1.0. INTRODUCTION

1.1. Background

More than 3 billion people in the world rely on solid fuels such as biomass (wood, agricultural residues and animal dung), charcoal and coal as the primary source of household energy. Domestic use of these solid fuels, although prevalent in many countries is a major source of indoor air pollution mostly in poor households of developing countries, this is because solid fuels in these households is often used in inefficient and poorly vented combustion devices that results in bulk of the fuel energy being emitted and wasted as toxic products of incomplete combustion. Further, their use in small and poorly ventilated kitchens in close proximity to household members on a daily basis over many years often spanning entire life time creates an exposure situation that is significantly detrimental to health of all family members, in particular women and children who spend the largest fraction of time within or near the kitchen. Although the use of solid fuels has been prevalent since many decades, the complexity of the exposure situation (in terms of the levels of pollutants, frequency, and duration being influenced by multiple household level determinants) coupled with severe technical and financial constraints in gathering scientific evidence in poor households of developing country settings (where such exposures predominate) has resulted in a somewhat belated recognition of this risk factor as a major contributor to population disease burdens. This chapter provides a brief overview of the sources and nature of these emissions and exposures as well as the evidence for related health impacts to serve as a prelude for the rationale behind this thesis. An annotated, detailed literature review is provided in chapter 3.
1.2. Characteristics of solid fuel smoke

The most significant issue that concerns indoor air quality in household environments of developing countries is that of exposure to pollutants released during combustion of solid fuels. Figure 1a and 1b shows the relative prevalence of solid fuel use across world regions (Mehta, 2002) and India (Census of India 1991). Typical settings of solid fuel use, commonly encountered in rural households of Andhra Pradesh (AP) and Tamil Nadu (TN) are illustrated in Figure 2a & 2b (Census of India 2001).

![National Household Solid Fuel Use, 2000](image1)

**Figure 1a**: Household fuel use across world regions (Mehta, 2002)

![Household fuel use in India](image2)

**Figure 1b**: Household fuel use in India (Census of India 1991)

Figure 2a: Distribution of solid fuel using households across various districts of AP (Census of India 2001)

Figure 2b: Distribution of solid fuel using households across various districts of TN (Census of India 2001)
Across households there exists a great deal of diversity in fuel, stove and kitchen types in addition to differences in fuel quantities and conditions of combustion (such as temperature, air flow, shape of the combustion chamber), all of which have major implications for the specific nature of emissions within a household. Under ideal conditions complete combustion of carbon would produce only carbon-dioxide and water. However, virtually all configurations of solid fuel use emit substantial quantities of products of incomplete combustion (PICs) as conditions for efficient combustion of these fuels are difficult to achieve in typical household stoves. These include Respirable Particulate Matter (RPM), gases such as carbon monoxide (CO) and nitrogen-dioxide, organic compounds including saturated hydrocarbons, polycyclic aromatic hydrocarbons (PAHs) including benzo[a] pyrene, alcohols, phenols, quinones / semi-quinones and chlorinated acids such as methylene chloride and dioxins. Combustion of coal, in addition to the above pollutants, may release oxides of sulfur and heavy metal contaminants including arsenic and fluorine. On the average, a typical solid fuel stove converts 6-20% of the fuel carbon into toxic substances. At least 28 pollutants have been shown to be toxic in animal studies and some 14 carcinogenic compounds, 6 cilia-toxic and mucous coagulating agents and 4 co-carcinogenic or cancer promoting agents have been identified in solid fuel smoke (De Koning et al., 1985; Smith, 1987).

In a recently concluded assessment by The International Agency for Research on Cancer, indoor emissions from household combustion of coal has been classified as being “carcinogenic to humans” (Group 1 carcinogen based on sufficient human and experimental evidence) while indoor emissions from household combustion of biomass fuel has been classified as “probably carcinogenic to humans” (Group 2A carcinogen on the basis of limited evidence of carcinogenicity of biomass combustion emissions [mainly from wood] in humans and experimental animals; sufficient evidence of carcinogenicity of wood-smoke extracts in experimental animals; and strong evidence of mutagenicity) (Straif et. al., 2006)
1.3. Indoor air pollutant levels – concentrations and exposures

Households using solid fuels in developing countries burn these fuels in poorly functioning stoves where incomplete combustion combined with poorly ventilated kitchens results in very high levels of indoor air pollution. While, the highest levels are experienced in the kitchen, depending on the layout and size of the dwelling, most other rooms experience high levels as well placing all members of the household at increased risk of exposures\(^a\).

Initial studies conducted in this setting used questionnaire based methods to assess the relative pollution levels in solid fuel vs. clean fuel (such as kerosene or LPG users). Indeed, such indicator based exposure levels (i.e. exposed vs. less/not exposed) are all what has been available to date for calculations of the disease burden attributable to solid fuel use. Over the two decades however, more than two hundred studies have been able to actually measure and quantify the levels of multiple pollutants including PM\(_{10}\), PM\(_{2.5}\) and gases such as CO, NO\(_x\) and SO\(_2\). A global database is now available that documents results of these measurements from about 110 studies in China and about 70 studies from developing countries of Asia, Latin America and Africa, with the most recent update of the database expected to be completed in 2010. A great majority of studies (especially at the time this thesis was initiated) have performed single pollutant measurements over short durations (typically the cooking duration) on a cross sectional sample of households. Initial results from this study have contributed to other recent studies that have made important contributions to examining temporal, spatial, or multi-pollutant patterns, in addition to day-to-day or seasonal variability in concentrations and exposures.

\(^a\): Concentrations refer to the level of the pollutant per unit volume of air while exposures refer to the concentration of pollutants in the breathing zone during specific periods of time. Individual exposures would therefore be determined by not only the concentrations but also by how long they spend breathing the polluted air. Women who cook, women who stay in close proximity to the stoves during periods of time spent cooking and young children who spend a considerable fraction of time with the mothers are thus likely to receive the highest exposures while men despite living in the same households with high concentrations have lower exposures as they are less likely to be where the pollution is.
Lack of uniformity in methods (varying study designs and measurement protocols), small sample sizes, differences in the profiles of exposure determinants and local research capacity limitations have made it somewhat difficult to draw comparisons across studies. However, collectively the evidence from these studies show that, rural women, children and men in solid fuel using settings experience extremely high levels of particulates, gases and other noxious pollutants often an order of magnitude higher than what is commonly considered as safe levels of exposure.

1.4. Health effects of exposure to solid fuel smoke

Evidence for health effects associated with exposure to smoke from combustion of biomass fuels was provided initially by studies on outdoor air pollution as well as by studies dealing with exposure to environmental tobacco smoke. Criteria documents for outdoor air pollutants published by the USEPA (USEPA, 1996), for example, detail the effects of many components also found in wood smoke including particulate matter (PM), carbon monoxide, oxides of sulfur and nitrogen and PAHs.

Considerable scientific understanding now exists about aerodynamic properties of the particles that govern their penetration and deposition in the respiratory tract. The health effects of particles deposited in the airway have been shown to be related to impaired defence mechanisms in the lung such as reduced particle filtration, mucociliary clearance and in situ detoxification (Demarest, 1979).

Some of the earliest epidemiological evidence linking indoor air pollution from biomass combustion with respiratory health came from studies carried out in Nepal and India in the mid-1980s. Since then have been a number of new studies, especially on women (who cook with these fuels) and young children. While a rigorous epidemiological framework that uses all criteria for establishing causality (such as the use of Bradford Hill’s criteria) cannot be created from available
studies, strong associations have been reported for a select set of health outcomes. These outcomes were used by World Health Organization (WHO) to prepare the first burden of disease estimates attributable to the household use of solid fuels in 2000. Since limited quantitative exposure estimates are available across multiple world regions (especially in developing countries where such exposures predominate), it was not possible to use a conventional exposure-response approach for these calculations. Instead, reported use of solid fuels was used as an indicator to stratify households as exposed versus not exposed in health studies. The odds ratios [OR], (Odds ratio is used particularly in case-control studies, estimates the chances of a particular event occurring in one population in relation to its rate of occurrence in another population) (OR) computed from these studies were then applied at a national/regional level where routinely collected demographic surveys provided fuel use information to allow burden of disease estimates (wherever fuel use information was not available it was modelled using econometric information).

For computing disease burdens associated with solid fuel use, estimates of relative risk (the ratio of the chance of a disease developing among members of a population exposed to a factor compared with a similar population not exposed to the factor ) obtained from epidemiological studies have been combined in meta-analyses for the three disease end-points for which there is strong evidence of an association with use of solid fuels viz. Acute Lower Respiratory Infection (ALRI) in children aged <5 years, Chronic Obstructive Pulmonary Disease (COPD) and lung cancer (only for use of coal). The WHO led Comparative Risk Assessment (CRA) exercise estimates that more than 1.6 million deaths and over 38.5 million DALYs were attributable to indoor smoke from solid fuels in 2000. Cooking with solid fuels is thus responsible for a significant proportion, about 3%, of the global burden of disease. These risks are comparable to risks from tobacco and only exceeded by malnutrition (16%), unsafe water and sanitation (9%) and unsafe sex (4%) (WHO, 2002).
1.5. Rationale and purpose of the study

The literature review clearly shows that indoor air pollution associated with household fuel use in India is a significant public health concern. Though dozens of studies concerning Indoor Air Pollution (IAP) levels/exposures associated with solid fuels combustion have been carried out in India for the last two decades, they had inadequate sample size and did not represent a state or a region as a whole. Compared to the North and West, relatively few studies have been carried out in Southern and Eastern India, which has a significant proportion of the national population. There are substantial climatic and socio-cultural differences between the northern and southern regions, including different food habits and the use of solid fuels for heating, which could have an important bearing on household exposures.

Despite strong epidemiological evidence relatively few studies have been carried out to measure population exposures quantitatively in the rural settings of developing countries including India where such exposures predominate. Most often, epidemiological studies have relied on proxy indicators such as “reported fuel use” to assess exposure. Such qualitative data often lacks precision for estimating household-level exposures. The influence of multiple household-level variables such as the type of fuel, type and location of kitchen, and type of stove on actual exposures could be poorly understood with this information, resulting in considerable ambiguity in understanding the exposure–response relationship.

While solid fuel combustion generates a cocktail of pollutants, limited technical feasibilities and difficult field logistics have restricted most previous studies themselves in the region to cross sectional measurements either measuring short-term concentrations of particulate matter or carbon monoxide, with few studies measuring daily average household concentrations or exposures of household members.
Given that around 192 million households in India (Census of India 2001) use solid fuels, measurements even within single districts would be too expensive, time consuming and inefficient in using resources to inform policy. Needed therefore are tiered exposure assessment methods that allow high resolution quantitative measurements performed on a nested sample of households to be interfaced with qualitative data on household level variables across a much larger sampling frame in the same geographical area so that reliable descriptives to represent the full region may be generated. This thesis is centered on such a tiered approach, a paradigm that has been seldom used in this exposure setting.

Against this background, the present study was designed to collect systematic quantitative information about actual levels of exposure to indoor air pollution experienced by rural households in India, identify key determinants of this exposure and develop a battery of exposure assessment methods that may be used for routine surveillance of exposures and readily applied in specific intervention efforts designed to reduce the IAP related disease burden.

1.6. Specific objectives:

The specific objectives of the thesis are listed below.

- Collect household information on multiple determinants of indoor air pollution (IAP) associated with solid fuel combustion through a structured questionnaire

- Monitor household pollution concentrations (respirable particulate matter) in a statistically representative sample in rural areas of southern India, across multiple exposure configurations (such as alternative fuel, kitchen, stove and ventilation types)

- Validate the use of respirable particulate matter as the single best indicator of exposure to IAP
• Record time/activity and other information at the household level to estimate the exposure of different household members

• Assess peak and daily average exposures of women cook and other household members to respirable particulate matter

• Measure levels of poly-cyclic aromatic hydrocarbons (PAHs) in select households to evaluate the feasibility of its use as a surrogate marker of exposure to carcinogens associated with combustion of solid fuel

• Measure the potential of select improved cook stoves to reduce health-damaging air pollution in rural homes

• Develop standard operating procedures for IAP related exposure assessment specifically for use in India and other developing countries