Indoor Air Pollution from Burning Biomass & Child Health

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Abstract: ***With approximately 3 billion people worldwide utilizing biomass as a source of energy, the World Health Organization rates Indoor smoke from biomass such as solid fuels as one of the major contributor to environmental exposure with one quarter of deaths and disease burden in children under 5 years of age. The ideal way to prevent or reduce the serious health impacts would be the withdrawal or reduction of exposure to these pollutants. This can be achieved with sustainable interventions such as key national and local level stakeholders to address the problem.***

Keywords: Biomass, Pneumonia, Particulate matter, Carbon monoxide, the energy ladder

1. Introduction

Biomass refers to biological organic material and is used most extensively as an energy source around the world [1]. Biomass energy is derived from burning wood, agricultural wastes, and other organic residues (e.g. dung). It is used for many purposes such as cooking, heating homes and buildings. Biomass energy is a sensible use of most waste products in a way that helps the environment, and it is a cheap source of energy. Biomass is composed of carbon, hydrogen, and oxygen [2].

Biomass energy still remains an important energy source (about 35%) for cooking and heating, especially to developing countries with a high rate of poverty that are not heavily industrialized, and do not have abundant supplies of fossil fuels [3, 4]. In developed countries it is used on a larger scale to generate electricity or to fuel vehicles. In Canada, several independent power producers generate electricity from the burning of wood wastes and other biomass materials. And on a smaller scale, burning of firewood continues to supply space heating in many Canadian homes. According to Natural Resources Canada, about 26 per cent of Canadians still use wood for home heating. This is most prevalent in Atlantic Canada in the province of Nova Scotia, Manitoba, New Brunswick, Newfoundland and Labrador [3].

Directly burning biomass in an enclosure is the simplest way to use it for energy. This enclosure restricts air flow and improves efficiency. This method can also be used to provide heat for a room or, heat water and pump it through pipes and provide heat to several rooms. It can even be extended to provide heat to several buildings from the same boiler, which is known as district heating [1]. In developing countries biomass fuel is burnt in open fireplaces within households. These fireplaces often consist of simple arrangements such as three rocks, a U-shaped hole in a block of clay, or a pit in the ground. Often in most of these stoves, combustion is incomplete. This results in substantial emissions and accumulation of toxic pollutants, such as particulate matter, carbon monoxide, sulphur oxides, nitrous oxides, formaldehyde, and volatile organic compounds, within the household [4, 5, 6].

The World Health Organization (WHO) estimates nearly 3 billion people (almost half of world's population), still cook and heat their homes using open fires and leaky stoves burning biomass and coal. It also estimates about 2 million deaths annually from diseases attributed to indoor pollution due to solid fuel use. Some of these diseases include pneumonia, chronic obstructive pulmonary disease (COPD), ischemic heart disease, and lung cancer [4, 5].

A health effect is determined by the exposure level; i.e. the level of pollution and by the duration of time in which people breathe polluted air. By comparisons people in developing countries are commonly exposed to very high levels of pollution for 3–7 hours daily over a period of many years [7, 8]. Women's exposure is much higher than men as they are more often involved with cooking, and their young children are swaddled to their backs or at their side when they cook. Also older children spend a large proportion of their time indoors, either at home or at school. Therefore it is not surprising that women and children in developing countries often face more serious health risks due to indoor pollution from solid fuel use [4, 5, 7, 8].

Children are more susceptible to air pollutants than adults because of their unique physiology and behavior [9]. Indoor pollutants therefore can cause more severe health effects in children.

Exposure to indoor air pollutants from burning biomass fuels, adversely affects the specific and nonspecific host defenses against pathogens especially in the respiratory tract of children. This increases their risk of developing respiratory tract infections such as pneumonia. WHO has identified pneumonia as the largest single cause of death in children under the age of 5 years. Nearly 50% of pneumonia deaths among children under five are due to particulate matter inhaled from indoor air pollution. Particulate matter particularly those less than 10 microns in diameter (PM10), can penetrate deeply into the lungs and appear to have the greatest potential for damaging health [5, 10]. Incomplete combustion of biofuels is also known to produce a colorless, odorless and tasteless toxic gas called carbon monoxide (CO). Since CO is not detectable by humans either by sight, taste or smell, it can cause serious health problems before people even notice it is present. When breathed in, CO binds to hemoglobin in the blood and reduces the oxygen carriage capacity. This reduced amount of oxygen in blood can cause lethargy, unconsciousness, and even death [11].

The purpose of this report is to highlight how indoor pollution from biomass fuel burning affects child health. In this report, we will discuss the impact of two criteria air pollutants most commonly associated with biomass fuel burning; namely particulate matter and carbon monoxide. Finally, the report will conclude by providing recommendations on how to reduce indoor pollution from biomass fuel burning.

2. Biomass

Biomass is regarded as one of the important alternative fuels and is defined as the group of biologic materials (living organisms, both animal and vegetable, and their derivatives) present in a specific area, collectively considered. Some of this material is used as fuel for cooking or home heating [22]. Almost half of the planet lives in poverty, and those households generally use biomass (wood, crop residues, charcoal, or dung) or coal as fuel for cooking and heating. The primitive fires typically fill homes with dense smoke, blackening walls and ceilings and sickening those within, with nearly half the world's population exposed to smoke from burning these fuels in their own home [13]. Women and children living in extreme poverty are at highest risk for adverse health outcomes from biomass fuel use, as it is attributes to indoor air pollution (IAP). The World Health Organization lists IAP from primitive household cooking fires as the leading environmental cause of death in the world, as it contributes to nearly 2.0 million deaths annually with a global burden of disease of approximately 2.5% of all healthy life-years lost.—more deaths than are caused each year by malaria [14, 15]. Whereas men tend to be physically removed from household smoke exposures during the day, women and children suffer high exposures, which lead to many of the same disease risks as if they were lifelong smokers of tobacco.

2.1 Source

Close to 3 billion people, use biomass fuels as their primary source of domestic energy for cooking, home heating, and light, extends from very low percentages in developed countries to more than 80% in China, India, Pakistan, Bangladesh and sub-Saharan Africa [12, 16, 17, 18].Biomass is the only fuel used for cooking daily meals in most of the rural and semi-rural areas in Bangladesh with varieties of bio fuels including cow dung, jute stick, rice straw, rice husks, bagasse, twigs, bamboo, dry leaves, woods, etc. being used in Bangladesh commonly [19]. In Pakistan, the use of biomass fuel in traditional three stone stoves (made of clay and husk) produces enormous quantities of smoke. The Pakistan Household Energy Strategy Study revealed that biomass fuels account for 86% of total household energy consumption in Pakistan [20]. In the rural areas of Latin America, approximately 30 to 75% of households use biomass fuels for cooking [21, 22]. Unfortunately most of the cooking with biomass is done indoor, without efficient ventilation. Population exposure to various air pollutants is likely to be higher in the indoor micro-environment than outdoors due to the amount of time people spend indoors. Consequently, indoor air quality has drawn considerable attention in recent years. Globally, there are noticeable differences in types and strengths of these sources, and they are closely linked to socioeconomic developments. In the developed world, the types, sources, concentrations of various indoor air pollutants, and their exposure profiles are significantly different from the developing world [22].

In developing countries, population explosion along with widespread industrialization coupled with urbanization has resulted in dense urban centers with poor air quality. In addition to the poor ambient air quality, people in developing countries can be exposed to high concentrations of indoor air pollution due to the use of biomass fuels as an energy resource.

Wood is the most frequently used biomass fuel, both as unprocessed wood and as charcoal, the latter having far lower impact in indoor air pollution. Wood smoke has also been reported to be probably carcinogenic [23, 24]. In some regions, especially in sub-Saharan Africa, roughly 20% of the wood energy harvest is processed into charcoal and could reach 50% in some countries [25]. Use of animal dung, crop residues, corncobs, and grass increases when wood is scarce or the forests are situated far away from the community.

Exposure to biomass smoke is estimated to cause a global death toll of 1.5 million every year [4]. Biomass burnings are producing particulate matter (soot), toxic gaseous pollutants (Carbon dioxide [CO_2], Carbon monoxide [CO], Nitrogen oxide), polycyclic aromatic hydrocarbons (PAH) and heavy metals (Pb, Cu, Fe, Zn, and Hg, etc). Biogeochemical cycles of trace elements in tropical regions may also be changing due to biomass burning emissions. Emission of heavy metals can cause local and regional pollution of the atmosphere as well as hydrosphere.

The use of solid fuels is linked to the gross national product per capita [17], and in general, in the same geographic zone, the use of solid fuels is higher in households with lower income [26].

2.2 Composition

Combustion of any fuel produces emission of complex mixtures containing particles, semi-volatile matter and gases. Modern fuels burn more efficiently, resulting in a greater proportion of the intended end products of carbon dioxide and water (as steam). Biomass fuels are much less efficiently burned, because of the greater difficulty in mixing the fuel with air during burning [27]. Typically, 30 to 40 wt.% of the dry matter in biomass is oxygen. The principal constituent of biomass is carbon, making up from 30 to 60 wt.% of dry matter depending on ash content. Consequently, a larger fraction of the carbon contained in the fuel is not fully combusted to carbon dioxide, and instead forms both particulate matter (e.g. soot) as well as a variety of organic compounds. Of the organic component, hydrogen is the third major constituent, comprising typically 5 to 6% dry matter.

The biomass fuels can be divided quite generally into four primary classes:

- wood and woody materials,
- herbaceous and other annual growth materials such as straws, grasses, leaves,
- agricultural by-products and residues including shells, hulls, pits, and animal manures and
- Refuse-derived fuels (RDF) and waste or non-recyclable papers often mixed with plastics. The latter class is often excluded from the category of biomass, but the origin, with the exception of mixed plastics, is appropriate for inclusion as a biomass type. A fifth class, that of energetic materials including decommissioned rocket fuels, is emerging as part of the fuel mix for biomass facilities. The properties of these materials can be substantially different than those for conventional biomass materials. The distinctions among the first three classes—woods, herbaceous materials, and by-products—are largely based on the structural compositions for hemi cellulose, cellulose, and lignin, and on the concentration and composition of inorganic materials.

Impurities in the fuels also result in the formation of inorganic compounds including carbon monoxide, sulphur dioxide, nitric oxide and ammonia [28]. Hundreds of individual compounds have been detected in wood smoke samples to date, attesting to the complexity of these emissions. Most of these constituents are organic carbon compounds. A wide variety of metals including nickel and arsenic have also been identified in wood smoke emissions, reflecting uptake of these elements by trees [29]. Due to incomplete combustion, the resulting smoke contains a range of health-deteriorating substances that, at varying concentrations, can pose a serious threat to human health. The pollutants emitted include carbon monoxide, nitrogen dioxide, particulate matter, transition metals, fluorine, polycyclic aromatic hydrocarbons, volatile organic compounds such as benzene and formaldehyde, and free radicals [30, 31, 32, 33, 34, 35, 36, 37, 38, 39].

2.3 Levels

Cooking is the most important activity contributing to high levels of indoor air pollution. However, in some regions, especially in Asia, heating is another important source [40]. The majority of rural households in developing countries burn biomass fuels in open fireplaces or in non-airtight stoves, resulting in substantial emissions, which, in the presence of poor ventilation, produce very high levels of indoor pollution with 24-hour mean PM10 levels in the range of 300 to 3,000 mg/m3, which may reach 30,000 mg/m3 during periods of cooking [22, 40]. The mean 24-hour levels of CO in the same households are in the range of 2 to 50 ppm, and can reach 500 ppm during cooking. The measurement of indoor air pollution from biomass combustion is complex because of the temporal and spatial distribution within the household, and the characteristics of the ventilation. In developing countries, the levels of indoor air pollution in homes using biomass fuels for cooking far exceed the health-based standards in the whole household, in both cooking and sleeping or living areas, with repeated episodes of intense emissions [40, 41, 42, 43, 44, 45].

In Pakistan, the mean daily levels of CO for wood use and natural gas were 24 and 5 ppm while the levels of PM2.5 were 12 and 0.25 mg/m3, respectively. However, during cooking periods in the kitchens using biofuel, a sharp rise in concentration of CO (150 ppm) and PM2.5 (300 mg/m3) was seen [20].

Cooking or heating with biomass fuels in stoves or fireplaces vented to the outdoors (airtight stoves) also produces high indoor air pollution, exceeding substantially the total global outdoor exposures to several important pollutants, including respirable particulates, although there is a substantial reduction in indoor concentration of pollutants compared with houses with unvented stoves.

Studies from China and from other developing countries provide data supporting the large contribution of indoor pollution to total exposure, especially for women and children [46]. In China, it has been estimated that 80 to 90% of the total exposure to PM10 results from indoor air pollution due to solid fuel use in the rural population and this contribution is less than 60% in the urban population [47]. The level of exposure of a population or an individual who uses solid fuels is extremely variable [16, 17, 48, 49, 50]. About half of the total exposure in women who cook with solid fuel may be derived by high-intensity episodes when they are close to the fire, especially when starting or stirring the fire [46].

2.4 Population's susceptibility

Indoor air pollution, from solid fuel use, is the tenth largest threat to public health [26]. Therefore, exposure to indoor air pollution from biofuels combustion is a major hazard in public health primarily affecting the poor in both rural and urban societies in developing countries. High levels of particulate matter and carbon monoxide have been reported, and generally, women and children get the maximum exposure. There is strong evidence that smoke from biofuels can cause acute lower respiratory infection in childhood [17, 44, 48, 51, 52, 53, 54, 55].

2.5 Biomass fuels & illness in children

Biomass releases particulate matter when burned, which can contribute to diseases such as pneumonia, cancer, tuberculosis, and asthma. Furthermore, a recent report on the national burden of diseases from indoor air pollution by the World Health Organization confirms the linkage between indoor air pollution due to solid fuels and different diseases, including acute and chronic respiratory diseases, tuberculosis, asthma, and cardiovascular disease and prenatal health outcomes [56].

Most of the burden of disease arises from respiratory infections, especially in children < 5 years of age, with a disproportionate amount of health problems falling on women and children, who are more likely to be at home or to have responsibilities for cooking and heating activities [57]. Women and their small children are at increased risk due to the amount of time spent close to the stove in the kitchen. Children are susceptible to exposure and susceptibility from hazardous chemicals and toxicants more than adults because of few following reasons [9, 58]:

- Children breathe a greater volume of air than adults relative to their body size.
- Children's organs, respiratory, immune and neurological systems are still developing. Gas exchange system in lungs continues to develop till about 2 years of age.
- Children are much closer to the ground, and as a result, breathe in more of the heavier airborne chemicals than adults.
- Infants and young children breathe through their mouths, more so than adults, which increases their risk of pulmonary exposure to particulates and fibers, which would otherwise be filtered out in the nose.
- Children have a higher heart rate than adults, which allows substances that are absorbed into the blood to permeate tissues faster.

During winter, in areas where wood is available, wood burning (indoor biomass burning) is common in essentially every part of the developed world for household heating. It is also popular for recreational use in fireplaces. This has implications for area-wide ambient levels and indoor pollution as well as what can be called "neighborhood" pollution, outdoors but sometimes localized in neighborhoods where woodstoves are in use.

Relatively few measurements seem to have been reported of indoor concentrations of wood-smoke in developed-country households. The majority of information regarding direct human health effects associated with wood-smoke exposure is derived from a relatively large number of epidemiologic studies, have documented.

Siddiqui et al. reported that mothers using wood as fuel gave birth to children with reduced weight compared to those who used natural gas [59]. For Pakistan, the number of deaths due to pneumonia and other acute lower respiratory infections among children under 5 years of age was estimated to be 51,760, the number of deaths due to chronic obstructive pulmonary disease 18,980, the total number of deaths attributable to solid fuel use 70,700 and the percentage of national burden of disease attributable to solid fuel use 4.6% [56].

It seems probable that the burning of common biomass fuels within small and poorly ventilated homes will produce high endotoxin exposures. The only available report in the scientific literature comes from a small study in the Ladakh region of India, where short-term sampling (< 60 min) of two homes produced average endotoxin concentrations of 24 and 190 EU/m3 [60]. These concentrations are within the range of those found in occupations involved in the handling and processing of large volumes of biological material.

3. Studies related to biomass

3.1 Experimental and animal toxicology studies

Many of the constituents present in wood smoke have been studied for their abilities to irritate mucous membranes and aggravate respiratory disease. Relatively few studies have evaluated the effects of whole wood smoke. Several studies have found an overall depression of macrophage activity as well as increases in albumin and lactose dehydrogenase levels, indicating damage to cellular membranes. Epithelial cell injury has also been demonstrated.

A preliminary report suggests that wood smoke exposure may lead to increased susceptibility to lung infections [61]. These observations lend support to epidemiological associations between wood smoke exposure and respiratory illnesses in young children, as discussed below:

- Mary Jane Selgrade of the U.S. EPA compared infectivity of Streptococcus zooepidemicus aerosols exposure in mice exposed previously to clean air, oil furnace emissions and wood smoke. The Streptococcus zooepidemicus causes severe respiratory infections. Two weeks post-exposure, 5% of the mice in the control and oil furnace groups died, compared to 26% of the wood smoke exposed group [61].

This study is best viewed as indications of plausibility for observed epidemiological associations and to help understand the mechanisms by which biomass smoke exposure may lead to adverse health outcomes.

3.2 Human studies

- A case control study conducted in Zimbabwe found a significant association between lower respiratory disease and exposure to atmospheric wood smoke pollution in young children. Air sampling within the kitchens of 40 children indicated very high concentrations (546-1998 ug/m3) of respirable particulates. Blood COHb was determined for 170 out of 244 children confirming that they did experience smoke inhalation [61].
- The association between exposure to air pollution from

cooking fuels and health aspects was studied in Maputo, Mozambique. Personal air samples for PM10 were collected when four types of fuels (wood, charcoal, electricity, and liquefied petroleum gas (LPG) were used for cooking. Wood users were exposed to significantly higher levels of particulate pollution during cooking time (1200 µg/m3) than charcoal users (540 µg/m3) and users of LPG and electricity (200-380 µg/m3). Wood users were found to have significantly more cough symptoms than other groups. This association remained significant when controlling for a large number of environmental variables. There was no difference in cough symptoms between charcoal users and users of modern fuels. Other respiratory symptoms such as dyspnoea, wheezing, and inhalation and exhalation difficulties were not associated with wood use [61].

Lifetime exposure from cooking fuels was estimated by multiplying the exposure level (1200 µg/m3 for wood) by years of exposure (23 for wood), duration of daily exposure (3 hours) and a use intensity factor (proportion of respondents using wood on the day of the measurement). The mean lifetime exposure variable was 2800 exposure years for those currently using wood as the principal fuel.

3.3 Clinical studies

A case-control study conducted among Navajo children evaluated the association between wood smoke exposure and acute lower respiratory illness (ALRI). Indoor particulate levels were measured in this investigation. 1–24 month old 45 children hospitalized with an ALRI were compared with age and gender matched controls who had a health record at the same hospital and had never been hospitalized for ALRI. Home interviews of parents of subjects elicited information on heating and cooking fuels and other household characteristics. Indoor PM10 sampling was conducted in the homes of all cases and controls. Matched pair analysis revealed an increased risk of ALRI for children living in households that cooked with any wood or had indoor particle concentrations greater than or equal to 65 µg/m3. The indoor particle concentration was positively correlated with cooking and heating with wood (geometric mean levels of approximately 60 µg/m3) but not with other sources of combustion emissions [61].

3.4 Questionnaire/ survey studies:

A questionnaire study of respiratory symptoms compared residents of 600 homes in a high wood smoke pollution area of Seattle with 600 homes (questionnaires completed for one parent and two children in each residence) of a low wood smoke pollution area. PM10 concentrations averaged 55 and 33 µg/m3 in the high and low exposure areas, respectively. When all age groups were combined, no significant differences were observed between the high and low exposure areas. However, there were statistically significant higher levels of congestion and wheezing in 1-5 year old between the two areas for all three questionnaires (1 baseline questionnaire and two follow-up questionnaires which asked about acute symptoms). This study supports the other investigations suggesting that young children are particularly susceptible to adverse effects of wood smoke [61].

3.5 Summary of studies:

The epidemiological studies of indoor and community exposure to biomass smoke indicates a consistent relationship between exposure and increased respiratory symptoms. These studies have mainly been focused on children, although the few studies which evaluated adults also showed similar results. Shorter duration episodes at lower air pollution concentrations have been linked with adverse impacts, while chronic exposure to higher levels of biomass air pollution and to lower levels of urban air pollution have been associated with development of chronic lung disease, pneumonia and decreased life expectancy.

4. Particulate Matter and Pneumonia

Pneumonia is an acute infection of the lower respiratory tracts that affects the lungs. There is inflammation of the alveoli (alveoli are microscopic sacs in the lungs that absorb oxygen). The alveoli become inflamed and are filled with pus and fluid, which makes breathing difficult and limits oxygen intake [10, 62].

It is known that pneumonia can be caused by different infectious agents, such as bacteria, viruses, and fungi. The most common are:

- Streptococcus pneumoniae – the most common cause of bacterial pneumonia in children;
- Haemophilus influenzae type b (Hib) – the second most common cause of bacterial pneumonia;
- Respiratory Syncytial Virus is the most common viral cause of pneumonia;
- In infants infected with HIV, Pneumocystis jiroveci is one of the commonest causes of pneumonia, responsible for at least one quarter of all pneumonia deaths in HIV-infected infants.

The organisms settle in the alveoli and continue multiplying. As the body responds by sending white blood cells to attack the infection, the sacs become filled with fluid and pus - causing pneumonia [10, 62, 63]. Knowing which pathogens lead to pneumonia is critical for guiding treatment and policies. Pneumonia can also be caused by inhaling irritants such as vomit, liquids, or chemicals. It can range from a mild to severe illness in people of all ages. Signs of pneumonia can include coughing, fever, fatigue, nausea, vomiting, rapid breathing or shortness of breath, chills, or chest pain [10, 62, 63].

Laboratory tests (such as x-rays and blood tests), are used to support diagnosis (extent and location) of pneumonia. However, in resource poor settings where these technologies may not readily be available, suspected cases of pneumonia are diagnosed by their clinical symptoms; and children and infants are presumed to have pneumonia if they exhibit a cough and fast or difficult breathing. UNICEF and WHO have published guidelines for diagnosing and treating pneumonia in community settings in the developing world. Prompt treatment of pneumonia with a full course of appropriate antibiotics is lifesaving and this approach is proven, affordable and relatively straightforward to implement [64].

Certain people are more likely to become ill with pneumonia. This includes 65 years of age or older adults; and children younger than 5 years of age [63]. Children are particularly more vulnerable to developing pneumonia. Healthy children are able to protect their lungs from the invading pathogens that cause pneumonia because of body's immune system. However, when the immune system is compromised and defence system weakened, children and infants cannot fight off these pathogens and subsequently develop pneumonia. A child's immune system can be impaired by malnutrition (particularly those not exclusively breastfed or with inadequate zinc intake); and pre-existing illnesses (suffering from illnesses such as AIDS or measles). Environmental factors, such as living in crowded homes and exposure to parental smoking or indoor air pollution, also have a role to play in increasing children's susceptibility to pneumonia and its severe consequences [8, 10, 62, 64].

4.1 Child health: Reducing child mortality to achieve MDG 4

According to a latest WHO/UNICEF/The World Bank combined report, progress has been made towards achieving MDG 4. In year 2011, 6.9 million children under five years of age died (that is nearly 19 000 children each day and almost 800 every hour). This is a 41% decline in under five mortality rate: from nearly 12 million deaths in 1990 to 6.9 million deaths in 2011. Although progress has been made in past decades, this progress is unequally distributed across regions, and countries, and within countries [65]. For the year 2011, almost 80 percent of the world's under-five deaths occurred in only 25 countries; and about half concentrated in only five countries: India, Nigeria, Democratic Republic of the Congo, Pakistan and China.

The leading causes of death among children under age five are preterm birth complications (14%), and infectious diseases. Of all the infections, pneumonia (18% of all under-five deaths) and diarrhoea (11%) were the leading causes of death [65].

Pneumonia is caused by a combination of exposure to risk factors related to the host, the environment, and infection. WHO and UNICEF identify indoor air pollution as one of the important risk factors to developing pneumonia, especially in children under five years old. Almost 50% of pneumonia deaths among children under five are due to particulate matter inhaled from indoor air pollution due to burning biomass [5, 8, 10, 62]. In houses with poor ventilation this indoor smoke can contain 100 times higher than acceptable levels of small particles [5]. Personal exposure usually depends on two important components: (a) the level in the home and (b) the length of time for which each person in the home is exposed to that level. It is know that typically women and young children (until they can walk), and girls (as they learn kitchen skills) are often exposed for at least 3–5 hours a day, and may be more. In some communities, and where it is cold, exposure will be for a much longer period each day. Most households in developing countries burn biomass fuels in open fireplaces in the presence of poor ventilation. This results in substantial emissions and production of very high levels of indoor pollution [52, 66].

Smoke from biomass burning has been quantified in several studies, both from developing countries and also from the United States. Most of the studies have been case-control studies however there has been a few cohort studies. All studies show a consistent and significant relationship between the exposure to solid fuel use and an increase of the risk of ALRIs. The odds ratio (OR) range from 1.8 to 5.5 (95% confidence interval [CI], 1.3– 8.5). The overall estimate of the risk of ALRIs, from the eight selected studies by Smith and colleagues, was 2.3 (95% CI, 1.9–2.7): 1.8 for children younger than 5 years and 2.5 for children younger than 2 years. The highest OR was found in children carried on their mother's back while cooking (OR, 3.1; 95% CI, 1.8–5.3) [46].

Air pollutants affect the specific and non specific host defence mechanism of the respiratory tract against the pathogen [54, 67]. Particles greater than 10 mm are likely to land in proximal airways and are removed by the ciliary activity. Small particulate matter (particulate matter <10 µm (PM10) have the potential to reach and be deposited deeper into lower respiratory tract and deep within the parenchyma of the lung. At this level the clearance of foreign bodies depend on phagocytosis and the mucociliary pathway. Although the healthy lung is capable of dealing effectively with a large number of particles deposited on to its surface, these defence mechanisms may be overwhelmed by either particle number overload or by the inherent toxicity of the particle. Therefore, when inhaled concentrations of particles are very high, 'lung overloading' with impairment of particle clearance has been observed. Lung overloading causes sustained neutrophilic inflammation [68]. This could increase the incidence of Acute Respiratory Illness (ARI). Air pollutants, such as mixture of sulphur dioxide and particulates, found both indoor and outdoor, have been shown to weaken components of the host respiratory tract defence mechanisms against infectious organisms. Furthermore exposure to air pollutants results in chronic inflammation of respiratory tract. The infecting organism further damages the already inflamed and possibly narrowed airways [54, 67]. Studies in animals have shown that exposure to wood smoke significantly altered both local and systemic immune response associated with bacterial infection [69].

4.2 Animal studies

To study the effects of air pollution on host defence, animal models are particularly helpful. They assess the function of all the components working together in vivo. These include anatomical barrier function, mucociliary clearance, and effects of secretory immunoglobulin A (IgA), surfactant, opsonising IgG, complement, alveolar macrophages, plasma components, and vasoactive mediators [54, 67]. The most relevant studies of biomass-induced vulnerability to infection use pathogens that cause clinically important respiratory disease in humans.

Respiratory syncytial virus (RSV) is an important cause of acute lower respiratory tract infection in young children especially in the developing world. By itself it predisposes children to bacterial co-infection in the lung. Laboratory studies done in mice has further demonstrated development of secondary pneumonia in animals exposed to ultrafine carbon and RSV. Studies have shown that in mice, RSV infection delays pulmonary clearance of Pneumococcus, S. aureus and Pseudomonas ; and therefore suggesting that the possible association between biomass smoke exposure and acute bacterial pneumonia, is in part, mediated via an increased vulnerability to RSV [70].

Few animal studies have examined the effect of biomass smoke, or carbon particles, on Staphylococcal killing in the lung. Staphylococcus aureus causes life-threatening pneumonia in the developing world. The few studies that have been done show that there is a dose-dependent increase in lung concentrations of S. aureus , after inhalation of wood smoke for 1 hour per day for 4 days. This adverse effect of wood smoke on pulmonary immunity occurs within 3 hours and lasts up to 5 days [71,72].

Alveolar macrophages are a major component of the innate immune defence mechanism of the lung. A study done by Lundborg et al. in 2006 assessed the effects of concentrated ambient particles (CAPs) from US city air on the binding and phagocytosis of S. pneumoniae by primary alveolar macrophages [73]. Although an increase binding of pneumococci to alveolar macrophages (by 67%) was observed in the presence of Carbonaceous-based CAPs; the ability of the macrophage to destroy the adherent bacteria was impaired, i.e. the overall effect of CAPs is to reduce the ability of alveolar macrophages to kill pneumococci. Similarly, phagocytosis of carbon black impairs the ability of alveolar macrophages to subsequently phagocytose Candida and Cryptococcus.

A study of alveolar macrophages sampling was done using sputum induction in women and children living in Gondar, Ethiopia. Examination of these cells under light microscopy showed very high levels of phagocytosed carbon from both children and mothers living in biomass-burning huts; further proving that the very high levels of air pollution measured in indoor air in the developing world, reflect exposure of lower airway cells [74].

Gökhan et al. 2006, demonstrated that exposure to airborne PM resulted in a dose-dependent reduction in alveolar fluid clearance in mice [75]. The study also found that exposure to even very low doses of particulate matter (10 µg), resulted in a significant reduction in alveolar fluid clearance that was maximal 24 h after the exposure, with complete resolution after 7 days. A decrease in lung sodium potassium ATPase activity (Na,K-ATPase activity) was also observed in these mice, therefore suggesting that the observed reduction in alveolar fluid clearance after exposure to PM might result from a reduction in active Na+ transport. The collection of fluid in alveoli may affect the ability of the animal to tolerate damage to the alveolar capillary barrier.

5. Carbon monoxide

Carbon monoxide (CO) is a colorless and odorless toxic gas [76, 77]. CO can kill the person before he gets aware of its presence because it is impossible to see, taste or smell the toxic fumes of CO [77].

5.1 Source

Direct emissions of carbon monoxide come from biomass burning and fossil fuels like natural gas, propane and oil as a common byproduct [76]. If fuel burning equipment is properly installed and maintained then it produces little carbon monoxide which can be vented outside safely [76]. However, decreased availability of oxygen or blockage in the vent can quickly increase the concentration of carbon monoxide in indoor air [76]. The main sources of carbon monoxide are unvented kerosene and gas space heaters; leaking chimneys and furnaces; back-drafting from furnaces, gas water heaters, wood stoves, and fireplaces; gas stoves; generators and other gasoline powered equipment; automobile exhaust from attached garages; and tobacco smoke [77].

In year 2005, estimated total CO emissions in Canada were 9,538,301 tonnes excluding open sources e.g. forest fires, prescribed burning (Environment Canada, 2012). The primary emitting sources were [78]:

- Transportation sources (e.g. on-road and off-road motor vehicles and engines, marine, air)
- Wood industry
- Aluminum industry
- Residential wood heating
- Other industrial sources (e.g. aluminum)

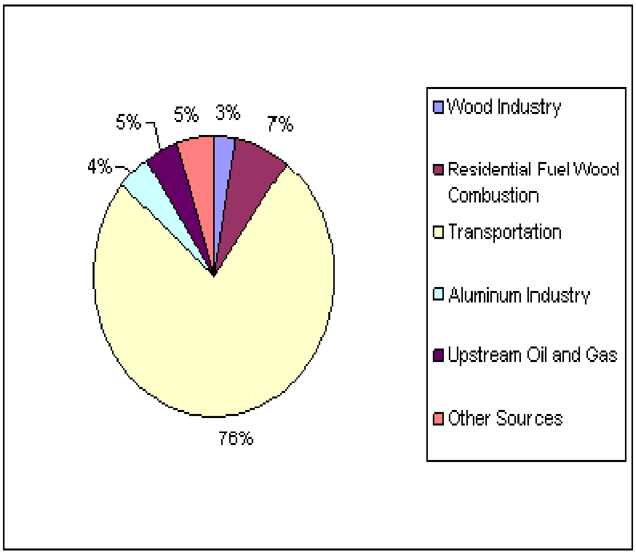

Figure 1: CO Emissions in Canada - Year 2005 (Environment Canada, 2012) (Without Open Sources- % of Total) [78]

5.2 CO uptake in the human body

After inhalation, carbon monoxide does not diffuse in to upper airways and so it is not a pulmonary irritant. It penetrates in to alveolar region and enters in to the blood stream. Carbon monoxide has 250 times more affinity to bind with haemoglobin than oxygen [79]. So it displaces oxygen and binds with haemoglobin and travels to all organs in to the body as a carboxyhemoglobin (COHb). High levels of COHb cause poor oxygenation of cells and tissues in the body (heart, brain, and skeleton muscle) [79].

5.3 Health Effects

CO poisoning is associated with following adverse health outcomes [76, 77].

Mild Exposure:

- Fatigue in healthy people
- Chest pain in people with heart disease
- Flu-like symptoms such as headache, running nose and sore eyes that clear up after leaving home.

Moderate Exposure:

- Reduced brain function which causes disorientation and confusion
- Drowsiness
- Dizziness

- Vomiting
- Angina

Extreme Exposure:

- Impaired vision and coordination
- Brain damage
- Unconsciousness
- Death

5.4 Health effects in children

Maternal exposure to carbon dioxide during pregnancy can be associated with adverse health outcome in the fetus. Fetal Hb is has higher affinity (approximately twice) and relatively small diffusion gradation for carbon monoxide than maternal Hb [80]. These two reasons slow the kinetics of COHb in fetal blood compared to maternal blood. Hence, study found that fetal COHb concentrations are 10-15% higher than maternal blood [58, 81].

Animal studies found possible association between maternal exposure to carbon monoxide during gestation and fetal developmental abnormalities like decreased birth weight, adverse central and peripheral nervous system development, altered sexual behaviour, cardiac and haematological effects [58]. Few epidemiological studies also support the result of these animal studies. A 1.4-ppm difference in maternal exposure to carbon monoxide was associated with 21.7 g lower birth weight (95% CI, 1.1–42.3 g) and 20% increased risk of intrauterine growth retardation (95% CI, 1.0–1.4) [58, 82]. Some epidemiological studies also found that prenatal and early life exposure to carbon monoxide reduces pulmonary function and exacerbates symptoms in asthmatic children [58, 83, 84]. A study conducted on rabbits by Astrup et al. in 1972 found that continuous maternal exposure to 0, 90, or 180 ppm CO throughout pregnancy was associated with 11 and 20% decreased fetal birth weight in the 90 and 180 ppm CO groups, respectively. They established that Lowest observed adverse effect level (LOAEL) was 90 ppm CO [12, 58]. Another study conducted on rats by Prigge & Hochrainer et al. concluded that continuous exposure to CO during gestational day of 0 to 21 is associated with significant decrease in hematocrit and haemoglobin level [58].

5.5 Exposure of CO in children:

Like adults, Children are also exposed to carbon monoxide through the inhalation of indoor and outdoor air [58]. Study by Dionisio et al. measured the exposure of children to CO, with emphasis on estimating “usual exposure” over a specified period of few weeks, which may be relevant for effects on childhood pneumonia. The authors also examined the association of exposure with household factors (e.g. fuel and location of cooking; insect coil and increase burning), season (rainy or dry), childcare (e.g. frequency of carriage on mother's back), and demographic (e.g. child's age) factors. They found higher association of CO exposure in household using charcoal, insect coil [85].

5.5. Levels in homes

- Average levels in homes without gas stove: 0.5-5 parts per million (ppm).
- Levels near properly adjusted gas stoves: 5-15 ppm.
- Levels near poorly adjusted gas stoves: ≥ 30 ppm [77].

5.6 Steps to reduce exposure to carbon monoxide

- Keep gas appliances properly adjusted.
- Consider purchasing a vented space heater when replacing an unvented one.
- Use proper fuel in kerosene space heaters.
- Install and use an exhaust fan vented to outdoors over gas stoves.
- Open flues when fireplaces are in use.
- Choose properly sized wood stoves that are certified to meet EPA emission standards. Make certain that doors on all wood stoves fit tightly.
- Have a trained professional inspect, clean, and tune-up central heating system (furnaces, flues, and chimneys) annually. Repair any leaks promptly.
- Do not idle the car inside garage [77].

Centers for Disease Control and Prevention (CDC) and U.S. Consumer Product Safety Commission (CPSC) recommends carbon monoxide alarms for every house. Additionally, CPSC also urges consumers to have an annual professional inspection of all fuel burning appliances [77].

6. Risk Assessment

6.1 Hazard identification

There is a growing body of evidence from human and animal studies that exposure to wood smoke poses a risk to human health at environmentally relevant concentrations, linked to adverse health outcomes and to indicators of early biological effects. These adverse health effects range from irritancy to serious respiratory diseases and chronic obstructive airway disease and lung cancer in adults [86].

The Risk Assessment considers two important future research questions [87]:

- Are there effects more intrinsically and specifically associated with exposure to wood smoke compared to emissions from traditional urban sources such as industrial and vehicular emissions?
- Is there a characteristic(s) common and unique to all wood smoke that is critical for assessing risk, or are there important differences in composition among different types of smoke (i.e., wild land vs. agricultural vs. woodstoves, etc.)?

6.2 Dose response

Wood-smoke exposure concentrations in the United States and other developed countries are typically lower than those that have been associated with severe lung disease as in developing countries. However, existing evidence suggests that short-term exposures can lead to irritancy and transient changes in inflammatory markers with chronic endpoints yet to be characterized. Low-level chronic exposures can impact susceptible individuals, such as children, and thus may affect a considerable fraction of the population in the developed countries where wood is used for space and water heating, or where exposures occur during controlled and uncontrolled fires. While the available evidence suggests that health endpoints associated with wood-smoke exposure under the conditions prevalent in the developed world are similar to those reported for urban PM, the relative potency in dose response for cancer and non-cancer endpoints remains uncertain [87].

Specific dose-response research questions identified from the risk assessment include:

- Given well-defined endpoints, is the potency of wood smoke particles similar to mixed ambient PM?
- Are there differences in the toxic potency of freshly generated versus aged wood smoke aerosols?
- Are there specific wood-smoke components that can be quantitatively linked to specific responses, and are these components unique to wood smoke?

6.3 Exposure assessment

Scenarios for assessing wood smoke exposure can vary widely with respect to concentration, composition, and duration. Given this complexity, identification of specific qualitative and quantitative tracers that can be used for source identification and exposure assessment, is a critical need. Evidence to date suggests that organic tracers such as LEVOGLUCOSAN and METHOXYPHENOLS are promising candidates as unique tracers, but there is significant variability in the relative quantitative composition of these tracers due to type of fuel combusted, burning conditions, and time course during the burning event [87].

The use of biomarkers to assess wood smoke exposure is promising, yet there are apparent limitations as quantitative indicators of exposures [87].

Important future research questions identified include [87]:

- What are the most prevalent exposure scenarios (i.e., source, concentration, duration) and path-ways of exposure?
- Are there specific components that can be used as external markers for wood-smoke exposure? If so, are they applicable across all scenarios, or only some scenarios?

6.4 Risk characterization

The objective of risk characterization is to determine the probability of adverse effects on human populations, and derives from the first three phases of the risk assessment process. Key risk characterization research questions include [87]:

- What is the fraction of the population exposed to wood smoke?
- Are there susceptible population subgroups at risk from exposure? Which is the critical endpoint(s)?

7. Prevention strategies

The ideal way to prevent or reduce the health impacts is the withdrawal or reduction of the exposure. However, the selection of the strategies to achieve this aim is very complex because it should take into consideration not only the personal exposure but also cultural and economic aspects at individual and local levels. Also the level of development, resources, the domestic energy needs, the sustainability of the considered sources of energy, and the protection of the environment. Interventions and research should consider all these aspects to offer feasible solutions [4, 22].

A logical first step for many of the poorest countries and communities is the development of projects to define the local resources and capacity to offer widespread and sustainable improvements in household energy [88].

Although a change to cleaner and sustainable fuels is the primary preventive strategy, substantial improvements can be obtained even when ‘‘dirty’’ biomass fuels are used, with following changes:

- Changes in ventilation characteristics of housing:
  - ✓ Locations and placement of windows and doors
  - ✓ Cooking locations
  - ✓ Space configuration.
- Ventilation practices:
  - ✓ Keeping doors and windows open after cooking.

From a public health point of view, local measures and the continued promotion of improved stoves can significantly reduce exposures within solid fuel using households. Despite all the initiatives, the use of cleaner fuels for most people exposed seems unlikely in the near future [89].

Some of the arrangements though within the means of poor families and may not be considered cost-effective. As income increases for poor people, they tend to switch to cleaner fuels for cooking and heating. But poor people cannot afford to wait for a rising tide of prosperity to clean up the air in their homes, and the international community has an obligation to ensure life is made more tolerable for today’s generation.

In a review of ways of reducing smoke levels, undertaken for the WHO and the United States Aid (USAID), alternatives were considered according to three areas. These comprise:

- Interventions at the source of smoke
- Interventions directed towards the living environment
- Interventions aimed at the user.

7.1 Dusts masks

Many different types of masks with variable filtration effectiveness can be used. Several of the most effective masks have been tested to meet United States of America National Institute of Occupational Safety and Health (NIOSH) standards for dust respirators. These masks passed a test procedure which uses 0.5 um silica particles and have been demonstrated to filter more than 99% of challenge particles.

However, in order for these masks to reduce human exposure by the same degree, the masks must provide an airtight seal around the face. As all masks are designed for use by adult workers, the effectiveness of even the highest quality masks for use by children has not been evaluated. It is unlikely that they will provide more than partial protection. Lower quality masks will offer even less protection. Also, children tend to be averse to use of face masks as it can be uncomfortable at times.

Table 1: Potential interventions for the reduction of exposure to indoor air pollution [90]

Source of smoke	Living environment	User
Improved cooking device: -Chimneyless improved biomass stoves -Improved stoves with chimneys **Alternative fuel–cooker combinations:** -Briquettes and pellets -Charcoal -Kerosene -LPG -Biogas -Producer gas -Solar cookers (thermal) -Other low smoke fuels -Electricity **Reduced need for fire :** -Efficient housing -Solar water heating	**Improved ventilation :** -Hoods/fireplaces -Windows/ventilation holes **Kitchen design and placement of 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

7.2 Substitution & the energy ladder

The energy ladder is a scale which rates the quality of household fuels. At the lower end of the ladder are the traditional biomass fuels: dried animal dung; scavenged twigs and grass; through to crop residues, wood and charcoal. Moving up the ladder, coal is next, followed by kerosene, bottled and piped gas, biogas (from digesting animal dung) and electricity. Gaseous fuels are the cleanest burning household fuel [90].

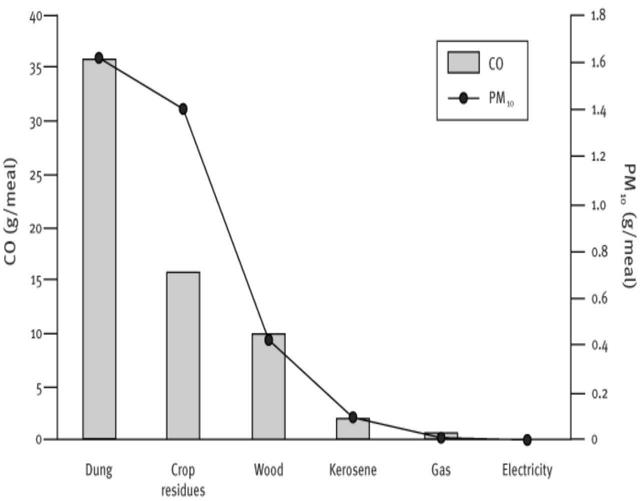

Figure 2: CO and PM emmision from different sources

7.3 Cooking on a cleaner fuel

The most effective means of reducing indoor air pollution is to switch to cleaner fuel that produces significantly lower emissions. While this may not currently be an option for many people due to high costs, lack of access to the fuel and other barriers, for those who are able the switch fuels, the benefits are great [90].

In many urban areas cleaner fuels, such as kerosene and LPG, cost less per unit of fuel than biomass. However, there is often a larger cash investment needed to purchase the fuels and the stoves. For example LPG must be bought each week or month by the bottle, but poor people usually purchase fuel daily in small quantities. Making fuel available in smaller quantities would benefit poorer customers [90].

In rural areas there is less incentive to switch fuels, as biomass is gathered at no financial cost to the user. Cost issues aside, there are other concerns about fuel switching. Many of the poorest members of society in developing countries make their living from collecting and selling biomass fuel. The result of a wholesale shift from biomass fuel could be the removal of a vital source of income for some of the most vulnerable people in society [90].

7.4 Biogas from dung and other waste

Biogas is extremely effective, as it converts a renewable material into a gaseous, clean fuel. While biogas is being introduced in parts of Asia very successfully – there are over 120000 bio-gasifiers in Nepal alone. The culture in much of Africa makes it harder to introduce there. Further research and development of renewable, clean cooking fuels will be essential for longer term cooking options [90].

7.5 Improvements in household ventilation and area distribution:

Simple improvements in ventilation of houses could significantly reduce PM10 and could be cost-effective interventions. An open window in the cooking area could reduce the indoor CO by 85% [88]. Large and better placed windows in the whole household and/or gaps between roof and wall may help, as well as maintaining the windows open while cooking. A kitchen physically separated from the living and sleeping area could reduce significantly the average exposure. In households in which the heating stove is different from the cooking stove, like in China, reducing exposures requires improvements in the stoves [88].

7.6 Improved biomass stoves

Improved stoves were primarily designed to increase energy efficiency.

- *The Upesi stove:* It has been promoted throughout Kenya and can reduce fuel use by about 40%. These stoves were developed with a specific reason. Reducing fuel requirements will ease demand on forestry, lessen the burden on women collecting fuel, and in urban areas cut expenditure on fuel [90].

The 2 primary types of advanced/improved cooking stoves are:

- *Forced air stoves:* It is fan powered & has an external source of electricity, or a thermoelectric device that captures heat from the stove and converts it to electricity. This fan blows high velocity, low volume jets of air into the combustion chamber, which results in much more complete combustion of the fuel. In some cases these stoves appear to be more robust to variations in how users cook, as well [91].

- *Gasifier stoves:* These force the gases and smoke that result from incomplete combustion of fuels such as biomass back into the cook stove's flame, where the heat of the flame then continues to combust the particles in the smoke until almost complete combustion has occurred, resulting in very few if any emissions. In a gasifier stove with a fan, the jets of air create superior mixing of flame, gas, and smoke and can be extremely clean. However, testing needs to confirm how robust these stoves are in field conditions [91].
- *Rocket Cookstoves:* Rocket stove is an insulated, L-shaped combustion chamber that allows for partial combustion of gases and smoke inside the stove. These stoves follow 10 design principles to also improve heat transfer efficiency using insulation and narrow channels directing the flow of hot gases closer to the pot or griddle. This design enables rocket stoves to achieve important emissions benefits as compared to three stone fires or crude stoves. Production of rocket stoves can range from centrally mass-produced products to locally produced artisanal products [91].
- *Solar Cookstoves:* Solar cook stoves, can be used in areas where solar energy is abundant for most of the year. Considering, NASA's solar insulation maps it indicates between 30 degrees north and south of the equator, consequently where much of the developing world is located. There are three types of solar cookers: panel, box and parabolic, all of which generate heat by directly capturing the sun's solar thermal energy [91].

Table 2: [90]. Cost-effectiveness of different stoves

Solution	Approximate cost	Possible reduction in indoor air pollution
Chimney stove	$10-150	0-80%
LPG stove	Burner $30-120 Cylinder deposit $50-60 Weekly cost for fuel $1-2	Up to 90%
Smoke hood	$10-60	Up to 80%
Biogas	$300	Very clean (not data currently available)
Solar cooker	$5-50	No emissions
Behavioural changes	Less than $5	Variable (no data available)

8. Successful interventions

8.1 Successful uptake of stoves in Sri Lanka

Despite persistent political instability, stove programmes in Sri Lanka have managed to reach over 25% of the households in the country. This success was due to combined initiatives of NGOs and the government. A new self-sustaining stove industry has been established within 20 years, benefiting around 250 producers and 800 000 cooks and their households. While not much more than US$1.5 million has been spent on stoves by development agencies and households since 1977, the financial benefits (mainly fuel wood savings) are valued at over $37.5 million. That does not take account of the unquantifiable but impressive quality of life, health and environmental benefits [90].

8.2 The success of the Ecostove in Nicaragua

After diarrhea, acute respiratory illness is the greatest cause of death in young children in Nicaragua. In both rural and urban parts of the country, Three-Stone fires are still commonly used. In urban Managua and smaller towns, a new stove is making inroads to replace the traditional stove. This is the energy efficient Ecostove, developed by the NGO Proleña, with technical support from Aprovecho. The Ecostove is an innovative woodstove which is insulated, with smoke vented through a chimney. The stove is sealed, preventing nearly all indoor air pollution, and reduces consumption and expenditure on wood fuel by 50% [90].

9. Recommendations

To tackle the problem of indoor air pollutants from burning biomass, the group recommends the following:

9.1 Research

More research is needed to be able to formulate effective target intervention programs. Chief priorities for research should include: in depth study into effects associated with exposure to wood smoke compared to emissions from traditional urban sources such as industrial and vehicular emissions; examine the toxic potency of freshly generated versus aged wood smoke aerosols; and evaluate role of biomarkers to asses effects of wood smoke exposure. Studies are also need to analyze the intervention programs currently in place in order to promote which is the most effective intervention (such as better stoves; dry/old versus moist/new biomass use; fuel substitution with coal).

9.2 Sustainability

To ensure sustainability of intervention programs, local artisans' skills and knowledge should be utilised to design and disseminate smokeless stoves. This will not only create jobs but also ensure economic independence and development.

9.3 A global partnership

Continued collaborative global commitment is needed to maintain the sustainability of intervention and research programs. The key national and local level stakeholders and the leading international organizations should address the problem jointly. Specialists from health, development, energy, shelter and environment sectors should work hand in hand towards a global solution to tackle indoor air pollution, especially in poor developing countries where most of the health impacts from indoor air pollution seems to occur.

9.4 Policy

In addition, more explicit policies should be developed to promote exposure-reduction, and to encourage households to move up the "energy ladder" and switch to cleaner fuels faster than they would otherwise. Policies should also address availability and supply reliability of high-quality fuels (LPG and kerosene) in all areas, especially in areas with largest exposure to indoor air pollutants.

10. Conclusion

Biomass use remains an important source of energy for cooking and heating homes for nearly 3 billion people globally. In most environments, biomass is burnt inside homes using open fires and leaky stoves, resulting in emissions of toxic pollutants such as carbon monoxide and particulate matter. Adverse health outcomes linked to these pollutants include respiratory diseases, asthma, and low birth weight babies. Children are more susceptible than adults, in part due to their physiology. WHO estimates about 2 million deaths annually from diseases attributed to indoor pollution due to solid fuel use.

The ideal way to prevent or reduce the serious health impacts would be the withdrawal or reduction of exposure to these pollutants. The selection of the strategies to achieve this aim is very complex because it should take into consideration not only the personal exposure but also cultural and economic aspects. Interventions, such as improved stove structures and substitution with cleaner fuel alternatives, has shown to significantly reduce exposures to these pollutants. However, these interventions must be sustained. It is therefore essential to involve key national and local level stakeholders to address the problem. A global partnership between the leading international players from the health, energy, and environment sectors, to work towards a global solution to tackle indoor air pollution should be a priority. Tackling indoor air pollution will help achieve the Millennium Development Goals (MDGs)4 (reduce child mortality); MDG 5 (improve maternal health); MDG 7 (Clean household energy will also ensure environmental sustainability); MDG 3 (contribute to gender equality); and MDG 1 (freeing women's time for income generation that helps eradicate extreme poverty and hunger).

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