Acute respiratory infection (ARI) is the most common cause of illness in children and a major cause of death in the world. Among children under five years of age, three to five million deaths annually have been attributed to ARI, of which 75% are from pneumonia. The World Health Organization estimates that approximately three million children under five died from ARI in 1993, exclusive of measles, pertussis, and diphtheria, and another 1.1 million died from conditions in association with these diseases (table I). ARI is one of the leading causes of death in the world, smaller only than heart disease, cancer, and cerebrovascular disease.

This chapter of the work deals with the overview of literature as concerned with IAP (IAP) and ARI. The objective is

a) To provide an insight to the already existing research in this field as available from various literature

b) To understand the areas that still require attention

The research in this area was brought to the notice of public health researchers as early as the late 70s, when the developed countries were first waking up to the life threatening effects of IAP. Therefore attention was paid to some literature published as early as 1978 when Shy, Goldman and Hackey published their findings in ATS News. The momentum of this type of research started gaining a pitch in the late 80s when medical practitioners too, woke to the sudden influx of upper respiratory and lower respiratory
tract infections. Therefore there is a large amount of medical research literature available during the 90s decade which is of importance to this study. It was also during this time that the public health scientists realised that there was a huge socio economic cause behind this sudden increase in morbidity and mortality from ARI. Though initially their work was concentrated in the African continent, attention shifted to the SAARC countries, when the data sources of these respective countries started reporting alarming incidence of ARI. Therefore the literature under survey concentrates on information published from late 80s.

Some of the limitations that was observed while examining the research that has already been undertaken pertain to the linkages between IAP and ARI

Early in the 20th century ARI, in the form of pneumonia, was also a major cause of death in the currently developed countries, but its importance diminished dramatically during the century, partly due to the development of vaccines and antibiotics. A large decline had already occurred before these medical interventions became available, however, probably largely reflecting improvements in housing environments and nutrition.

There are a number of risk factors that affect ARI accounts for 33% of all deaths from infectious disease in the world and for 27% of the entire burden of infectious diseases. 80% of the ARI burden occurs in children under five years from less developed countries, accounting for about 6.7% of the global burden of disease from all causes ARI rates in young children, including malnutrition, lack of breast feeding, and the incidence of other diseases that affect susceptibility. The child's environment also affects risk through such factors as crowding, chilling, and air pollution. This survey of literature explores what is known about the contribution of household air pollution to the risk of

ARI in young children worldwide, with particular focus on less developed countries.

Table 2.1

<table>
<thead>
<tr>
<th>Annual mortality in children aged under five years from developing countries in 1993</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>ARI related:</td>
<td>4.1 million</td>
</tr>
<tr>
<td>ARI alone</td>
<td>3</td>
</tr>
<tr>
<td>ARI with measles</td>
<td>0.64</td>
</tr>
<tr>
<td>ARI with pertussis</td>
<td>0.26</td>
</tr>
<tr>
<td>ARI with malaria or HIV</td>
<td>0.23</td>
</tr>
<tr>
<td>Neonatal or perinatal</td>
<td>3.1 million</td>
</tr>
<tr>
<td>(many involving ARI)</td>
<td></td>
</tr>
<tr>
<td>Diarrhoea related:</td>
<td>3.0 million</td>
</tr>
<tr>
<td>Diarrhoea alone</td>
<td>2.7</td>
</tr>
<tr>
<td>Diarrhoea with measles or HIV</td>
<td>0.27</td>
</tr>
<tr>
<td>Measles /TB/tetanus/pertussis alone</td>
<td>1.2 million</td>
</tr>
<tr>
<td>Malaria alone</td>
<td>0.68 million</td>
</tr>
<tr>
<td>Other</td>
<td>0.2 million</td>
</tr>
<tr>
<td>Total</td>
<td>12.2 million</td>
</tr>
</tbody>
</table>

Source: World Health Organization

ARI = acute respiratory infection. Other ARI information:

2.1 Introduction to ARI and air pollution

Early in the 20th century dramatic episodes of outdoor air pollution in developed countries showed that air pollution could cause excess deaths and those children might be at particularly increased risk during the times of high pollution. For example, during the London fog of 1952, which was due mainly to smoke from coal burning household stoves, several thousand excess deaths occurred. Infants and young children as well as the elderly were noted to be at higher risk than others and the proportion of deaths attributed to respiratory causes was increased in comparison with the weeks before and after the fog. Outdoor air pollution has now been examined as a risk factor for respiratory morbidity and mortality in numerous epidemiological studies and the evidence continues to indicate that infants and young children are at risk for adverse effects. Even though ambient pollution levels have now declined in developed countries, the epidemiological evidence continues to

indicate adverse effects on both respiratory morbidity and mortality. New studies are indicating adverse effects of inhaled particles at levels that were previously considered to be safe and are now frequently reached in many urban areas.

During the last two decades the potential significance for child health of exposures to air pollutants in indoor environments has also been recognized. The world's children are exposed to inhaled pollutants as they breathe air in diverse indoor and outdoor locations. Total personal exposure to an air pollutant can be estimated as the weighted average of the pollutant concentrations in the environments where a child spends time; the weights are proportional to the time spent in each of these environments having distinct pollutant concentrations.

This concept of pollution exposure, termed the micro-environmental model, makes clear the health relevance of both indoor and outdoor pollution exposures and the potential for widely varying contributions of indoor and outdoor exposures to total personal exposures for children living in different countries throughout the world, depending on sources and time-activity patterns. It emphasises that one must be sure to examine pollution where the people spend most time, as well as in places where ambient levels are high.

Using particulates as the indicator pollutant, for example, total population exposure globally has been estimated to be dominated by household environments in developing countries where solid fuels are used for cooking and heating. This is because of confluence of exposure factors—that is, large populations adjacent to frequently used devices with large emission factors.

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Crop residues, dung, wood, and coal are widely used globally, perhaps accounting for about half of all fuels used daily to cook meals. From the standpoint of particle levels, the most polluted urban outdoor environments in the world are also in developing countries—notably, but not exclusively, in the coal using cities of Asia. Exposures to environmental tobacco smoke (ETS) track tobacco consumption; this has been dominated by developed countries but rates in these countries are now static or declining while in the developing world they are growing steadily.

It was found in a study of middle income homes of Delhi found particulate matter levels to be extremely high even in homes where there was no cooking or smoking activities. Which means that for middle-income groups, pollution can be attributed to other sources like carpets and air conditioners?

In a study of not so poor households in Bombay found that indoor – outdoor exposure ratios RSP to be 1.1 for households (5 in number) away from as well as near roads. Most of these used LPG cylinders for cooking. Hence the contribution of cooking smoke to daily RSP levels may be negligible. But for households (5 in number) in poor areas were the use of biofuels was greater IAP (for RSP) was found to be greater.

TERI in a survey based on the consumption pattern of energy in some slums of Delhi indicated that kerosene is the predominant fuel followed by other solid fuels. They found that it accounted for 60% of the total energy consumption. Solid fuels accounted for 19% of the consumption in the east zone and 26% in the west zone.

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9 Kumar, P. (2001), 'Characterisation of Indoor Respirable Dust in a Locality of Delhi'. Indoor and Built Environment, Pp 95 – 95-102
Gender Aspects of IAP and Health

Poor women in rural areas of the developing countries are the primary collectors and users of biomass fuels, fodder, water and other natural resources for household consumption.

WHO (1995)\textsuperscript{12} in a study South Asian countries found that women work anywhere between 7 – 21 hours more than men. Cooking accounts for a large share of women’s household work, and compared to men, women contribute 75\% or more to cooking activities in most countries.

Agarwal\textsuperscript{13}, in a study of the rural areas of India, especially in the Himalayan foothills found that men tend to spend more time in and around the cooking area. Consequently, women had much higher levels of exposure to TSP (mg m\textsuperscript{-3})\textsuperscript{14} and CO (ppm)\textsuperscript{15} than men.

In a study by Smith (1996)\textsuperscript{16} he showed that men’s and women’s bodies respond differently to different pollutants. For example, carbon monoxide (CO), a major component of biomass smoke, is a pollutant of particular concern to women. CO acts by displacing oxygen in the haemoglobin in the blood to make carboxyhaemoglobin (HbCO), effectively reducing the amount of oxygen reaching the body tissues. Women generally have less haemoglobin in reserve than men and are naturally more prone to anaemia than men. It was\textsuperscript{17} also suggested that exposure to air pollutants hinders the uptake of essential nutrients. High Prevalence of bronchitis

\textsuperscript{14} TSP = Total Suspended Particulate Matter, measured in milligrams per cubic meter
\textsuperscript{15} CO = Carbon Monoxide, measured in parts per million.
among women in developing countries is associated with exposure to indoor smoke from cooking. Sims (1994)\textsuperscript{18} associated \textit{Cor Pulmonae}, a right-sided heart failure in an uncommonly early age in women with long-term exposure to domestic smoke, particularly in high cold regions. As women with these conditions are not treated or hospitalised, official statistics still report those mainly affected by chronic lung disease to be male.

Mishra et al (1997)\textsuperscript{19}, is a study based in India found that the use of biomass fuels for cooking substantially increases the risk of active tuberculosis. In a WECF study (2000), Armenian women report that due to prolonged fuel scarcity many urban dwellers took to the burning of municipal waste for cooking and house heating. Burning of plastic, bleached paper, preserved wood and many other modern types of household waste exposed them to heavy loads of dioxin like substances, PAH and heavy metals.

Smith (1987)\textsuperscript{20} found that cooking with biomass fuel or coal generates multiple risks and exposures, which form an intergenerational vicious circle. The health risks to women and infants depend on low-grade fuel for cooking and heating can be characterised as follows:

- Gathering and transporting fuel (time and energy costs, musculoskeletal disorders, falls and fractures, increased risk of prolapsed uterus)
- Smoke from biomass / coal burning (respiratory disease, eventually heart disease)
- Eye infections and disorders (conjunctivitis and cataract)
- Depressed immune response from smoke exposure
- Exposure of foetus to CO (affects foetal development and birth weight)
- Infant vulnerability to infectious disease


• Risk of stunting for infant.

According to Longo (1977)\textsuperscript{21} women, during pregnancy, naturally produce more CO internally and the natural rate of internal CO production can up to 50\% higher than the normal level. Therefore, women have higher levels of HbCO during pregnancy. Pregnant women’s blood has 20 – 30\% less oxygen carrying capacity due to lower concentration of haemoglobin.

Ritz and Yu (1999)\textsuperscript{22} has also reported high association between CO exposure from ambient air pollution and reduced birth weights. Since women do most of the cooking, which results in greater exposure to CO from cooking smoke, there is a double burden on women (especially among those cooking with biomass fuels) i.e., greater exposures and greater impact to exposures.

Waldron (1985)\textsuperscript{23} suggests that in early years of life biological genetic factors are favourable to female children than male children to most infectious diseases. To the extent that this occurs, effects of cooking smoke exposure may be greater in boys than in girls.

According to Sommerfelt and Arnold (1998)\textsuperscript{24} as women in developing countries, particularly among the poor households rely on traditional fuels for cooking, tend to be more malnourished than men, effects of IAP are likely to be stronger among women than among men. However since, there is little gender-disaggregated analysis of effects of IAP on health, it is not clear if greater smoke exposures to women necessarily lead greater health impacts.

In the case of childhood malnutrition, the general assumption and evidence that young girls are discriminated against boys in quality quantity and


timeliness in feeding, in schooling, in clothing and in treatment and care when sick is not reflected in the empirical evidence on gender differentials in the nutritional status of boys and girls.

It is generally believe that cumulative exposure overextended periods, as they occur in the case of women cooking with to biofuels several hours per day over the years, cause greater health damage. According to Smith (1996)\textsuperscript{25}, little is known about these cumulative exposures or their health impacts. It is not known what the shape of the dose-response curve is for specific pollutants and health outcomes and what the thresholds are. It is possible that if the IAP levels are very high, beyond a critical level then one may not find a sex differential in the effect, even if women are more exposed.

In a joint UNDP – ESMAP (World Bank)\textsuperscript{26} chose to review the exposure to IAP and the subsequent effect on it by the improved cook stoves programme in Andhra Pradesh, India. The study found that in spite of the project IAP did not reduce much to affect the women positively. They quantified the exposure levels of SPM and CO indoors and found important gender dimensions of the IAP problem. They concluded that the cook stoves made cooking more efficient but did not do much to reduce IAP.

Cecelski (1995)\textsuperscript{27} says that the source of exposure to air pollutants depend on gender roles. While women do much of the cooking and stay indoors, men may also have substantial exposures to biomass smoke from other sources, such as brick making, charcoal making and sugar making activities, sitting around open fires and household heating during winter as well as indoor cooking. Agarwal (1995)\textsuperscript{28} also says, because men spend more time outdoors and at work places they are more likely to be exposed to ambient air


\textsuperscript{28} Agarwal B. (1995), \textit{‘Cold Hearth and Barren Slopes’}, The Riverdale Company Publishers Inc.
pollution, secondary tobacco smoke and employment related air pollutants than women. Men are also more likely to come in contact with the people carrying the disease. Moreover, Parikh (1995)\textsuperscript{29} found that much of women's work go much beyond the household sector and involves manufacturing and services as well. Therefore it is important to recognise that women are not a homogenous group and there are considerable class gender differences in both gender roles and their implications. Therefore, women are not only exposed to a disproportionate share of IAP but also other employment related pollutants.

In two separate studies\textsuperscript{30} they found that young children are often carried by the mothers or kept in the kitchen area during cooking, exposing them to high levels of smoke. In some parts of the world (esp. Gambia), young girls are likely to be carried or kept on mothers back or lap during the cooking than young boys, but in other areas (esp. India), where son preference is strong, boys are more likely than girls to be carried than girls to be carried or kept in the kitchen area where mothers are cooking. In India, with strong discrimination against females, such discriminatory practices may actually benefit girls and result in grater exposure to boys. It was \textsuperscript{31} found that young children who usually stay with their mothers indoors also have elevated exposures.

In a study in\textsuperscript{32} of 240 children under two years of age followed weekly for six months in Nepal found a strong relationship between reported number of hours per day the children spent near the cooking stove and incidence of moderate to severe acute respiratory infections.

\textsuperscript{31} Albalak R. (1997), 'Cultural Practices and Exposure to Particulate Pollution from Indoor Biomass Cooking Effects on Health and Nutritional Status among the Aymara Indians of the Bolivian Highlands', University of Michigan
\textsuperscript{32} Parikh et al (1999), 'Indoor Air Pollution: A Reflection on Gender Bias', \textit{Economic and Political Weekly}, Feb 27, Pp 539- 44.
\textsuperscript{31} Pandey et al (1989), 'Chronic Bronchitis and Cor Pulmonale in Nepal', Mrigendra National Trust, Kathmandu Nepal.
Kussove, (1982)\textsuperscript{33}, in a study of 744 children below three years in Zimbabwe found a significant association between the presence of wood-smoke pollution in the house and lower respiratory disease. The study compared 244 children reported with lower respiratory disease at a hospital with 500 children of similar nutritional and socio-economic background reported to a local Well Baby Clinic.

In a study of 500 Gambian children, less than 5 years of age by Armstrong and Campbell (1991)\textsuperscript{34} observed a significant relationship between cooking smoke exposure and ALRI in girls carried on their mothers' back while cooking. However, this study failed to show any such effect on boys.

Azizi and Henry (1991)\textsuperscript{35} examined the effects of indoor environmental factors on respiratory illness among 7 - 12 year old 1500 schoolchildren in Kuala Lumpur and found no relation between the exposure to kerosene stoves or wood stoves and ARIs. Instead, they observed a significant relationship between respiratory illness and mosquito coil smoke. This means that it is only the pre-school children who are the most susceptible to ARIs.

Anderson (1979)\textsuperscript{36}, also did not find any relationship wood smoke and respiratory disease in school children. He studied 112 school children at weekly intervals for 30 weeks in Papua New Guinea.

This lack of relationship between cooking smoke and respiratory illness in school-aged children may be due to the fact these children tend to spend more time outdoor lowering their exposure indoors and that children living in households with lower levels of indoor pollution can get infected from close interaction with other children in the school.


This survey focuses on indoor exposures of the world’s children to pollution from combustion of biomass fuels.

The survey could not address IAP convincingly linked to ARI, but has been inconsistently related to respiratory symptoms.

2.2 A brief discussion of mechanisms

ARI comprise a set of clinical conditions of various aetiologies and severities that are generally divided into two main forms: upper respiratory tract infections (URI) and lower respiratory tract infections (ALRI). The risk of severe ARI, which can be fatal, is highest in very young children and in the elderly. Clinical and epidemiological criteria are available for separating URI from ALRI but, unfortunately, worldwide there are no uniformly accepted criteria and the definitions in use are not fully consistent. For research and case management under field conditions in less developed countries the WHO defines URI to include any combination of the following symptoms: cough with or without fever, blocked or runny nose, sore throat, and/or ear discharge. URI can usually be treated successfully with supportive therapy at home. ALRI include severe ARI involving infection of the lungs, with pneumonia being the most serious form\textsuperscript{37}. Serious infections are most commonly caused by bacteria, although they may sometimes be viral. Clinical signs of ALRI include any of the above symptoms of URI with the addition of rapid breathing and/or chest indrawing and/or stridor. Severe ALRI caused by bacteria are treated with antimicrobial therapy, without which they can sometimes be fatal.\textsuperscript{35}

Air pollutants could increase the incidence of ARI by adversely affecting specific and nonspecific host defences of the respiratory tract. The non-specific mechanisms include filtration and removal of particles by the upper

airway, the mucociliary apparatus of the trachea and bronchi, phagocytosis promoting components of the epithelial lining fluid, and phagocytosis and killing of infecting organisms by cells in the airways and alveolar macrophages. The specific mechanisms involve various components of humoral and cellular immunity. Organism specific immunoglobulins promote phagocytosis; cell mediated immunity is required to kill organisms capable of living within alveolar macrophages\textsuperscript{38}.

Smoke from household solid fuels is a complex mixture which contains many potentially relevant components from a toxicologic perspective. These mixtures are inherently highly variable with characteristics determined by sources, materials burned, time since generation, and other factors. The chemical and physical characteristics of these mixtures have been characterised to some extent\textsuperscript{39} particularly in the form of wood smoke from metal heating stoves used in developed countries. Thus, only generalisations can be drawn concerning mechanisms by which particular air pollutants could increase the risk for ARI.

A number of pollutants commonly found in indoor and outdoor air have been shown to adversely affect components against infectious organisms. Exposure to air pollutants might also act to increase the severity of respiratory infections and thereby increase the proportion of illnesses clinically considered to involve the lower respiratory tract, and even to increase morbidity and mortality.

2.3 Indoor Air Pollution

In addition to the strength of sources, the impact of indoor emissions on air quality depends directly on ventilation and air mixing of the space. Most


housing in developed countries lies at temperate latitudes and has relatively low exchange rates of indoor with outdoor air. Even low emission rates in such housing can result in indoor pollutant concentrations at levels of public health significance. Ventilation rates for houses in developing countries, which lie primarily in tropical and subtropical regions of the world and are often open to the outdoors, are likely to be greater. Strong sources can be readily identified in developing countries, however, including biomass (wood, crop residues, and dung) and coal burning for cooking and heating.\textsuperscript{40}

Indoor pollutants can be grouped by source into four principal classes: combustion products; semi-volatile and volatile organic compounds released by building materials, furnishings, and chemical products; pollutants in soil gas; and pollutants generated by biological processes.\textsuperscript{41} The principal combustion pollutants include carbon monoxide, nitrogen and sulphur oxides, particles, and volatile organics. The complex mixture in indoor air produced by tobacco smoking has been referred to as environmental tobacco smoke (ETS). There are many biological agents in indoor environments including, for example, pollens and moulds, insects, viruses, and bacteria.

Although systematically collected data are unavailable, it is likely that the relative importance of the four types of IAP varies throughout the world with climate and level of development. For combustion sources, the focus of this review, some generalisations can be made. After tobacco smoking, gas stoves have been the most common indoor pollution source of concern in studies in developed countries. In the global context, however, gas stoves are near the upper end of a historical evolution in the quality of household fuels, called the energy ladder.\textsuperscript{42} On the lowest rungs are dried animal dung and scavenged


twigs and grass as cooking fuels. The next rungs in the sequence are crop residues, wood, and charcoal. The first non-biomass fuel on the ladder is kerosene or coal, and bottled and piped gases and electricity are highest. In general, each successive rung on this ladder is associated with increases in the technology of the cooking system, cleanliness, efficiency, and cost.

**Biomass fuel**

Nearly half the world's households are thought to cook daily with unprocessed solid fuels— that is, biomass fuels or coal. In a significant proportion of the households using biomass fuels, the bulk of the emissions is released into the living area. Although rates of exchange of indoor with outdoor air are relatively high in most housing in developing countries, the pollutant emission rates for such fuels are also high, and indoor concentrations and associated exposures can be high as a result. Compared with gas stoves, even stoves using wood, one of the cleaner biofuels, can release 50 times more pollution during cooking. In addition, unvented space heating with biomass fuels is common in much of South Asia and in the highland areas of developing countries of Asia, Africa, Latin America and Oceania.

Incomplete combustion of unprocessed solid fuels produces hundreds of chemical compounds under the operating conditions of simple cooking stoves. Such complex mixtures are produced by burning of both coal and biomass fuels, although the blends of compounds in the smokes are different. Unlike coal, biomass fuels generally contain few intrinsic contaminants (sulphur, trace metals, and ash) and, under proper conditions, they can be burned without releases other than the products of complete combustion (carbon dioxide and water). Unfortunately, optimum conditions for complete combustion are rarely achieved in primitive cooking stoves because of factors such as poor air supply and fuel moisture.

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combustion are difficult to create with inexpensive household devices. Smoke from cooking stoves is a complicated and unstable mixture\textsuperscript{44}. Although a large scale worldwide survey of smoke concentrations has not been conducted, the findings of studies from different parts of the world provide an indication of typical indoor concentrations of the major pollutants. Compared with various national standards, WHO recommendations, or even outdoor concentrations typical of the most polluted of cities, these indoor levels are dramatically high. One cannot presently derive an accurate estimate of the total population in developing countries exposed to indoor concentrations that would be considered unacceptable, nor can one readily apportion the contributions to total personal exposure of indoor and outdoor sources. Additionally, in some rural areas outdoor pollution penetrates indoors to a significant extent and fuel burning indoors may be a prominent contributor to outdoor pollution. Furthermore, there are no internationally recognised standards for pollutant concentrations indoors. Assuming that indoor standards should be at least as stringent as outdoor standards, the number of people exposed at unacceptable levels indoors is expected to rival or exceed the number exposed to unacceptable ambient concentrations in all of the world's cities\textsuperscript{45}.

2.4 Epidemiology

For focused attention in this review we were able to identify 13 more recently published studies which quantitatively addressed the relationship between exposure to household biomass smoke and ALRI in young children in developing countries in which ALRI case selection reasonably corresponded to established WHO or other authoritative criteria in use at the time the study was done. Such criteria have evolved over time and thus, as discussed below,


have not been entirely consistent among the studies. It is our judgement, however, that the protocols in these 13 studies have been sufficiently rigorous to warrant treating them as part of the same evidence pool. Nine were conducted in Africa and one each in India, Brazil, Argentina, and Nepal. Only one dealt with case fatality and the others dealt with morbidity. In addition, only two studies from a developed country (USA) of the relationship between household wood smoke and ALRI among Navaho children. These 15 studies are chosen for particular attention because they address actual ALRI, although confirmed by different means, in children under five years old and involve indoor exposures to biomass fuel smoke. Each is sufficiently quantitative to allow calculation of odds ratios and confidence intervals.

*Incidences of ALRI in young children of developing countries*

Outcome measures differed among the 13 studies. Two of the cohort studies and the one prospective case-control study used reported shortness of breath to screen for children with lower respiratory disease. The first two assessed severity by counting respiratory rate and assessing for chest indrawing and signs of cardiorespiratory failure. O'Dempsey et al. confirmed cases by laboratory tests and radiography. Pandey et al. presented analyses for moderate and severe lower respiratory infections. In an expanded study of the same region in the Gambia studied by Campbell et al. pneumonia was confirmed radiologically in 50% of children with symptoms and signs of lower respiratory disease. The remaining studies were based on children with pneumonia, severe wheezy bronchitis, or bronchiolitis diagnosed clinically or according to WHO recommendations in a hospital setting, or by verbal

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These outcome measures would tend to include children with more severe illness. Exposure to household smoke pollution was also assessed using different approaches. Broadly, the studies examined the relationship of the outcome measure with cooking practices such as use of an open wood fire compared with cleaner fuels such as kerosene, 57 behavioural practices—for example, carriage on mother's back while cooking or presence of sources 50. Pandey et al 51, for example, used time spent by mothers near the cooking stove as a categorical exposure measure in exploring the dose-response relationship of exposure to smoke with lower respiratory disease in children. Only one study actually measured pollutant levels and only in a subset of study households 52.

Air pollution studies in Kenya and the Gambia suggested that conditions were not favourable for detecting a relationship between concentrations of pollutants and lower respiratory disease in children because of the homogeneity of levels among households 53. Collings et al, however, found a significant difference in levels of total particles during cooking in households of 20 children with lower respiratory disease and 20 with upper respiratory disease, but few details were provided. The possibility of using carboxyhaemoglobin as a marker of smoke exposure was also explored in one study, but proved unsatisfactory because of the difficulty of controlling for time since exposure.

All but one of the eight morbidity studies finding significant associations were in Africa. The data in the one non-African study (Nepal) were consistent

50 Johnson, A. W., Aderele, W. I., (1992), 'The Association Of Household Pollutants and Socioeconomic Risk Factors with the Short-Term Outcome of Acute Lower Respiratory Infections in Hospitalized Pre-School Nigerian Children'. *Annals of Tropical Paediatrics*; vol 12, 421-32
with larger relative risks for more severe disease, but the numbers were too small to exclude chance as an explanation. The study by Shah et al. provided limited information on socioeconomic circumstances for cases and controls, and in any case did not report an increased odds ratio for smoke exposure. The study from urban Argentina by Cerqueiro et al. matched on five factors including socioeconomic status and district of residence. Overall, it appears that this bias was probably not important in this group of case-control studies, although without specific information on care seeking it remains a possible source of error.

The study by Cerqueiro et al. found a large odds ratio (9.9, 95% CI 1.8 to 31) for home heating with "charcoal" in patients with hospital diagnosed ALRI compared with controls matched by socioeconomic level, nutritional status, and other factors often addressed only by multivariate analysis in other studies. No pollution measurements were reported and little information was provided about the type of stove and fuel involved. Cooking with gas (rather than electricity) also produced a significant odds ratio (2.2, 95% CI 1.2 to 3.9).

It is intriguing to note that the three studies that found no significant association were the only ones which relied on questionnaires to determine what type of cooking stove or fuel was used at home without additional information about family behaviour patterns. In Kerala, India the measure of exposure was a question about the existence of a "smokeless" stove (with a flue) at home. Unfortunately, however, such stoves in India often do not actually lower IAP levels. The case-control study reported by Johnson and

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Aderele\textsuperscript{58} in Nigeria found no significant association of ALRI morbidity with reported type of household fuel, but did find a strong relationship of fuel type with case fatality.

Other studies

A study of ARI in infants aged less than one year in India\textsuperscript{59}, found somewhat conflicting results in urban slum communities where some households used biomass fuels and others kerosene. This was possibly due to strong interference by large scale urban outdoor pollution and local outdoor "neighbourhood" pollution from the cooking stoves themselves and other neighbourhood sources. Another study was an observational study of 650 randomly chosen pre-school children aged 1-59 months in Lucknow, 14.5\% of whom were found to have respiratory disease as defined by runny nose, cough, sore throat, breathlessness, or noisy respiration\textsuperscript{60}. After adjusting for age, weight, sex, income, and house type, use of dung as cooking fuel and crowding were associated with one or more of these respiratory symptoms. The location of the child during cooking, ETS, and cooking with coal, kerosene, or wood were not associated with respiratory symptoms in this study. Somewhat different results were obtained in the previously discussed six month prospective study of 650 children aged 1-53 months in the same area. With fortnightly household visits, a significant association of symptoms and/or duration of symptoms was found with outdoor TSP measurements. Morbidity due to "probable pneumonia" was also determined by cough and difficulty in breathing and was found only to be weakly but significantly related to the use of dung fuel.


A study of 658 children aged 0-6 years in Jakarta found that, although respiratory symptom rates were, after multivariate analysis, related to evidence of uncollected refuse around the house, they were not related to the type of cooking fuel used\textsuperscript{61}. The author speculates that the sample size of households using wood burning stoves (not given) was too small to find an effect, and that the impact of the refuse may be a result of the smoke generated by its frequent burning.

A large national household survey in India found a statistically significant relationship between reported use of household biomass fuel and reported incidence of respiratory infection in the previous week among children under five years\textsuperscript{62}. Since the survey did not distinguish cases by ALRI, URI, or severity, however, it probably is not a good predictor of the risk of severe, life threatening ALRI.

Morbidity studies indicate that smoke pollution is a risk factor for both milder and more severe cases of lower respiratory disease. Effective strategies for pneumonia case management will modify the relationship between the incidence of pneumonia and mortality.

*Incidence of ALRI in young children from developed countries*

Studies of the health effects of biomass smoke in developed countries have focused on households using enclosed metal heating or cooking stoves with chimneys. The indoor pollutant concentrations are normally substantially less than those found in village homes using open fires\textsuperscript{63}. Although not increased to the extent suffered by children from developing countries, the age adjusted ALRI mortality rate of Native American children has been some six times that of non-Hispanic white children. A study of young Navaho

\textsuperscript{61} Surjadi, C. (1993), 'Respiratory Diseases Of Mothers And Children And Environmental Factors Among Households In Jakarta'. *Environment and Urbanization*, vol 5, Pp 78-86


children in Arizona found that household cooking/heating with woodstoves (with flues) produced a significant odds ratio after multivariate analysis for physician-confirmed ALRI in hospitalised patients using radiographs\textsuperscript{64}. Cases were thus confirmed as bronchiolitis or pneumonia, but no information was given on the mix. A second study was designed to address factors not covered in the first—in particular, to include the difficulty of reaching the clinic in the multivariate analysis and to actually measure IAP levels\textsuperscript{65}. Honicky \textit{et al}\textsuperscript{66} performed a historical prospective study of 68 preschool children, half of whom came from homes with wood heating stoves, and found significantly more respiratory symptoms in the exposed group. Careful matching was done to assure that the groups did not differ by income, ETS, residence, etc, but no multivariate analysis was reported. Butterfield \textit{et al}\textsuperscript{72} found a significant correlation between hours of reported wood stove use and five of 10 respiratory symptoms in 59 children aged less than 66 months. Browning \textit{et al} on the other hand, found no significant relationship between respiratory symptoms in 823 children aged over one year and location in high or low wood smoke neighbourhoods. However, a non-significant trend was observed in those aged 1-5 years. Ambient monitoring showed an approximate difference of 20 ug/m$^3$ PM$_{10}$ levels between the two neighbourhoods.

\textit{Morbidity in school aged children}

Exposure to pollution from wood stoves has been associated with chronic respiratory symptoms, changes in lung function, and/or hospital visits in studies of school aged children in the USA exposed to wood smoke from stoves in their own home and/or their neighbourhoods. Larson and Koenig\textsuperscript{67}

\textsuperscript{64} Morris, K., Morgenlander, M., Coulehan, J.L., et al. (1990), 'Wood-Burning Stoves And Lower Respiratory Tract Infection In American Indian Children'. \textit{American Journal of Diseased Child}, vol 144, 105-8.

\textsuperscript{65} Robin, L.F., Les,s P.S., Winget, M., et al. (1996), 'Wood-Burning Stoves And Lower Respiratory Illnesses In Navajo Children'. \textit{Pediatric Infectious Disease Journal} vol 15, 859-65


reviewed six such studies in school aged children, two of which dealt with asthmatics and five of which found significant risks. The one study lacking statistical significance was based on telephone interviews with 399 households. In addition, the Harvard Six Cities study of air pollution found use of wood stoves to be associated with a 30% increase in respiratory illness (chronic cough, bronchitis, chest illness, wheeze or asthma) in a large sample of children aged 7·10 years. Such studies suggest an adverse effect of biomass pollution on lung function and are consistent with irritation and inflammation of airways and impaired host defences.

Similar associations were not found in one study in Malaysia. In a study involving 12147 12-year-old children the presence of a wood or kerosene stove in the home was inversely associated with the forced vital capacity (FVC) and forced expiratory volume in one second (FEN), but in a multiple logistic regression analysis that included passive smoking the association with stove type was no longer significant.

More recent studies in developing countries, however, have found effects in school aged children. A study in Adana, Turkey found by questionnaire in a group of 617 9-12-year-olds that those in homes heated with coal had significantly more cough than those using kerosene, oil, or electricity. The lowest statistically different lung functions were in children from wood burning homes. A similar study of 1905 7·13-year-olds in Jordan found that open wood and/or kerosene burning was statistically related to lower lung function with about twice the negative impact of ETS. No multivariate analyses were reported for these studies.

Conclusions

Indoor and outdoor environments are widely contaminated by complex mixtures of gases and particles that are produced by combustion. Components of these mixtures have been shown to adversely affect host defences against respiratory infections and it is thus plausible that such pollutant mixtures increase the incidence of respiratory infections. Air pollutants might also increase the severity of respiratory infections by causing inflammation of the lung airways and alveoli. Infants and young children are particularly susceptible to these adverse effects because of the immaturity of respiratory defence mechanisms and the geometry of the airways. Patterns of time-activity, which place children near sources of pollution such as cooking stoves, cigarettes, vehicle exhaust, or other contaminated environments, may contribute to the increased risk of ARI from airborne pollutants in young children.

Combustion of household solid fuels in developing countries produces exposures to smoke components that are remarkably high by the standards set for outdoor air in developed countries. Adverse effects of these exposures would be anticipated on a toxicological basis. Although the epidemiological evidence on smoke from biomass fuels and pneumonia is not yet abundant, associations have been demonstrated between exposure measures and indicators of illnesses involving the lower respiratory tract. When interpreted within the broad framework of epidemiological and toxicological evidence on inhaled pollutants and ARI, the association of smoke from biomass fuels with ARI should be considered as causal, although the quantitative risk has not been fully characterised.

Risk estimates from individual studies are imprecise because of relatively small sample sizes and misclassification of exposure and outcome. Given the imprecision and uncertainty in characterising the risk of biomass smoke exposure, quantitative risk assessments cannot be offered with great
confidence. On the other hand, the large population of children exposed and even our limited database on levels of exposure implies a significant burden of attributable ARI. The extent to which excess biomass smoke can be prevented is uncertain, however, because of the lack of information on exposure-response relationships. We urge further research directed at the time-activity patterns of children under the age of five years as well as studies designed to characterise total personal exposures and the contributions of indoor and outdoor pollution sources to children's exposures in developing countries. The resulting data would facilitate the design of additional case-control and cohort studies to better quantify the relationship between smoke exposure and ARI and to identify the most effective intervention strategies.

Unlike most sources of ambient air pollution, however, household sources of exposure such as cooking and heating offer the opportunity for conducting randomised trials of potential interventions, both engineering and behavioural. Thus, of even higher priority than further observational studies is the promotion of well designed randomised intervention trials in households in less developed countries in conjunction with careful exposure assessment. Data from intervention studies could quantify exposure-response relationships for ARI, convincingly demonstrate to policy makers the health benefits of practical interventions such as clean fuels, improved stoves, and householder education and, ironically, given past scientific inattention to this particular problem, move air pollution epidemiology in general closer to the "gold standard" of randomised clinical trials.

Globally, even though the attributable fraction of pneumonia/ARI mortality due to air pollution is not yet certain, it is probable that this disease outcome represents the largest class of health impacts from air pollution exposure worldwide. This is likely to be the case in terms of total morbidity and mortality but, because much of the burden falls on young children, is almost certainly the case with regard to measures of ill health that consider the lost
life years involved. This is due to three factors: (1) the relatively high odds ratios apparently involved, (2) the seemingly high and prevalent exposures in less developed countries, particularly in low income households, and (3) the high base rate of the disease in these nations.

Relatively recently there has been a significant increase in attention in many developed countries to issues related to "environmental justice"—that is, the unfortunate tendency for the highest exposures to environmental pollutants to be experienced by some of the most disadvantaged populations. Globally, however, even more examples of this injustice prevail. Indeed, few if any large groups are more disenfranchised and disadvantaged than poor rural women in developing countries and their young children, who experience the bulk of global airborne exposures to many pollutants.

There is a need for an organised international effort to monitor, evaluate, and mitigate air pollution in the places where people live and work. A principal goal of this effort should be rapid reduction of the alarming global burden of ARI.

2.5 The Status of IAP on India and its Effect

Air pollution has become a major concern in India in recent years both because it is now clear that large parts of the Indian urban population are exposed to some of the highest pollutant levels in the world (Smith, K. R. (1993), World Health Organization (1999))\(^{72}\) and also because new studies around the world on the health effects of air pollution have increased confidence in estimates of the risks posed by air pollution exposures (Holgate, S. T., Samet, J. M., Koren, H. S. & Maynard, R. L., eds. (1999), Lippmann, M., ed. (2000))\(^{73}\).

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Annual concentrations reported at urban monitors in India for PM10 particles less than 10 microns in diameter (Smith, K. R. & Jantunnen, M. (2001))\textsuperscript{74} for comparison, estimated that the most polluted urban area in the United States in the early 1990s had annual concentrations substantially less than the cleanest Indian city reported, although, unlike the U.S. cities, many Indian cities are not yet instrumented. Kumar, P. (1997), Zhang, J., Smith, K. R., et al (2000)\textsuperscript{75} found that even higher concentrations result, from the widespread practice of using unprocessed solid fuels (biomass and coal) for cooking and/or space heating in India and other developing countries, often in unventilated situations. Such concentrations result from high emissions factors from such fuels in simple small-scale combustion devices. The frequent result is indoor particulate concentrations well above even the dirtiest of cities. Smith, K. et al (1994)\textsuperscript{77} showed that the distribution of village means overlap with the higher end of Indian urban concentrations but extends considerably higher. During the cooking period itself, of course, much higher levels are reached. In addition, high household emissions from solid-fuel use result in elevated "neighborhood" pollution in densely populated communities. Few other activities involve as many person-hours as cooking does, because it is done in essentially every household every day in most of the world. The combination of high pollution levels in places with many person-hours is a prescription for large total population exposures. Indeed, indoor exposures to the combustion products of unprocessed solid fuels have been estimated to produce the majority of (nonsmoking) human exposures to particulates and

\textsuperscript{74} Smith, K. R. & Jantunnen, M. (2001) \textit{Atmospheric Environment}.


probably to a range of other pollutants as well (Smith, K. R. (1987))\textsuperscript{78}. With its large, poor, urban and rural populations still using simple solid fuels, the Indian population bears a significant fraction of this exposure (World Health Organization (1997))\textsuperscript{79}. It can be expected, of course, that the pattern of health effects would follow exposure patterns. Sakse, S. & Dayal, V. (1997)\textsuperscript{80} found in their study that exposure-response relationships have been derived for outdoor air pollution in developed-country urban situations, however, raises a number of questions about their suitability for application in developing-country (LDC) populations, particularly those exposed to IAP in rural areas.

2.6 Status of Household Fuel Use in India
The 1991 National Census included for the first time a question about the primary household fuel used and reflected that about 95% of the rural population still relied primarily on biomass fuels (dung, crop residues, and wood). A small fraction uses coal, which means about 97% of households relied principally on these unprocessed solid fuels. Nationwide, some 81% of all households relied on these fuels; 3% used coal and 78% used biomass. An independent probability-weighted national survey of 89,000 households in 1992 derived very similar results (NFHS I)\textsuperscript{81}. Unfortunately, such fuels are substantially more polluting per meal than the liquid and gaseous fuels further up on the "energy ladder." The amount of important health-damaging pollutants (e.g., PM\textsubscript{10}, CO, PAH, HCHO, VOC) breathed by a cook during a typical meal is about 2 orders of magnitude lower when burning bottled gas than burning wood or crop residues (see footnotes 1, 14)\textsuperscript{82}. Thus, as a first approximation, the use of unprocessed

\textsuperscript{80} National Family Health Survey I (1992-93), International Institute of Population Studies, Bombay
solid fuels in the household is an indicator of the potential for excessive air pollution exposures. In this way, access to clean fuels is parallel to the often-cited proxy indicator of disease risk.

Improved Stoves. India has active programs promoting introduction of improved biomass cookstoves (ICs) with chimneys and/or combustion improvements (Ramakrishna, J. (1991). Kohli, S. & Ravi, M. R. (1996))\(^83\). These include privately run programs run by nongovernment organizations as well as the large Government of India program itself, conducted by the Ministry of Non-conventional Energy Sources through nongovernment organizations and government agencies. The principal objective of the programs is to improve fuel efficiency, although lowering smoke exposures is a secondary goal. Although it has been found to be surprisingly difficult to spread ICs successfully over wide regions in India, some important progress has been made. Indeed, some 25-30 million ICs have been introduced since the mid-1980s\(^84\). By 1991-1992, the target year for this study, about 12.5 million had been disseminated. Unfortunately, according to Natarajan, I. (1999)\(^85\), as most of introduced ICs apparently have lifetimes of 2 years at most, only a fraction of those introduced before 1990 were likely to be still in use in 1992. To be conservative, however, assuming that 7.6 million households (6% of all solid-fuel households; 5% of all households) were using ICs in 1991-1992 that were 100% effective in eliminating air pollution exposures (TERI,(1989), NCAER,(1993))\(^86\). But according to Ramakrishna,
J., Durgaprasad, M. B. & Smith, K. R. (1989)\textsuperscript{87}, the latter condition is actually rarely the case, however, because even the best ICs leak smoke into the room and some of the smoke released from the flue outdoors will make its way back into the same house or others.

Ventilation.

Not all of the remaining households cook indoors at every meal, however. Many cook outdoors or in semi enclosed courtyard settings for part of or all of the year. Some may cook indoors for one meal and outdoors for other meals during the same day. There seem to be few systematic surveys that would allow an estimate of the overall scale of this practice. Barnes, Openshaw, Smith et al (1994)\textsuperscript{88} has assumed that 25\% of all household meals are cooked outdoors annually throughout the nation. Also assuming, quite conservatively, that cooking outdoors results in no air pollution exposure. In reality, solid-fuel stoves are sufficiently polluting to produce significant exposure even when used outdoors. Thus, the 25\% figure could be interpreted to mean that 50-75\% of the households cook outdoors part of the year.

2.7 Important Air-Pollution-Related Diseases and Their Relative Risks

The global burden of disease studies\textsuperscript{89}, to be sure that other factors were not confounding the results, multivariate analyses would have been done to statistically correct for them. In reality, however, the available published studies are less than ideal. Compared with the potential scale of the problem and to the effort spent on air pollution studies in developed countries, they are relatively meager. Some studies have not been able to control for potential confounders, although all have tried to deal with the problem in


some way, for example, by matching exposed and unexposed groups. Few studies actually measured air pollution. Most relied on indirect exposure indicators such as type of fuel or stove or number of years cooking. No randomized trials have been done. Tobacco smoking exacerbates basically the same set of diseases and may overwhelm the impact of air pollution in active smokers. In rural India, however, women probably receive the highest air pollution exposures because of their role as cook but they smoke at low rates (WHO, (1998))\textsuperscript{90}. Children under 5 years have the highest risks for the acute respiratory disease thought to be affected by air pollution and of course do not smoke. In addition, particularly in the first few years, they spend much time with their mother and thus receive higher exposures than older children, who may spend much time away from the household. Because of these factors, the focus of this study is entirely on the effects in women (over 15 years) and children under 5 years. No attempt is made here to calculate the burden on men, which is probably dominated by smoking or on older children (5-15 years) who spend more time out of the household.

The strong evidence comes from passive and active smoking studies, urban air pollution studies, and multiple studies of solid-fuel use in developing countries. \textit{[ARI in children under 5 years (India: 13\% of deaths; 11\% of NBD; 24\% of National Burden Disease for children under 5 years)]}. Of the major diseases thought to be associated with indoor air quality is ARI, a class that includes infections from a wide range of viruses and bacteria, but with similar symptoms and risk factors\textsuperscript{91}. In every country, young children contract these diseases at similar rates, but in India and other poor countries, they often proceed to severe stages, including pneumonia and death. It is generally acute lower respiratory infections (ALRI) that impose the highest burden and greatest risk of mortality.

ARI is the largest single disease category for India, accounting for about one-ninth of the national burden\textsuperscript{92}. For the world as a whole, ARI is also the largest category, accounting for about 8.5\% of the global burden. Astonishingly, Indian ARI is actually the largest single disease category in the world, in the sense of being subject to attention by one government. The Indian portion of this one disease class, which affects mainly one age group, accounts for 2.5\% of the entire global burden of ill health\textsuperscript{93}.

Since severe childhood ARI is rare in developed countries, few air pollution studies there have focused on it through lack of interest or insufficient cases for statistical significance. Ironically, when developed-country exposure-response information is applied to LDC situations, ARI has often been left out.

As documented (Smith, K. R., Samet, J. M., Romieu, I. & Bruce, N. (2000))\textsuperscript{94}, a number of studies have been done in the developing world that give quantitative estimates of the relative risk of severe ARI for children living in biomass-burning households: South Africa\textsuperscript{95}, Zimbabwe\textsuperscript{96}, Nigeria\textsuperscript{97}, Tanzania\textsuperscript{98}, Gambia\textsuperscript{99}, Brazil\textsuperscript{100}, India\textsuperscript{101}, Argentina\textsuperscript{102}, and

Nepal\textsuperscript{103}. Although none of these studies had the resources to do the kind of sophisticated analysis commonly found in developed-country studies, as a group they make an intriguing case. A study among Native Americans (Navaho) also showed strong and significant effects of woodstove use at much lower indoor pollution levels than the levels found in developing countries\textsuperscript{104}. There are even larger groups of studies that show various childhood respiratory symptoms (coughing, wheezing, etc.) to be associated with solid-fuel smoke exposures, but do not provide sufficient evidence to calculate odds ratios (i.e., the risk of contracting disease in the exposed vs. unexposed populations) of ARI itself. Some work has been done to identify possible mechanisms in the developing-country context as well\textsuperscript{105}.

\textit{COPD in women}

Today in developed countries, nearly all cases of COPD are attributable to tobacco smoking. Undoubtedly, smoking is also a significant factor in COPD incidence among LDC men. In India, even though relatively few rural women smoked during the past decades, COPD in rural women today is not uncommon. Although a number of studies have looked at various symptoms of chronic respiratory ill health in women cooking with open biomass stoves, eight seem to have actually determined the prevalence of COPD in a


way that allow quantification: Saudi Arabia\textsuperscript{106}, Columbia\textsuperscript{107}, Mexico\textsuperscript{108}, Nepal\textsuperscript{109}, India\textsuperscript{110}, Bolivia\textsuperscript{111}.

\textit{Cor pulmonale}. a serious heart condition secondary to COPD, is also often found among rural women nonsmokers in India and has long been attributed to chronic biomass smoke exposures\textsuperscript{112}). There is also good evidence of interstitial lung disease from long-term exposures to biomass smoke, but not of a character that allows determination of odds ratios\textsuperscript{113}. Even silicosis has been attributed to such exposures, usually in association with soil dust\textsuperscript{114}. In addition, several studies have found reductions in lung function, cough, and various other respiratory conditions associated with biomass smoke exposures in women.

\textbf{Lung cancer in women (India: 0.4\% of deaths; 0.1 \% of NBD: 0.1 \% of NBD for women).} Lung cancer in women is a well demonstrated outcome of cooking with open coal stoves in China\textsuperscript{115}. In China, there is also evidence of lung cancer from use of certain cooking oils\textsuperscript{116} and other health effects from

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arsenic and fluorine in household coal. There is little evidence connecting lung cancer to biomass fuel, however. Biomass smoke, however, contains a wide range of chemicals that are known or suspected human carcinogens, and it contains particles in the small sizes known to penetrate the deep lung. Overall, being mainly nonsmokers and noncoal users, Indian women have low lung cancer rates.

**Asthma**

Asthma rates are officially low in India, although there is some recent evidence that the true prevalence is higher than previously thought. Studies in Kenya, Malaysia, and China have quantitatively associated childhood asthma with various measures of indoor pollution from solid-fuel use. As the reported background rate is so small, however, asthma contributes relatively little to the total burden of deaths or DALYs.

**Adverse pregnancy outcomes**

A large proportion of perinatal effects consists of diarrhea and ARI, the chief killers of children younger than 5 years, but specific diagnosis/autopsy is difficult with such young infants. Only one study seems to have examined this factor in India as an outcome of biomass fuel use. This study, done in Ahmedabad, found an excess risk of 50% of stillbirth among women using biomass.

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biomass fuels during pregnancy\textsuperscript{124}. A Chinese study of urban ambient pollution also found a strong relationship of particulate levels with preterm delivery\textsuperscript{125}. The same group found that particulate air pollution was also associated with low birth weight as was also found with exposure to household biomass smoke in Guatemala\textsuperscript{126}. Intrauterine mortality, low birth weight, prematurity, and early infant death have been strongly associated with urban outdoor pollution at much lower concentrations than typically found in biomass-using households\textsuperscript{127}.

Low birthweight is a risk factor for a number of childhood\textsuperscript{128} (119) and, probably, adult (120) diseases, not just those of the respiratory system. Although there is likely to be an important effect from this mechanism for indoor biomass and coal smoke, at present it is hard to provide an estimate of the potential burden in India.

\textit{Heart disease in women (India: 17\% of deaths; 5\% of NBD: 7.3\% of NBD for women).} Ischemic heart disease (IHD) rates among Indian women are not high by world standards. As with all diseases associated with air pollution, IHD has other important risk factors, smoking and diet in this case being the largest. Indeed, studies in developed-country settings show that the risks of air pollution and smoking for heart disease are relatively modest compared, for example, to the risks for respiratory disease. Because the background rate of heart disease is so high, however, the absolute impact on public health is among the highest.


2.8 An overview of the findings

If verified, the ill health estimated from IAP is a substantial portion of the national total in India, 4.2-6.1%\textsuperscript{129}. It is equivalent to 6.3-9.2% of the burden for women and children under 5, who make up about 44% of the population but bear about two-thirds of the disease burden. IAP would seem to classify as a major cause of ill health in India for it rivals or exceeds TB, IHD, all cancers, road accidents, or all of the "tropical" diseases combined. On a risk factor basis, the burden of dirty air at the household level lies behind only dirty water at the household level (poor water/sanitation/hygiene = 10%) and poor food at the household level (malnutrition = 22%), the largest two risk factors in India in the early 1990s. The burdens of the latter two, however, are steadily increasing in India, unlike IAP. Nevertheless, by any standard, indoor air quality would seem to be a major health issue in the country.

At the global level, India seems to have some 30% of all household solid-fuel stoves, although the estimates are generally much less reliable than in India where fuel use is determined in the national census. On that basis, the total world health impact on women and children would be roughly three times larger than the Indian estimates. To be more precise, would require duplicating the entire process used here of combining exposures, risks, and background disease rates in each region.

By themselves, epidemiological studies do not prove causality, only association. Nevertheless, when a number of studies find similar associations in different populations, places, and times; in situations of different mixes of confounders; and done by different investigators with different methods; the argument for causality starts to become stronger. The case for causality is not helped, however, by the current poor understanding of the actual physiological mechanisms that link airborne particles with ill health. A number of studies bring out the difference between rural and

The principal differences between developed-country urban and developing-country rural populations are as follows:

1. Differences in the pollutant mix attributable to different fuel sources mean that existing exposure-response estimates may not be applicable in developing countries; i.e., although particulates can be used as indicator of hazard in both cases, biomass fuels as commonly used in Indian households produce relatively more organic compounds (e.g., benzene, formaldehyde, butadiene, polyaromatic hydrocarbons), and fossil fuels produce more sulfur oxides. Thus risk estimates derived for the latter fuel may not apply to the former.

2. In a similar fashion, the chemical and other characteristics of the particles produced by biomass combustion are not the same as those produced by fossil fuel use, although of course wood smoke is found seasonally in the outdoor air of many developed-country cities.

3. Different populations have different exposure patterns; i.e., indoor concentrations tend to vary much more during the day (because of household cooking and heating schedules) than do outdoor urban levels.

4. Exposure levels are also different; i.e., the average exposure levels of concern in households using unvented biomass fuels are 10-50 times greater than the levels studied in most recent urban outdoor studies (Smith, K. R. (1993)130. As is common with toxicants, there may be a diminishing of the effect per unit increase in exposure The patterns of disease, competing risk factors, and age distributions differ dramatically between urban developed country populations, the world's richest, healthiest, and oldest populations, and people exposed to IAP in developing countries, who tend to be the poorest, most stressed, and youngest in the world.

5. Most developed-country studies are time-series studies that determine short-term changes in mortality and other end-points in association with

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short-term changes in air pollution. Implications for long-term health are unclear. These more fundamental concerns are in addition to severe constraints imposed by incomplete information on the distribution of air pollution levels experienced by the Indian population. There have been no studies of pollution levels in Indian households based on stratified random sampling designs, for example. (This is also a problem, although to a lesser extent, with outdoor pollution levels in Indian cities.)

7. Additional uncertainty is created because those relatively few particulate measurements done to date have been mostly with respect to total particulates, although most of the consistent exposure-response results have been with regard to smaller size fractions (PM$_{10}$ or PM$_{2.5}$; particles less than 10 μm or 2.5 μm in mean aerodynamic diameter, respectively).

8. To be most useful for policy making, such estimates should assess more than mortality but also derive lost life-years and time lost to associated diseases of different severities.

Given these concerns, estimating ill health (mortality) is a rather crude and uncertain way of predicting the impact of air pollution for the exposures of interest. Given the apparent high total exposure to these populations, however, it has seemed well justified to apply the best available risk information, even if far from ideal.

Over the last decade or so, however, a number of epidemiological studies of individual diseases for particular age groups have been done in India and other developing countries in solid-fuel-using households. Although not in nearly the quantity or sophistication that are warranted by the size and exposure of the population involved, their number and consistency are sufficient to enable their use for estimating overall health impacts. The following steps summarize the approach taken here:

- By using data from the Census and other sources, the size of the exposed population is determined, which is defined simply as those that use solid fuels.
• By using the results of epidemiological studies in biomass-burning households in South Asia, Latin America, Sub-Saharan Africa, and elsewhere, appropriate risk factors (relative risks) for specific diseases in specific age groups are determined. Such studies are available in sufficient quantity and quality only for adult women and children under 5, who have the highest exposures to stove emissions.

• By using the national burden of disease (death and disability) database for India, the current patterns of these diseases in these population groups are determined.

By using the standard procedure for determining the population attributable fraction, the total disease burden attributable to use of household fuels is determined. By using the known mortality-morbidity relationships for specific diseases for each age group in India, total lost life years and total sick days are estimated.

1. Being based on studies of biomass-using households, the differences in pollutant mix, particle composition, and exposure patterns and levels are greatly reduced.

2. Although not all done in India, the studies were all done in poor, mostly rural, developing-country populations presumably much more similar to the exposed Indian population than urban developed-country populations.

3. The studies address directly the specific health endpoints over time periods appropriate to the each and thus do not reflect the possible "harvesting" that may be seen in time-series studies.

The studies in India and other LDC solid-fuel-using households reviewed here have generally not directly measured exposures, nor have they been as nearly as extensive or sophisticated as those in developed-country urban settings. Nevertheless, a number of studies have been done by different investigators in different countries that found similar results. Combined
with the evidence that the average particle levels do not seem to be qualitatively inconsistent with the developed-country studies. On the other hand, given that most actually measured the risk of solid fuel use, there may be risks to health, in addition to air pollution, perhaps through the physical burden of harvesting such fuels. Their alarming scale, however, argues for additional efforts to understand and ameliorate the conditions that lead to such severe pollution levels in the village and urban slum homes of India and elsewhere in the Third World. At the very least, they call for a serious effort to conduct the medical and abatement research that would pin down more accurately the impact of the pollution and effective ways to reduce it. Over the next decade, millions of lives may depend on it.