Review

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Biomass fuel exposure and respiratory diseases in India

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Summary **One half of the world's population relies on biomass fuel as the primary source of domestic energy. Biomass fuel exposure causes a high degree of morbidity and mortality in humans. This is especially true in the context of developing countries, which account for 99% of the world's biomass fuel use. Biomass fuel consists of fire wood, dung cakes, agricultural crop residues such as straw, grass, and shrubs, coal fuels and kerosene. Together, they supply 75% of the domestic energy in India. An estimated three-quarters of Indian households use biomass fuel as the primary means for domestic cooking. Ninety percent of rural households and 32% of urban households cook their meals on a biomass stove. There are wide variations between the rural and urban households regarding the specific type of biomass fuel used. Globally, almost 2 million deaths per year are attributable to solid fuel use, with more than 99% of these occurring in developing countries. Biomass fuel accounts for 5-6% of the national burden of disease. Burning biomass fuels emits toxic fumes into the air that consist of small solid particles, carbon monoxide, polyorganic and polyaromatic hydrocarbons, and formaldehyde. Exposure to biomass fuels has been found to be associated with many respiratory diseases such as acute lower respiratory infections, chronic obstructive pulmonary disease, lung cancer, pulmonary tuberculosis, and asthma. Biomass fuel exposure is closely related to the burden of disease in India. Hopes are that future studies will examine the morbidity associated with biomass exposure and seek to prevent it. Concerted efforts to improve stove design and transition to high-efficiency low-emission fuels may reduce respiratory disease associated with biomass fuel exposure.**

Keywords: Biomass fuels, chronic obstructive pulmonary disease (COPD), tuberculosis, cancer

1. Introduction

One half of the world's population relies on biomass fuel as the primary source of domestic energy (*1*). Biomass fuel causes a high degree of morbidity and mortality in humans. This is especially true in the context of developing countries, which account for 99% of the world's biomass fuel use (*2*). Biomass fuel consists of firewood, dung cakes, agricultural crop residues (such as straw, grass, and shrubs), coal fuels, and kerosene. Together, they supply 75% of the domestic energy in India. The rest of the country relies on cleaner fuels, namely liquified petroleum gas (LPG) and natural gas.

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2. Biomass fuel use in India

An estimated three-quarters of Indian households use biomass fuel as the primary means for domestic cooking. Ninety percent of rural households and 32% of urban households cook their meals on a biomass stove. Only 25% of the cooking is done with cleaner gases. Ninety percent of households using biomass fuels cook on an open fire. There are wide variations between rural and urban households regarding the specific type of biomass fuel used. In rural India, 62% of households use firewood and 14% cook with dung cakes while 13% use straw, shrubs, grass and agricultural crop residues to fire their stoves. In urban India, 22% use firewood, 8% use kerosene, and the rest uses cleaner fuels like LPG or natural gas (*3*). According to World Health Organization, an estimated 58% of the Indian population depended on solid fuels for domestic use in 2010 (*4*). Seventy-five percent of rural households reported firewood as their primary cooking fuel as compared to only 22% of urban households. Clearly, factors such as affordability, education, availability, constraints on cooking space, social customs, and demographics (*e.g.* working women) play a significant role in the choice of fuel in urban areas (*5*).

3. Morbidity and mortality

Globally, almost 2 million deaths per year are attributable to solid fuel use, with more than 99% of these occurring in developing countries (*1*). The number of disability-adjusted life years (DALYs) attributable to indoor air pollution from solid fuel for all uses is calculated to be 40 million. India's figures are very alarming. With a yearly death toll of 662,000 attributed to biomass fuel exposure, India tops the list of fuel-related deaths in the South Asian region (*2*). Biomass fuel attributes for 5-6% of the national burden of disease (*6*). Indoor air pollution from solid fuel use in all developing countries was estimated to account for about 1.6 million deaths annually in 2004 and about 500,000 in India in 2010, suggesting a serious impact on health (*7,8*).

4. Emissions from a biomass stove and exposure-determining factors

When firewood (an essential biomass fuel) is burnt, its combustion efficiency is far less than 100%. This indicates that biomass fuels are at the high end of the fuel ladder in terms of pollution emissions and at the low end in terms of combustion efficiency (*9*). Typical biomass cook stoves convert 6-20% of the fuel carbon to toxic substances. What fuels actual cooking is only 18%, whereas 74% of the carbon is dissipated as waste heat (*10*). Burning biomass fuels emits toxic fumes into the air, and the content of these fumes will now be described in detail.

4.1. *Small solid particles*

Particles with a diameter smaller than 10 µm (PM10), and particularly those with a diameter smaller than 2.5 µm (PM2.5), can penetrate deeply into the lungs and appear to have the greatest potential for damaging health. Several studies have shown remarkable consistency in the relationship between change in daily ambient suspended particulate levels and subsequent changes in mortality (*11*). The range of risk was found to be 1.2-4.4% increased mortality per 10 mg/m^3 increase in concentration of respirable suspended particles. The concentration distribution of indoor particles less than 10 µm (PM10) measured over 24 h in Indian households using solid fuels was over 2,000 µg/m^3 compared to 30 µg/m^3 in the US (*11*). The determination of the concentration of suspended particles offers the best indicator of health risk (*12*). A simple Monte Carlo single-box model is presented as a recent approach to examine the relationship between emissions of pollutants from fuel as well as stove combinations and the resulting Indoor Air Pollution (IAP) concentrations (*13*). This model combines stove emission rates with expected distributions of kitchen volumes and air exchange rates in the context of a developing country to produce a distribution of IAP concentration estimates that can be used to predict if IAP concentrations will meet air quality guidelines, including those recommended by the WHO for fine particulate matter (PM2.5) (*14*). The modeled distributions of indoor PM2.5 concentration estimated that only 4% of homes using fuel wood in a rocket-style cook stove, even under ideal conditions, would meet the WHO Interim-1 annual PM2.5 guideline of 35 mg/m^3. According to the model, the PM2.5 emissions that would be required for even 50% of homes to meet this guideline (0.055 g MJ-delivered-1) are lower than those for an advanced gasifier fan stove, while emissions levels akin to those of liquefied petroleum gas (0.018 g MJ-delivered-1) would be required for 90% of homes to meet the guideline. Although the predicted distribution of PM concentrations (median-1,320 µg/m^3) from inputs for traditional wood stoves was within the range of reported values for India (108-3,522 µg/m^3), the model likely overestimates IAP concentrations.

4.2. *Carbon monoxide*

An estimated 38 g, 17 g, 5 g, and 2 g/meal of carbon monoxide is released during household cooking using dung, crop residues, wood, and kerosene, respectively (*15*). The short-term health effects of CO exposure include dizziness, headaches, nausea, and feeling weak. An association between long-term exposure to carbon monoxide from cigarette smoke and heart disease and fetal development has been noted (*16*).

4.3. *Polyorganic and polyaromatic hydrocarbons*

Polyaromatic hydrocarbons include a large class of compounds released during the incomplete combustion of organic matter (*17*). Benzopyrene is one of the most important carcinogens in this group (*18*). In addition to PAH, azo and amino compounds have also been found to be potentially carcinogenic. A study by the National Institute of Occupational Health showed that the indoor levels of PAH (total) in air during use of dung, wood, coal, kerosene, and LPG were 3.56, 2.01, 0.55, 0.23, and 0.13 µg/m^3, respectively (*19*). These PAHs include fluorine, pyrene, chrysene, benzoanthracene, benzofluoranthene, benzofluoranthene, benzopyrene, dibenzanthracene, benzoperylene, and indenopyrene.

All but the first three of these PAHs have been classified as possible carcinogens.

4.4. *Formaldehyde*

The mean levels of formaldehyde emitted from cattle dung (670 μg/m^3), wood (652 μg/m^3), coal (109 μg/m^3), kerosene (112 μg/m^3), and LPG (68 μg/m^3) have been calculated (*20*). In an epidemiological study in the UK, significantly excess mortality from lung cancer was observed in workers exposed to high levels of formaldehyde (*21*). Formaldehyde is recognized as an acute irritant and long-term exposure to it can cause a reduction in vital capacity and chronic bronchitis. It is known to form crosslinks with biologic macromolecules. Inhaled formaldehyde forms DNA and DNA-protein cross-links in the nasal respiratory mucosa (*22*). Studies in workers occupationally exposed to formaldehyde have consistently noted a higher incidence of leukemia (*23*).

Biomass smoke has a pathological effect. The toxic fumes released from a biomass stove contain organic chemicals that are known mutagens, immune system suppressants, severe irritants, blood poisons, inflammatory agents, CNS depressants, cilia toxins, endocrine disruptors, and neurotoxins. A number of other chemicals released have been demonstrated to be human carcinogens. Several toxic inorganic chemicals are known to cause asphyxiation, stillbirth, infant death, heart disease, and severe acute and chronic lung disease. Many mechanisms of cell injury are still unexplained.

5. Household composition and biomass smoke exposure

The level of exposure to the toxic fumes from a biomass stove varies widely with the house architecture and household composition. Quantitative exposure assessments have been conducted in various households in different parts of India in order to determine exposure-response relationships. The climatic and cultural variations between northern and southern India have influenced outcomes significantly. Cooking areas in many Indian households tend to be poorly ventilated, and about one-half of all households do not have a separate kitchen. Most households lack a chimney or other means of ventilation. One study conducted in Porur, Chennai reported that 36% of households use biomass fuels to cook in indoor kitchens without partitions, 30% cook in a separate kitchen inside the house, 19% cook in a separate kitchen outside the house, and 16% cook in an outdoor kitchen (*24*). The level of individual exposure to respirable particles in biomass smoke does not significantly differ for cooks using an indoor kitchen with or without partitions and cooks using a separate kitchen outside the house but it does differ significantly ($p < 0.05$) for cooks using open outdoor kitchens as emissions are dispersed more outdoors. Therefore cooks using an open outdoor kitchen have less exposure than cooks using an enclosed kitchen. Households with kitchens without partitions have higher concentrations of particles in living areas. Young children and the elderly often occupy living areas and are exposed to higher levels of smoke in unpartitioned indoor kitchens. Among individuals not cooking in a household using solid fuels, women who were not involved in cooking and men with outdoor jobs had the lowest exposure, while women who assisted with cooking and men staying at home had the highest exposure. The level of exposure does not appear to be significantly associated with the length of cooking, the number of meals cooked, outdoor area measurements, or the presence or absence of chimneys (*10,24*).

6. Respiratory effects of biomass fuels

Many respiratory diseases have been found to be associated with exposure to biomass fuels. The strength of association varies for diseases like acute respiratory infections (ALRI), chronic obstructive pulmonary disease (COPD), lung cancer, pulmonary tuberculosis (TB), asthma, and interstitial lung disease (ILD). The evidence relates to this strength of association is depicted in Table 1 (*25*). The relative risks shown in the table are generally applicable since they are based on the entire evidence base. The relative risks include the results of formal meta-analyses with regard to ALRI, COPD, and lung cancer (from exposure to coal smoke). More recent studies including meta-analyses of the available epidemiological evidence have been conducted in India, as summarized in Table 2.

6.1. *ALRI in children under 5 years of age*

ALRI accounts for 13% of deaths and 11% of the national burden of disease (*6*). One of the major diseases associated with indoor air quality is ALRI. It includes infections from a wide range of viruses and bacteria but with similar symptoms and risk factors (*26*). Many studies have found that various respiratory symptoms (coughing, wheezing, *etc.*) are associated with solid fuel smoke exposure. However, none have provided sufficient evidence to calculate odds ratios. A host of odd's ratios ranging from 1.9-2.7 have been calculated (*25*). These ratios pertain to children with ALRI younger than 5 years only. Other factors might strongly influence the incidence of ALRI, such as housing type, cooking location, and cultural practices (*27*). Some of the studies in India have reported no association between use of biomass fuels and ALRI in children. In a case-controlled study of children under five years of age in southern Kerala, India, children

Table 1. Evidence relating to the strength of the association between biomass fuels and some common respiratory diseases in developing countries

Evidence	Health outcome	Group (age) (ys)	Relative risk	95% CI	Studies	Location	*Ref.*
Strong[a]	ALRI	Children < 5	2.3	1.9-2.7	Campbell, Armsrong & Bypass (1989)	Gambia	(*45*)
					Armstrong & Campbell (1991)	Gambia	(*46*)
					Cerquiero (1990)	Argentina	(*47*)
					Collings, Sithole & Martin (1990)	Zimbabwe	(*48*)
					De Francisco (1993)	Gambia	(*49*)
					Ezzati & Kammen (2001)	Kenya	(*50*)
					Johnson & Aderele (1992)	Nigeria	(*51*)
					Kossove (1982)	S. Africa	(*52*)
					Morris (1990)	USA	(*53*)
					Mtango (1992)	Tanzania	(*54*)
					O'Dempsey (1996)	Gambia	(*55*)
					Pandey (1989)	Nepal	(*56*)
					Robin (1996)	USA	(*57*)
					Shah (1994)	**India**	(***28***)
					Victora (1994)	Brazil	(*58*)
Strong[a]	COPD	Women ≥ 30	3.2	2.3-4.8	Albalak, Frisancho & Keeler (1999)	Bolivia	(*59*)
					Behera, Dash & Yadav (1991)	**India**	(***60***)
					Dennis (1996)	Colombia	(*61*)
					Dossing & Khan (1994)	Saudi Arabia	(*62*)
					Dutt (1996)	**India**	(***63***)
					Gupta & Mathur (1997)	**India**	(***30***)
Moderate-I[b]	COPD	Men ≥ 30	1.8	1.0-3.2	**Malik (1985)**	**India**	(***64***)
					Menezes, Victora & Rigatto (1994)	Brazil	(*65*)
					Pandey (1984)	Nepal	(*66*)
					Perez-Padilla (1996)	Mexico	(*67*)
					Qureshi (1994)	**India**	(***68***)
Strong[a]	Lung Cancer (Coal smoke exposure)	Women ≥ 30	1.9	1.1-3.5	Dai (1996)	China	(*69*)
					Du (1988)	China	(*70*)
					Du (1996)	China	(*71*)
Moderate-I[b]	Lung Cancer (Coal smoke exposure)	Men ≥ 30	1.5	1.0-2.5	Gao (1987)	China	(*72*)
					Huang (1999)	China	(*73*)
					Ko (1997)	Taiwan	(*74*)
Moderate-II[c]	Lung Cancer (Biomass smoke exposure)	Women ≥ 30	1.5	1.0-2.1	Lei (1996)	China	(*75*)
		Children 5-14	1.6	1.0-2.5	Liu, He & Chapman (1991)	China	(*76*)
					Liu (1993)	China	(*77*)
					J. Liu & H. Hu (Unpublished data)	China	(*78*)
					Luo (1996)	China	(*79*)
					Shen (1996)	China	(*80*)
					Sobue (1990)	Japan	(*81*)
					Wang, Zhou & Shi (1996)	China	(*82*)
					Wu (1985)	USA	(*83*)
					Wu-Williams (1990)	China	(*84*)
					Wu (1999)	China	(*85*)
					Xu (1996)	China	(*86*)
					Yang, Jiang & Wang (1988)	China	(*87*)
Moderate-II[c]	Asthma	All ≥ 15	1.2	1.0-1.5	Azizi, Zulkifi & Kasim (1995)	Malaysia	(*88*)
					Mohamed (1995)	Kenya	(*89*)
					Xu, Niu & Christian (1996)	China	(*90*)
Moderate-II[c]	Tuberculosis	All ≥ 15	1.5	1.0-2.4	**Gupta & Mathur (1997)**	**India**	(***30***)
					Mishra, Retherford & Smith (1999)	**India**	(***98***)
					Perez-Padilla (1996)	Mexico	(*67*)
					Perez-Padilla (2001)	Mexico	(*91*)

[a] "Strong" indicates that the results of studies on household pollution in developing countries reveal a consistent, sizeable, plausible, and coherent relationship, with supporting evidence from studies of outdoor air pollution, active and passive smoking, and laboratory animals. "Moderate" indicates a relatively small number of suggestive findings from studies on household pollution in developing countries, and some evidence from studies on outdoor air pollution, smoking, or laboratory animals indicating further more studies are required to strengthen the evidence base and pinpoint risks. Moderate can be further classified as: [b] "Moderate-I" indicates an association between solid fuel use and a health outcome for which there is strong evidence for specific age and sex groups; [c] "Moderate-II" indicates that there is as yet no strong evidence. Note: Studies conducted in India are shown in bold. Adapted from Desai MA, Mehta S, Smith KR. WHO protection of the human environment, Geneva, 2004 (*25*) and Smith KR. National burden of disease in India from indoor air pollution. Proc Natl Acad Sci. 2000 (*6*).

Table 2. Major Indian studies depicting the association between current solid fuel use relative to cleaner burning fuel or electricity and the risk of common respiratory diseases

Respiratory disease	Authors	Study type	Outcome	Odd's ratio/Incidence risk ratio (95% CI)	*Ref.*
Tuberculosis	Gupta *et al.* (1997)	Case-control India	Clinical pulmonary	2.54 (1.07-6.04)	(*30*)
	Mishra *et al.* (1999)	Cross-sectional: India (National Family Health Survey)	Self-reported	2.58 (1.98-3.37))	(*98*)
	Shetty *et al.* (2006)	Case-control India	Clinical Pulmonary	3.26 (1.25-8.46)	(*93*)
	Mageshwari U *et al.* (2008)	Case-control India	Clinical Pulmonary	0.22 (0.12-0.41)	(*102*)
	Kolappan *et al.* (2009)	Case-control India	Clinical pulmonary	2.9 (1.8-4.7)	(*36*)
	Behera D *et al.* (2010)	Case- control India	Clinical pulmonary	0.60 (0.22-1.63)	(*95*)
	Lakshmi *et al.* (2012)	Case-control India	Clinical pulmonary	2.33 (1.18-4.59)	(*94*)
ALRI	Mishra *et al.* (2005)	Cross-sectional survey	Self-reported symptoms	1.58 (1.28-1.95)	(*98*)
	Dherani *et al.* (2008)	Meta-analysis	24 studies for calculation of OR	1.78 (1.45-2.18)	(*96*)
	Ramaswamy P *et al.* (2011)	Longitudinal cohort	Clinical symptoms and estimation of the incidence risk ratio among children from households using biomass fuels relative to cleaner fuels	1.33 (1.02-1.73)	(*103*)
Lung cancer	Gupta D *et al.* (2001)	Case- control India	Clinical, radiological, and histopathological assessment	1.52 (0.33-6.98)	(*99*)
	Behera D *et al.* (2005)	Case-control India	Clinical, radiological, and histopathological assessment	3.59 (1.07-11.97)	(*33*)
	Sapkota A *et al.* (2008)	Case-control India	Clinical, radiological, and histopathological assessment	3.76 (1.64-8.63)	(*34*)
	Hosgood HD *et al.* (2011)	Meta-analysis	25 studies for estimation of OR	2.15 (1.61-2.89)	(*100*)
COPD	Behera D *et al.* (1991)	Descriptive study	Clinical assessment	3.04 (2.15-4.31)	(*101*)
	Qureshi *et al.* (1994)	Case-control India	Clinical assessment	2.10 (1.50-2.94)	(*68*)
	Kurmi OP *et al.* (2010)	Meta-analysis	12 studies for estimation of OR	2.80 (1.85-4.0)	(*97*)

with severe pneumonia (meeting WHO criteria) were compared to those with non-severe ALRI seen as outpatients. According to the study, cooking fuel was not a major risk factor for severe ALRI (*28*). In a cross-sectional study involving 642 infants dwelling in urban slums of Delhi where wood and kerosene were used, Sharma *et al.* found no significant difference in the prevalence of ALRI infections and the type of fuel (*27*).

6.2. *COPD*

COPD accounts for 1.5% of deaths and represents 0.9% of the national burden of disease in India (*6*). Both men and women have similar rates of incidence of chronic cor pulmonale. This is despite the fact that only 10% of women are smokers compared to 75% of men. Another point to note is that chronic cor pulmonale occurs 10-15 years earlier in women than in men (*29*). Various Indian studies have calculated a relative risk of 2-4 for biomass fuel exposure (*6*). Despite the progress made in highlighting the association between biomass fuel exposure and COPD, many problems still exist. Smoking is an important confounding variable for COPD and particularly so when men are included in the analyses. Another major confounding factor is age. The risk of COPD increases with age and many age-matched studies have provided insufficient quantitative evidence to develop an odds ratio. The overall risk of COPD in women exposed to biomass fuel has been estimated as 3.2 (95% CI 2.3-4.8) (*25*). There is much less evidence available about the impact on men, but the risk seems to be lower with an odds ratio (OR) of 1.8 (95% CI 1.0-3.2). This may be attributed to the lower exposure of men to biomass fumes (*30*).

6.3. *Lung cancer*

Lung cancer in women is an amply demonstrated outcome of cooking with open coal stoves in China (*31*). Indian women generally have low lung cancer rates (*32*). This may be attributed to the minimal use of coal for cooking in Indian households. Nevertheless, a few studies in India have suggested an association with lung cancer even after adjusting for active and passive smoking. An odds ratio of 3.59 (95% CI 1.07-11.97) has been calculated (*33*). In conclusion, there is a general lack of epidemiological evidence associating lung cancer with biomass fuel exposure. The few cases reported have been linked to exposure to coal fires (*34*).

6.4. *TB*

TB is a major public health problem in India. Out of the 9.4 million new cases recorded globally, 1.98 million are reported from India (*35*). An estimated 276,000 deaths occur annually due to TB in India. There is a strong association between the use of biomass fuel and pulmonary TB. A high risk of pulmonary TB exists in individuals using wood and cow dung cake as cooking fuel (*36*). Lowered immunodefense mechanisms of the lung may why the disease develops. Biomass fuel poses a higher risk (969/100,000) of TB compared to cleaner fuels (378/100,000). Fifty-one percent of active TB in individuals over 20 is believed to be attributed to smoke from cooking with biomass fuels (*37*).

A study in Nepal implicated the use of kerosene stoves and wick lamps in the development of TB. Compared to use of a cleaner fuel like LPG or biogas, the adjusted OR for using a biomass fuel stove was 1.21 (95% CI 0.48-3.05). A kerosene fuel stove had an OR of 3.36 (95% CI 1.01-11.22). The OR of biomass fuel for heating was 3.45 (95% CI 1.44-8.27). Kerosene lamps used for lighting had an OR of 9.43 (95% CI 1.45-61.32). This study further found that use of indoor biomass fuel for heating purposes is associated with TB in women (*38*). This is supported by a recent study in India (*94*). Given the prevalence of TB in India and its likeliness to increase with HIV, these findings need to be followed up with more detailed studies.

6.5. *Pneumoconiosis and ILD*

Pneumoconiosis has been reported from Ladakh, a hilly region in northernmost India (*39*). This place is completely devoid of industries or mines, and yet cases of a disease resembling miner's pneumoconiosis have been reported. Another factor for this respiratory morbidity is exposure to dust from dust storms. In the spring, dust storms blanket villages in fine dust. The practice of not allowing wood to burn quickly and allowing it to smoulder to conserve fuel adds to the high level of respirable particles indoors. Low oxygen levels or some other factor associated with a high altitude may contribute to pneumoconiosis because miners working at high altitudes are more prone to develop pneumoconiosis than their counterparts who are exposed to the same levels of dust and work in mines at normal altitudes (*40*). Biomass fuel exposure has not been proven to cause pneumoconiosis (*39*). Although a few case reports have similarly linked ILD and biomass fuel exposure, the validity of the association is still debatable (*41*).

7. Toxicological evidence of the strength of the association between biomass fuels and respiratory diseases

Toxicological studies are quite useful to study the effects of air pollutants on humans but cannot be conducted directly because of limitations such as societal concerns, ethical and legal issues, and cost. Therefore, predictive health assessments of inhaled pollutants need to include information gained from animal exposure studies and, in some cases, *in vitro*/*ex vivo* assay systems in order to overcome these limitations. These animal studies contribute to a better understanding of the possible mechanisms(s) by which smoke, and its associated PM, may act to bring about increased pulmonary morbidity in exposed individuals and also have the potential to help uncover information concerning the mechanisms of toxicity and relative toxicity of different mixtures and sources. Few toxicological studies in India have indicated that exposure to smoke results in significant impacts on the respiratory immune system and can produce long-term or permanent lesions in lung tissues at high doses. These effects seem to be most strongly associated with the particle phase. Lal *et al.* examined the hematological and histopathologic responses of rats exposed repeatedly to smoke generated from the combustion of wood dust and they found that the rats had cell desquamation, pulmonary edema, and perivascular infiltration of neutrophils upon acute exposure and emphysematous alveolar destruction as well as eosinophilia upon chronic exposure (*42*). Bhattacharyya *et al.* examined the effects of pinewood smoke exposure on rabbit tracheal explants for 20 minutes and found degeneration of the mucociliary epithelial sheath although shorter exposure to smoke of 10 minutes resulted in retained tissue integrity but altered epithelial morphology (*43*). Thus, these toxicological studies indicate biological plausibility of the epidemiologic evidence suggesting that exposure to smoke emissions adversely affects human health. Clearly, short-term inhalation of smoke appears to compromise pulmonary immune defense mechanisms that are vital to maintaining host resistance against pulmonary infections. These studies lend support to the notion that inhaled smoke contributes to the increased incidence of infectious respiratory disease reported in children living in developing nations and/or near homes heated by wood burning devices (*44*). Data are currently insufficient to reliably distinguish the toxicological effects of different types of biomass smoke. More work in this area is needed to better understand the mechanisms by which adverse effects observed in exposed individuals might occur.

8. Conclusion

In conclusion, biomass fuel exposure contributes substantially to the burden of disease in India. Many studies in this vein have discovered significant associations with diseases like ALRI and COPD. More evidence is needed to establish the association between solid fuel smoke and other diseases. Implementing strategies to reduce or eliminate exposure is very challenging because it must consider the level of individual exposure as well as cultural and economic aspects at the individual and local levels, including the level of development, resources, technical capacity, domestic energy needs, the sustainability of the sources of energy considered, and protection of the environment. Substantial improvement can be brought about by health education and cultural changes, modification of stove design, and switching over to cleaner fuels or other high-efficiency low-emission fuels for cooking. Physicians and health administrators should have a heightened awareness of the health effects of solid fuel smoke inhalation as this may spur research and preventive measures and facilitate the diagnosis and treatment of future patients. Hopes are that future studies will examine the morbidity associated with biomass exposure and seek to prevent it. This is a pressing issue given the great risk posed by solid fuels in rural India.

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