectively.

COSTS

Examples of the costs, and potential reductions in IAP levels is presented in Annex C for the three categories of intervention (source, living environment, user behaviour interventions). It is not within the scope of this paper to provide a comprehensive overview of interventions in different countries and settings, nor indeed to be precise about specific costs and benefits, particularly as good evidence is relatively scarce. Nevertheless, a wide range of experience can be drawn on to highlight some of the key issues that need to be considered in assessing the benefits of each type of intervention. A limited number of references, where available, are provided in the table (Annex C).

In reviewing and summarising the 'performance' of these various interventions, it is necessary to distinguish between the effectiveness of (for example) an improved stove reducing IAP when newly installed and in good condition, and how it performs after months or years of daily use, with (as is often the case) little or no maintenance (26,69). In addition, whereas many modern fuels such as LPG and electricity are extremely clean in use for specific tasks, it is often the case in developing countries that households with access to these fuels continue to use more polluting fuels and stoves for a variety of practical (e.g. space heating) and economic reasons (collecting wood may be free). As a result, the overall impact on IAP levels of the availability of LPG or electricity may be less than expected (70,71).

The social and economic impacts of potential interventions are also of great importance to the long-term health benefit that the intervention offers. An improved stove which is inconvenient to use, or which heats up too slowly, for example, even though it's use may result in significant exposure reductions, may have a limited impact in the long term if the users feel the disadvantages outweigh the advantages and stop using it. This is the case for interventions such as solar cookers that frequently require the user to cook under the midday sun, or to change cooking practices and habits. In addition to the appliance costs and operating costs, durability, appearance, ease of operation and maintenance, convenience and flexibility are among those factors that are likely to influence long-term acceptance and suitability of interventions.

Comparative cost - benefits of reducing IAP

Although at an early stage, and hampered by a lack of evidence on the specific health benefits of actual reductions in IAP exposure[2] (see also 15,16) some work has been carried out to assess cost-benefits of interventions to reduce IAP in terms of mortality avoided, monetary equivalent of prevention, and comparative cost per DALY averted. Summarised in Annex D are two case studies developed by Larson and Rosen (90) which attempt to define the costs and benefits for (a) mortality reduction, based on the potential pollution reduction achieved by improved stoves in Guatemala and Kenya and (b) for morbidity (ALRI) reduction based on data from Pakistan. The conclusion of these studies is that for mortality, benefits outweigh costs by a factor of around ten or more.

Cost per DALY saved

In terms of the costs per DALY saved, there are a few studies available that attempt to assess the effectiveness of selected interventions outside the purview of the health sector in achieving health improvements. A review by the World Bank has yielded the following estimates:

Comparative costs per DALY gained

- Water connections in rural areas - $35 per DALY (81)
- Hygiene and behavioural change: US$20 per DALY (91)
- Malaria control: US$35-75 per DALY (92)

[2] An international study group, with WHO support, has been developing a randomised intervention trial to test the effect on ALRI incidence (up to 18 months) of reducing IAP through substitution of traditional open fires with locally made chimney stoves in rural Guatemala. This study is now scheduled to begin in latter part of 2001.

- Improved biomass stoves US$50-100 per DALY (93)
- Use of kerosene and LPG stoves in rural areas - $ 150-200 per DALY (81)
- Improved quality of urban air: large variations, from negative costs or win-win solutions to US$70,000 per DALY and more for some pollution control measures. Most measures cost over US$1000 per DALY. (47,82)

Source - World Bank

These data suggest that the cost-effectiveness of measures to improve health covers a wide range, particularly evident in the area of ambient air pollution control, where a larger number of studies and measures are available.

It has been proposed that health interventions up to $150 per DALY saved can be considered cost-effective, given the opportunity cost of one dollar of public investment, even in most poor countries. Interventions that are considerably more expensive can be cost-effective in rich countries (67). While there is a need for more studies and careful analyses of this kind, interventions to reduce exposure to IAP would appear to be cost-effective in reducing the burden of disease - by comparison with many measures to control urban air pollution and by comparison with many (curative) health measures.

Nevertheless it should be emphasised that there are considerable difficulties in making comparisons with other health interventions in terms of net cost per DALY saved, due to the uncertainty about the coverage and efficacy of many public health programs which may exist. Comparing preventive measures with curative ones is also complicated by the difficulty of assessing the benefits of avoiding episodes of ill –health rather than curing those who actually fall ill (81).

Thus investments in infrastructure may be relatively more expensive than many public health programs as they offer higher levels of prevention with more certainty and over a longer term.

Work done in Andhra Pradesh in India, concludes that expenditures on cleaner fuels are clearly cost-effective by comparison with alternative options for reducing the burden of disease and on any cost-benefit criterion that attaches even modest values to the benefits of lowering child mortality and preventing other adverse health outcomes. Such expenditures also benefit a large proportion of the population, especially those in poverty, or below average levels of household income (81).

Scaling up and sustaining interventions

It is important to recognise that for many of the poorest countries and communities, where there is little in the way of effective programmes for reducing the impact of indoor air pollution from household energy, well-targeted demonstration projects tied into existing local capacity and initiatives are appropriate in the first instance, from which to build broader-based strategic action. On the other hand, there are countries with a great deal more experience and capacity that will need to build on that base. In general, the approach required for scaling up might include the following elements:

Scaling Up

- Strengthening of government, multi/bilateral and international agency commitment
- Facilitating collaboration between relevant sectors (government - health, environment, housing, energy, etc - NGOs, business) at national and local levels.
- Involvement of communities, particularly women
- Support for technical development and evaluation of interventions; micro-credit for households; policies promoting more equitable access to cleaner fuels; support for favourable institutional and market structures, small business development, capacity building, information and dissemination.

Although all components listed above may incur some cost, in terms of external funding support the costs relate most clearly to the last item above – specific areas of support in the medium term (and in some cases the longer term).

Estimates of costs

The estimation of costs for scaling up and implementing effective action that will impact substantially on the urban and rural poor is a complex (and setting-specific) issue, which will require further development with a range of countries to agree targets, time scales for change, and appropriate policies and interventions for the diverse urban and rural communities that make up the poorer sectors of national populations. The approach to implementation should draw on the key lessons and principles that have been discussed in foregoing sections of this paper. Sustainable changes will only be achieved through developing the circumstances whereby poor households are able to choose and afford the initial and ongoing costs of one or more suitable options that meet their needs. The operation of local and national market factors will play a substantial part, whether or not supported by limited public and NGO financing and credit facilities.

In selected local settings, even modest, well targeted resources and externally funded support (including capital to facilitate local micro-credit) could start to have a substantial impact on the health burden associated with IAP and household energy over a period of 3-5 years, so long as resources are accompanied by 'joined up' decision-making by international players and national governments.

CONCLUSIONS

More than 2 billion of the world's poorest people still rely on biomass and coal-burning for household energy needs such as cooking and heating, putting women and children at increased risk of diseases such as pneumonia, chronic respiratory disease and lung cancer (coal only) – which is estimated to account for a substantial proportion of the global burden of disease in developing countries. Intervention measures to reduce the impact of IAP include changes to the source, living environment and user behaviour, and can be delivered through policies operating at national and local level. IAP interventions perform favourably in terms of cost-effectiveness, with, for example, an improved stove programme costing $50-100 per DALY saved. Although evidence on health effects and on cost-effectiveness is still in need of strengthening, concerted global action on a major preventible public health hazard impacting predominantly on the poor is long overdue. It is time to act.

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Annex A

Pollutant	Range of ambient levels in LDC studies for simple stoves		WHO and USEPA guidelines		
	Period	*Level*	*Period*	*WHO*	*EPA*
Particulates less than 10 microns in aerodynamic diameter (PM_{10} in $\mu g/m^3$)	Annual	Not available, but expect similar to 24 hour	Annual	Guidance presented as exposure-outcome relationships	50
	24 hour	300-3,000 +	24 hour		150 (99th percentile)
	During use of stove	300 - 30,000 +			
Carbon monoxide (CO in parts per million - ppm)	24 hour	2-50 +	8 hour	10	9
	During stove use	10-500+	1 hour	30	35
			15 minutes	100	
	Carboxy-haemoglobin	1.5–13%	Carboxy-haemoglobin	Critical level < 2.5% Typical smoker: 10%	

Annex B: Biomass Fuel Use and ALRI in Children Under 5 in Developing Countries. Note: This list is confined to quantitative studies that have used internationally standardized criteria for diagnosing ALRI.

Study	Design	Case Definition	Exposure	Confounding	Comments	OR (95% CI)
Rural South Africa (1980) Natal: Kossove (28)	Case Control 0-12 months 132 cases 18 controls	Outpatients Cases: Wheezing, bronchiolitis & ALRI. Clinical + X-ray Controls: Non-resp problems	Asked: "Does the child stay in the smoke?" Prevalence = 33%	Routine data collection: • number of siblings • economic status Examined, not adjusted	Only 63% of 123 X-rayed had pneumonic changes. Control group was small. Exposure assessment was vague.	4.8 (1.7 to 13.6)
Rural Nepal (1984-85) Kathmandu Valley: Pandey (27)	Cohort 0-23 months 780 (study 1) 455 (study 11)	Two weekly home visits: ARI grades 1-1V (Goroka) Breathlessness	Asked mothers for average hours per day the child near fireplace. In Study 1, same team asked about exposure and ARI therefore bias possible. 77% exposed over 1 hour	Confounding not taken into account since homes were judged to be 'homogeneous,'	Dose response relationship found Exposure assessment not validated	2.2 (1.6 to 3.0)
Rural Gambia (1987-88) Basse: Campbell (94)	Cohort 0-11 months 280	Weekly surveillance Mother's history of "difficulty with breathing" over subsequent 3 month period	Reported carriage of child on the mother's back Prevalence = 37%	Adjusted for • birth interval • parental ETS • crowding • socio-economic score • nutritional indicators • vaccination status • Number of health centre visits • ethnic group	Father's ETS only other significant factor. Cautious about interpretation, ability to deal with confounding , and to establish causation where exposure and incidence high	2.8 (1.3 to 6.1)

Study	Design	Case Definition	Exposure	Confounding	Comments	OR (95% CI)
				• maternal education		
Urban, Argentina (1984-87) Buenos Aires: Cerqueiro (29)	Case-control 0-59 months. Cases:516 in-patients; 153 outpatients Controls: 669	Three hospitals: Cases: ALRI within previous 12 days Controls: well-baby clinic or vaccination, matched by age, sex, nutritional status, socioeconomic level, date of visit, and residence.	Interview with mother: Household heating by charcoal; heating with any fuel; bottled gas for cooking	None, but success of matching verified. Multivariate analysis "currently underway"	No data available re charcoal heating in outpatient households. Chimney smoke nearby found to be associated (OR=2.5-2.7) with ARLI in both kinds of patients. ETS not significant for either.	9.9 (1.8 to 31.4) for charcoal heat for in-patients. 1.6 (1.3 to 2.0) for any heating fuel in in-patients. 2.2 (1.2 to 3.9) for gas cooking in out-patients
Rural Zimbabwe Marondera: Collings (20)	Case control 0-35 months 244 cases 500 controls	Hospital: Cases: Hospitalised ALRI, clinical and X-ray Controls: Local well-baby clinic	(a) Questionnaire on cooking/exposure to woodsmoke (b) COHb (all) (c) TSP (2 hr. during cooking): 20 ALRI and 20 AURI cases 73% exposed to open fire	Questionnaire: • maternal ETS • overcrowding • housing conditions • school age siblings paternal occupation not adjusted	Confounding: only difference was number of school age siblings, but not adjusted. COHb not different between ALRI and AURI. TSP means: -ALRI (n=18) 1915 $\mu g/m^3$ -AURI (n=15) 546 $\mu g/m^3$	2.2 (1.4 to 3.3)
Rural Gambia Upper River Division: Armstrong (95)	Cohort 0-59 months 500 (approx.)	Weekly home visits: ALRI Clinical and X-ray	Questionnaire: Carriage on mother's back while cooking	Questionnaire: • parental ETS • crowding • socio-economic index • number of siblings • sharing bedroom • vitamin A intake • no. of wives • no. of clinic visits	Boy/girl difference could be due to greater exposure of young girls. Report carriage on back quite a distinct behavior so should define the two groups fairly clearly with low level of misclassification	Approach (i) (All episodes) M: 0.5 (0.2 to 1.2) F: 1.9 (1.0 to 3.9) Approach (ii) (1st episode) M: 0.5 (0.2 to 1.3) F: 6.0 (1.1 to 34.2)

Study	Design	Case Definition	Exposure	Confounding	Comments	OR (95% CI)
				Adjusted in MLR		
Urban Nigeria (1985-86) Ibadan: Johnson (21)	Case control 103 cases 103 controls 0-59 months	Cases: Hospitalized for ALRI (croup, bronchiolitis, pneumonia, empyema thoracis) based on clinical, x-ray, and biolab workup Controls: infant welfare clinic, age and sex matched, no respiratory disease.	Interview: Type of cooking fuel used at home (wood, kerosene, gas)	None	Age, nutritional status, ETS, crowding, and location of cooking area also not significantly associated with ALRI.	NS
Urban Nigeria (1985-86) Ibadan: Johnson (21)	Case fatality among 103 cases 0-59 months	Cases: Death in hospital among ALRI patients (see above)	Interview Type of cooking fuel used at home (79 = kerosene, gas=5, wood=16, other=3)	None	Overall case fatality rate = 7.8%. 5 of 8 deaths were from wood-burning homes; one additional death had partial exposure to woodsmoke. Poor nutrition (1.8x), low income (1.5x), low maternal literacy (2.1x) were more frequent in wood-burning homes. ETS rates were similar. Yet, paternal income, maternal education, household crowding, ETS not related to case fatality rate.	12.2 ($p<0.0005$) for those exposed to wood smoke compared to those to kerosene and gas.
Rural Tanzania (1986-87)	Case-control Cases: ALRI	Cases: Verbal autopsy certified by physician of all deaths in period	Household interview: Child sleeps in room	Adjusted for: • Village • Age	About 95% of all groups cook with wood. No tendency to be different distances from road.	All deaths: 2.8 (1.8 to 4.3) for sleeping in room

Study	Design	Case Definition	Exposure	Confounding	Comments	OR (95% CI)
Bagamoyo District: Mtango (96)	deaths = 154 Other deaths = 456 Controls = 1160 0-59 months	Controls: Multistage sampling (40 of 76 villages). Children with ALRI were excluded.	where cooking is done; Cook with wood	• questionnaire respondent • maternal education • parity • water source • child eating habit • whether mother alone decides treatment.	Perhaps confusion of ALRI with other diseases (e.g., measles) . Water not from tap had OR = 11.9 (5.5 to 25.7). Models with all deaths, pneumonia deaths, and non-pneumonia deaths all had same significant risk factors. No difference in source of treatment by location where child sleeps. Maternal education, religion, crowding, and ETS, not significant	with cooking. 4.3 for pneumonia only; 2.4 for other deaths (95% CI not given)
Rural Gambia Upper River Division: de Francisco (97)	Case-control Cases: 129 ALRI deaths Controls: 144 other deaths 270 live controls 0-23 months	Cases: Verbal autopsy confirmed by 2 of 3 physicians Controls: Matched by age, sex, ethnic group, season of death, and geographic area	Indoor air pollution index based on location and type of stove, carrying of child while cooking, and parental ETS (details not provided)	Cases vs. live controls: Adjusted for factors significant in univariate analysis: • Socio-economic score • crowding • parental ETS • nutrition indicators • maternal education. No significant factors for cases vs. dead controls.	Only other significant risk factor remaining after multiple conditional logistic regression was whether child ever visited welfare clinic OR = 0.14 (0.06 to 0.36) Misclassification of ALRI deaths (e.g., confusion with malaria) is possible reason for lack of significant difference between cases and dead controls.	5.2 (1.7 to 15.9) for cases vs. live controls
Urban Brazil (1990) Porto Alegre:	Case control 0-23 months 510 cases	Cases: ALRI admitted to hospital, clinical and	Trained field worker interview: -Any source of indoor	Interview: • cigarettes smoked • housing quality	Only 6% of children exposed to indoor smoke. Urban population with	Indoor smoke: 1.1 (0.61 to 1.98)

Study	Design	Case Definition	Exposure	Confounding	Comments	OR (95% CI)
Victora (22)	510 controls	X-ray Controls: Matched for age and neighbourhood	smoke (open fires, woodstoves, fireplaces) -usually in kitchen while cooking	• other children in hh • income/education • day centre attendance • history of respiratory illness • (other) Hierarchical model/MLR	relatively good access to health care. Not representative of other settings in developing countries	Usually in the kitchen: 0.97 (0.75 to 1.26)
Urban and Rural India (1991) South Kerala-Trivandrum: Shah (23)	Case control 2-60 months 400 total	Hospital: Cases: Admitted for severe or very severe ARI (WHO definition) Controls: Outpatients with non-severe ARI	History taken, including -type of stove, with 'smokeless' category -outdoor pollution	History: • smokers in house • number of siblings • house characteristics • socioeconomic conditions • education • birth weight. etc. Adjusted in MLR	This is a study of the risk factors for increased severity, as the controls have ARI (non-severe). On MLR, only age, sharing a bedroom, and immunization were significant. Exposure assessment was vague and unvalidated.	'Smokeless" stove: 0.82 (0.46 to 1.43).
Rural Gambia (1989-1991) Upper River Division: O'Dempsey (98)	Prospective Case-control 80 cases 159 controls 0-59 months	Attending clinic: Cases: if high resp. rate, transported to Medical Research Council facility where physician diagnosed pneumonia after lab tests and x-ray Controls: selected randomly from neighbourhood of cases, matched by age	Household questionnaire: Mother carries child while cooking	Adjusted for: • mother's income • ETS • child's weight slope • recent illness • significant illness in last six months.	No effect of bednets, crowding, wealth, parental education, paternal occupation, age of weaning, and nutritional status. ETS OR = 3.0 (1.1 to 8.1). Aetiological (preventive) fraction for eliminating maternal carriage while cooking = 39%; for eliminating ETS in house = 31%. May be reverse causality, i.e., sick children being more likely to be carried.	2.5 (1.0 to 6.6)

Study	Design	Case Definition	Exposure	Confounding	Comments	OR (95% CI)
Peri-urban Durban, South Africa: Wesley (24)	Case-control 48 cases, 3-36 months 48 control, matched by age and time of presentation	Hospital: Cases of pneumonia, x-ray proven Controls: AURI All children with birth weight less than 2,500 gm and/or overt protein calorie malnutrition excluded	Home visit to assess: Type of fire (wood, coal, other)	Confounding not adjusted for. Levels of: • Crowding • Occupancy of child's sleeping room • Nutritional status • Parental smoking were reported to be similar in cases and control	No association of traditional risk factors for ARI found. Use of wood or coal stove in 19% cases and 14% controls. Parental smoking for 75% cases and 69% controls	NS
Urban Santiago, Chile: Lopez Bravo (25)	Cohort N=437 from birth, with 379 (87%) completing follow-up to 18 months	Physician diagnosis of acute lower respiratory illness, including pneumonia, bronchitis, obstructive bronchial syndrome. Pneumonia confirmed in 89% cases with X-ray Children with birth weight <2,500 gm, congenital and perinatal diseases excluded.	Interview of mothers: Type of fuel (electricity, LPG, kerosene, firewood, coal). Categorised for analysis into 'polluting' (kerosene, firewood, coal) and 'non-polluting'. Gas used in 97% homes for cooking, but 'polluting' fuels used by 81% for heating.	Appears that only univariate (unadjusted) associations presented, and multiple logistic regression not carried out. However, significant association between fuel type and pneumonia not found.	The setting of this study is unlikely to be typical of developing countries, it being a lower to middle class area of Santiago. It is also noted that Santiago is a highly polluted city, which would tend to confuse indoor and outdoor sources. A significant association (univariate) was found between polluting fuel and $\geq$2 episodes of obstructive bronchitis.	Association of polluting fuels with with one or more episodes of pneumonia NS (p=0.14)
Rural Kenya	Cohort.	ARI: (not further	Area PM_{10} combined	Adjustment in MLR for	Socio-economic status and	Reported by PM_{10}

Study	Design	Case Definition	Exposure	Confounding	Comments	OR (95% CI)
Mpala Ranch, Laikipia Ezzati (15,16)	Total n=345 people (all ages); n=93 age 0-4 years	described here). ALRI: Home visits initially every 2 weeks, then weekly, by trained nurse using WHO ARI assessment protocol. Data not obtained if adult not present at visit, or child for examination. Other visits for health care also recorded.	with time-activity	sex, age, village type, number of people living in house, smoking. Birth weight was not included as data not available.	birth weight not adjusted for, although authors observe that income, housing and nutrition appear to vary little due to social organisation of community on ranch. Exposure-outcome data is presented graphically in paper (first published example of this association)	level. Trend of increasing risk with higher level of PM_{10}: significant for 1000-2000 (vs. <200 $\mu g/m^3$) OR=2.33 (1.23-4.38); and >3,500 (vs. <200 $\mu g/m^3$) OR=2.93 (1.34-6.39)

Annex C

(a) Source interventions

Intervention	Approximate cost to users in US$	Reduction in particulate indoor air pollution (%)
Ceramic chimney-less stove	$4-7	50% for improved woodstoves (9); 40 % (72) Some studies have shown increases in emissions (3,73)
Chimney stove	$10-150	Range 0 – 80%, depending on type, cost, condition, etc. (26, 74-78)
LPG	Burner $30-120 Cylinder deposit and regulator - around $50 -60 for 12.5 kg (47,79,80) Fuel: $1-2 per week: for most recent data for India see (81)	Range 50-90+%, depending on whether meets all needs or fire still used for some tasks (77,78)
Kerosene	Ordinary burner $3-30 Pressurised stove $5-50 Fuel <$1-3 per week depending on variation in international prices and domestic subsidies (80-82)	Quality of fuel (and therefore cleanliness) varies. Also depends on stove type – unpressurised wick stoves not uncommon and more polluting. Range 50-90%
Charcoal	Jiko stove $5-10 [$7 (79) Fuel per week - $1 (79) but very country specific, approximately in the range of < $1 – 2 (83)	Low PM emissions, but sometimes not used for all cooking and space heating needs. Range 50-90%
Grid electricity (Local, e.g. micro-hydro etc. generally not used for home tasks	2-ring stove $20-50 Oven up to $100+ Weekly fuel costs (range) - $0.5 - 2 based on annual consumption/household of 1000 kWh (79,80,82)	Very clean (at point of use), but often not used exclusively for cooking and space heating. In practice, up to 50% reduction may be achieved, although uptake of electricity will depend on level of poverty and other factors (70,84).
Biogas, and other processed biomass (ethanol gel fuel)	Digester and gas stove $300 – Nepal (85) Weekly fuel costs: no market price (only labour and stove maintenance)	Very clean (at point of use), but only a fraction of households have access to animals, zero grazing and reliable water supply for routine use of biogas. For those that do, biogas can meet 100% of needs. Wider production and use of other fuels (e.g. gelfuel) being evaluated
Solar cookers	$5-50 depending on materials used	No emissions, but use limited for practical reasons.

Intervention	Approximate cost to users in US$	Reduction in particulate indoor air pollution (%)
Improved energy efficiency of house	e.g. Roofing Passive solar orientation – low cost at time of construction	Results of work in this area not yet available. Note that reduced ventilation could potentially increase IAP, or minimise gains in air quality achieved by lower fuel use

(b) Living environment interventions

Intervention	Approximate cost to users in US$	Reduction in IAP (%)
Hoods	$10-60, depending on material, number	May be substantial if suitable design found which is practical and affordable. Currently being assessed in Kenya (86)
Cooking window	$5-15, depending on design of house	Up to 85 % based on CO measurements (87)
Enlarged, better placed windows	$<1-5 each	Uncertain as requires windows to be open during use of fire

(c) User behaviour interventions

Intervention	Approximate cost to users in US$	Reduction in IAP (%)
Fuel drying	Nil	Not studied to date
Use of pot lids	$<1-5	50% on total particulate emissions per cooking task (88)
Good maintenance	Depends on stove or appliance	Important. Effects not directly studied to date, but should help achieve higher range of potential reductions with e.g. chimney stoves
Keeping children out of smoke	Nil	No studies reported to date, although under review and assessment being developed (89)

Annex D: Cost-benefit Studies

A summary of analysis presented at WHO/USAID global consultation on household energy, indoor air pollution and health, Washington May 2000 (90)

Mortality

A three-step method has been used to compute the cost-benefits of interventions to control indoor air pollution:

1. Estimate the three types of health impacts (direct child and adult and indirect child).
2. Estimate the monetary value to the household of these health impacts.
3. Compare the monetary value to the costs of the intervention.

Step 1. Studies of interventions in Guatemala and Kenya were used. Improved stoves were compared with traditional three-stone fires, yielding estimated reductions of 920 (*plancha* stove, Guatemala) and 1251 (ceramic lined stove, Kenya) $\mu g/m^3$ of annual averages of PM_{10}. To estimate the change in mortality risk due to reductions in PM_{10}, epidemiological studies conducted in urban developed country settings indicate that an approximate 1% increase in total daily mortality occurs for every 10 $\mu g/m^3$ of PM_{10} in ambient air[1]. This translates into an estimated *'particulate coefficient'* (the additional annual mortality risk per person, per year, per 1 $\mu g/m^3$ of PM_{10}) of 8.5×10^{-6} [Larson 1999] Thus, the health impact expressed as change in annual mortality risk due to the intervention is –0.0078 (920 multiplied by the particulate coefficient) in Guatemala and –0.0106 in Kenya. The risks for adults and children are combined, since there are no separate estimates for children and adults in the literature. Likewise, information is not available to estimate the third health effect, indirect health improvement for children generated from improved adult health.

Step 2. A reduction of 0.001 in annual mortality risk is given a monetary value, based on surveys in developed countries of the value of a statistical life. Then the result is weighted by the income ratio between the developing country and the country in which the value of a statistical life was estimated. These computations put a value of US$27 on a 0.001 reduction in annual mortality risk in Guatemala and US$18 in Kenya.

Step 3. It is now possible to compare the benefits with the costs of the intervention. The annual benefits per person are US$210 in Guatemala ($27 X 7.8) and US$190 in Kenya ($18 X 10.6). Using an average of five persons in a household, the benefits per household then are US$1,050 in Guatemala (cost of an improved *plancha* stove $150) and US$950 in Kenya (cost of an improved stove is US$8-20. Larson et al 2000

Morbidity (ALRI)

Step 1: This example examines the benefit of reducing ARI using information from Pakistan. To begin, the literature suggests that using a traditional stove increases the risk of ALRI by 2-5 times relative to improved stoves, cleaner fuel, or lower exposure. Using the lower end of the range, a relative risk of 2, it could be estimated that the benefits of using an improved stove (or switching to other fuels) would be about a 50 percent reduction in annual ALRI risk for children. Data show that children under five in

[1] This estimate presented by Larson is lower than that derived from cohort studies [Kunzli 2000], but in any case caution should be exercised in applying risk estimates from urban developed country studies to developing country populations. As has been pointed out, exposure-response data from developing countries is essentially lacking.

Pakistan have an average of one case of ALRI per child per year, of which some lead to death and some (most) do not. As a simple estimate, then, the morbidity impact of an improved stove could be an average reduction of 0.5 cases of ALRI per under-five child per year.
Step 2: Two approaches to value this risk reduction are taken, one based on medical treatment costs and the other using a benefits transfer approach. The medical treatment cost of a typical case of ALRI for a child under five in Pakistan is approximately $67. If a household actually sought treatment and paid these costs, then it is reasonable to conclude that the value to the household of treating the child (and presumably eliminating the direct morbidity effects of pneumonia and related mortality risks) would be at least as great as $67. If a household did not seek treatment, then its implied value would be less than $67. For households that do **seek medical treatment**, the 0.5 reduction in annual ARI cases suggests a lower bound value of $33.50. For households that do not seek treatment, this figure would be lower. For a young child, the present value of this annual figure over 5 years is $110 with a 20 percent discount rate. For the **benefits transfer** approach, the starting point is an estimated U.S. value of $100 to avoid one day of illness. The annual value of the ALRI risk reduction could be estimated at $10 ($2 at 10 days per event for a 0.5 risk reduction). For a young child, the present value of this annual figure over 5 years would be $30 with a 20 percent discount rate.
Step 3: These benefits again compare favourably with the cost of an improved stove, particularly as over a period of years the investment would typically benefit at least 2-3 children.

These examples suggest that the direct household benefits of reduced ALRI in children alone could justify an investment in an improved stove. This would presumably be greater if more than one child per household benefits during the lifetime of the intervention.