Commentary: Switching to biogas – what effect could it have on indoor air quality and human health?

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ABSTRACT

Indoor combustion of solid biomass fuels such as wood and charcoal is common in large parts of the world and has been demonstrated to lead to high levels of exposure to fine particulate matter and gases such as carbon monoxide. Such exposures have been shown to be linked to increased risk of respiratory and cardiovascular illness and may contribute to as many as 2 million early deaths globally per annum. There are a range of interventions currently being trialed including improved cookstoves and changes in fuel type. Small household biogas digesters are now available and are likely to have the capacity to significantly reduce household concentrations of respirable particulate matter and carbon monoxide. Although no direct evidence is available, comparison with households using Liquified Petroleum Gas (LPG) would suggest that improvements in indoor air quality may be of the order of 66-99%. Such improvements in households taking up this technology could bring respiratory and cardiovascular health benefits of the order of 20-25% reduction in risk of a wide range of diseases. There is a need for well-designed longitudinal studies to examine the impact of introducing biogas digesters to communities on both exposure to indoor air pollution and the health effects this may bring.

Keywords

Biogas
Indoor air quality
Sub-Saharan Africa
Anaerobic digestion

Abbreviations

CO = Carbon monoxide
LPG = Liquified Petroleum Gas
PM = Particulate matter
$PM_{2.5}$ = Particulate matter that is less than 2.5 microns in diameter

1. Health effects of using solid biomass fuel for household energy

Finding energy to provide household heating, lighting or the ability to cook food is a daily struggle for more than 2 billion people globally who use biomass fuels [1]. Use of wood, charcoal and/or dried animal or plant residues is the primary means of cooking in large areas of the world and for approximately 90% of the sub-Saharan African population. Much of this cooking activity takes place using simple 3-stone stoves and may occur within indoor areas of the home with little or no ventilation to remove the generated smoke. The fine particulate matter (PM) and carbon monoxide (CO) generated from incomplete combustion of biomass fuels have been shown to produce a range of respiratory [2], cardiovascular, eye and perhaps even neurological health effects. These effects can occur across the life-course from low-birth weight and reduced lung function due to neo-natal exposure, and increased risk of pneumonia in childhood [3] through to chronic obstructive pulmonary disease [4], lung cancer [5], elevated blood pressure [6] and cataracts in later life [1]. The health effects of exposure to biomass fuel smoke are well documented and have been quantified as being responsible for approximately 2 million early deaths per annum and producing a global health burden of about 4% of total healthy life years lost [7]; a figure similar to that from malaria. The burden of ill-health from biomass fuel smoke tends to fall disproportionately on women and young children who, due to their caring and household roles, tend to have greatest exposure to the smoke.

Concentrations of PM or CO in homes burning wood and/or charcoal are well described in a wide range of global settings. Table 1 provides details from a small sample of the studies carried out to date. To put these figures in some context the World Health Organisation recommends that $PM_{2.5}$ (PM less than 2.5 microns in diameter) exposure averaged over 24 hours should not exceed 25 $\mu g\ m^{-3}$ while the guidance for CO is for 24-hour exposures to be kept below 7 $mg\ m^{-3}$ [8]. From our own studies it is common to see household $PM_{2.5}$ exposures reach peak values exceeding 5,000 $\mu g\ m^{-3}$ and for 24-hour average figures to be in the 100-300 $\mu g\ m^{-3}$ range [9]. Carbon monoxide concentrations reaching peaks over 120 $mg\ m^{-3}$ are frequently measured in homes burning charcoal [9]. Figure 1 illustrates typical time plots of household $PM_{2.5}$ and CO levels in a wood-burning home in Malawi measured by members of our group.

2. Reducing exposure to products of incomplete combustion

There is a currently considerable global research and intervention work aimed at improving our understanding of the relationship between exposure to different biomass fuel smoke and ill-health in a variety of populations [12]. Interventions can take numerous forms and invariably require local adaptations to specific conditions, practices and belief systems, but generally can be divided in to four broad areas: improved cookstoves; improved ventilation; changing fuel; and changing cooking behaviours.

Introduction of more efficient cookstoves that reduce the amount of fuel required to cook each meal while producing lower emissions of PM and CO in to the household air is the focus of considerable work in south and central America (e.g. [13,14]), and other areas including Africa (e.g. [15]). Typical exposure reductions reported are in the order of 60-70% in personal $PM_{2.5}$ with larger reductions of close to 90% for CO [14]. However, some recent work has suggested that the uptake and continued use of improved cookstoves can be problematic [16].The barriers to uptake include the lack of knowledge that indoor air pollution is a significant health hazard, prioritization of other needs over cookstoves and a lack of willingness to change from free traditional technology to a stove that has upfront costs.

Improved ventilation in the form of chimneys and other methods of extracting smoke from the house have also been examined (e.g. [17]) and suggest a 50-60% average reduction in the personal exposure of mothers and children to CO. Educating householders about the effect of biomass fuel smoke and simple exposure control methods may also lead to reductions in personal exposure levels by about 50% [18]. Switching fuels and encouraging use of gas, solar or liquid based fuels are other approaches to reducing exposure to incomplete combustion products.

Improving access to different energy sources that provide cleaner combustion with less emission of PM and CO is likely to be a highly efficient method of exposure reduction for any given population.

While the ideal may be provision of electricity to all homes that currently use biomass fuel, this is clearly unrealistic, but smaller scale interventions that encourage the use of locally produced methane or biogas have been growing in interest in recent years [19].

Biogas digesters are simple devices that use natural anaerobic digestion of animal and plant waste to produce a supply of methane gas for cooking and lighting. Further details of the range of different construction techniques and methods of use are outlined in the accompanying papers [20,21]. Digesters produce a gas flow that is about 60-70% methane gas which, when burned in a simple cooking stove, is likely to produce minimal levels of respirable particulate and much reduced quantities of CO. Similar to other household level interventions, biogas digesters face a range of constraints and barriers to their introduction and continued use. The need to have suitable land for installation of the equipment and a number of animals for the supply of waste is a significant barrier for the very poorest in many communities, while the upfront purchase costs of materials for the digesters can also represent a considerable fraction of household income. Availability of regular substrate from animals and crop wastes together with adequate water supply can also be problematic, and this can impact on gas supply and hence reliance on the system. Training in the use and maintenance of the digester is also essential to ensure efficient delivery of energy to the home.

3. Biogas: lack of direct evidence of effect on household air quality

A review of the scientific and grey literature for data describing exposure reductions from interventions that introduced household biogas digesters produced no results, suggesting the need for real-world research to quantify the actual changes in personal exposure of householders who move from solid biomass fuels to biogas. Data on the impact of biogas interventions is available for increased crop production from use of the digestate as a fertilizer (e.g. [22]) but to the best of our knowledge no exposure or health change measurement studies have been carried out to date.

The closest comparison that may shed some light on the exposure reductions and health benefits that are likely to be achieved by encouraging a switch to biogas, may be found by examining the differences in exposure in households using traditional biomass (wood/charcoal) and those using Liquified Petroleum Gas (LPG). Table 2 presents a summary of a selection of data identified relating to cross-sectional comparative data for LPG compared to other biomass fuel using homes in similar communities. The study by Titcombe & Simcik [23] measured $PM_{2.5}$ personal exposures in typical homes in Tanzania using four different cooking fuel arrangements. The homes burning charcoal and wood had the highest average exposures of 588 and 1574 $\mu g\ m^{-3}$ respectively compared to those burning a charcoal-kerosene mix (88 $\mu g\ m^{-3}$) and LPG (14 $\mu g\ m^{-3}$). The study by Kurmi et al. [24] in Nepal also suggests that homes cooking with LPG had 24h respirable PM levels of less than 10% (67 $\mu g\ m^{-3}$) of those measured in biomass burning homes (792 $\mu g\ m^{-3}$). Data from Dutta et al. [25] in India also suggest that PM exposure levels in LPG using kitchens were about one-third of the level of those measured in biomass using kitchens although these data may under-estimate the differences given that the sampling period (7am-3pm) tended to miss the cooking of the evening meal.

Clearly, care must be taken when comparing such cross-sectional data due to the different socio-economic conditions of the households involved. Unfortunately there does not appear to be longitudinal data describing the changes in household exposures when homes transfer from traditional biomass to LPG.

4. Potential exposure reductions and health impact

Using the air quality data for LPG using homes it seems plausible that homes switching to biogas as their primary cooking fuel may experience $PM_{2.5}$ reductions between 66-99%. While there is no direct exposure-response relationship data to quantify direct health impacts of such changes, it is possible to consider the potential effect of indoor air quality improvements. The RESPIRE study in Guatemala provides some of the most recent and comprehensive indications of the benefits of reductions in indoor air pollution levels. Work by Smith et al [26] reported a reduction in relative risk of pneumonia of 18% within homes that received improved stoves and reductions in indoor air pollution levels of about 50% [26] while McCracken et al [13, 27] demonstrated differences in blood pressure and heart physiology in those who experienced exposure reductions from improved stove technology within the same population. A wider analysis carried out by Pope and colleagues [28] on the shape of the exposure-response relationship between fine particulate matter and health suggests that for many types of $PM_{2.5}$ exposure there is now good epidemiological evidence to suggest that risk of cardiovascular and cardiopulmonary ill-health is linearly related to the log of the inhaled $PM_{2.5}$ dose. Applying some very rough estimates of the daily dose of $PM_{2.5}$ in a traditional biomass using home (24 h x 60 min x 0.8 mg m^{-3} x 0.025 m^3 min^{-1} respiratory rate) compared to a biogas using home (24 h x 60 min x 0.08 mg m^{-3} x 0.025 m^3 min^{-1}) would suggest a 90% reduction in the inhaled dose from 29 mg to 2.9 mg of $PM_{2.5}$. From the dose-response relationship published by Pope and colleagues [28], this would suggest a reduction in relative risk of a wide range of pulmonary and cardiovascular ill-health from about 1.8 to 1.4.

The dose-response relationship suggested by Pope et al. [28] is primarily derived from European and North American epidemiological work and uses data from outdoor air pollution studies, investigations of non-smokers living with smokers and on the health effects of actively smoking cigarettes and so the estimates derived here should be treated with some caution. It does however, broadly agree with the data generated from the RESPIRE study by Smith and colleagues [26] suggesting a similar scale of impact in terms of childhood pneumonia, one of the biggest causes of mortality and morbidity in biomass burning homes.

The exposure reductions achievable by switching from wood/charcoal to biogas use are likely to be large, although there is significant uncertainty about how sustained the use of digesters will be, and how much uptake occurs at a population level within a given community. There is a need to assess uptake and sustainability in particular but if both of these are high in future trials, then the pulmonary and cardiovascular health benefits are likely to be considerable. Given the epidemiological data from stove interventions available from other sources, together with studies examining the health of communities using solid biomass fuels compared to LPG [25, 29], the number of cases of pneumonia, COPD, heart attack and other illnesses could be reduced by the 20-25% figure suggested from our crude assessment.

5. Conclusions & future direction

Switching from combustion of wood and charcoal to biogas as the primary household energy source has the potential to lead to substantial reductions in exposure to $PM_{2.5}$ and CO. There is however a lack of real-world direct evidence for the impact of such a switch and there is a need for good quality indoor air pollution data from biogas installations carried out at household level. Ideally this should be carried out longitudinally in homes making the switch from traditional biomass fuels to biogas, with data on exposure to $PM_{2.5}$ and CO gathered prior to the installation and again once the installation has been completed. Such work should also consider how best to characterize exposure to biogas combustion products in detail, and examine the determinants of exposure depending on different waste material used in the digester. In a wider sense, the installation of biogas in homes can also be used as a focus to educate householders and the local community about the health effects of solid-fuel smoke from wood and charcoal.

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REFERENCES

[1] Fullerton DG, Bruce N, Gordon SB. Indoor air pollution from biomass fuel smoke is a major health concern in the developing world. Trans R Soc Trop Med Hyg 2008;102:843-51.

[2] Po JY, FitzGerald JM, Carlsten C. Respiratory disease associated with solid biomass fuel exposure in rural women and children: systematic review and meta-analysis. Thorax 2011;66:232-9.

[3] Rehfuess EA, Tzala L, Best N, Briggs DJ, Joffe M. Solid fuel use and cooking practices as a major risk factor for ALRI mortality among African children. J Epidemiol Community Health. 2009;63:887-92.

[4] Kurmi OP, Semple S, Simkhada P, Smith WC, Ayres JG. COPD and chronic bronchitis risk of

indoor air pollution from solid fuel: a systematic review and meta-analysis. Thorax. 2010;65:221-8.
[5] Kurmi OP, Arya PH, Lam KB, Sorahan T, Ayres JG. Lung cancer risk of solid fuel smoke exposure: a systematic review and meta-analysis. Eur Respir J 2012; [Epub ahead of print]
[6] Baumgartner J, Schauer JJ, Ezzati M, Lu L, Cheng C, Patz JA, Bautista LE. Indoor air pollution and blood pressure in adult women living in rural China. Environ Health Perspect 2011;119:1390-5.
[7] Bruce N, Perez-Padilla R, Albalak R. Indoor air pollution in developing countries: a major environmental and public health challenge. Bull World Health Organ 2000;78:1078-92.
[8] World Health Organisation. WHO Guidelines for Indoor Air Quality. Selected Pollutants. 2010. ISBN 978 92 890 0213 4. Copenhagen, Denmark, WHO.
[9] Fullerton DG, Semple S, Kalambo F, Suseno A, Malamba R, Henderson G, Ayres JG, Gordon SB. Biomass fuel use and indoor air pollution in homes in Malawi. Occup Environ Med 2009;66:777-83.
[10] Dionisio KL, Howie S, Fornace KM, Chimah O, Adegbola RA, Ezzati M. Measuring the exposure of infants and children to indoor air pollution from biomass fuels in The Gambia. Indoor Air. 2008;18:317-27.
[11] Rumchev K, Spickett JT, Brown HL, Mkhweli B. Indoor air pollution from biomass combustion and respiratory symptoms of women and children in a Zimbabwean village. Indoor Air. 2007;17:468-74.
[12] Global Alliance for Clean Cookstoves [home page on the Internet]. The cookstove story: view the impact. Washington (DC): Global Alliance for Clean Cookstoves (a United Nations Foundation Initiative). [2013; cited 2013 Oct 01] available from http://www.cleancookstoves.org/
[13] McCracken JP, Smith KR, Díaz A, Mittleman MA, Schwartz J. Chimney stove intervention to reduce long-term wood smoke exposure lowers blood pressure among Guatemalan women. Environ Health Perspect. 2007;115:996-1001.
[14] Clark ML, Peel JL, Burch JB, Nelson TL, Robinson MM, Conway S, Bachand AM, Reynolds SJ. Impact of improved cookstoves on indoor air pollution and adverse health effects among Honduran women. Int J Environ Health Res. 2009;19:357-68.
[15] El Tayeb Muneer S, Mukhtar Mohamed el W. Adoption of biomass improved cookstoves in a patriarchal society: an example from Sudan. Sci Total Environ. 2003;307:259-66.
[16] Mobarak AM, Dwivedi P, Bailis R, Hildemann L, Miller G. Low demand for nontraditional cookstove technologies. Proc Natl Acad Sci U S A. 2012;109:10815-20.
[17] Smith KR, McCracken JP, Thompson L, Edwards R, Shields KN, Canuz E, Bruce N. Personal child and mother carbon monoxide exposures and kitchen levels: methods and results from a randomized trial of woodfired chimney cookstoves in Guatemala (RESPIRE). J Expo Sci Environ Epidemiol. 2010;20:406-16.
[18] Barnes B, Mathee A, Thomas E. The impact of health behaviour change intervention on indoor air pollution indicators in the rural North West Province, South Africa. Journal of Energy in Southern Africa;22:35-44.
[19] Brown VJ. Biogas: a bright idea for Africa. Environ Health Perspect. 2006;114:300-3.
[20] Tumwesige V, Davidson G. Biogas Appliances in Sub-Sahara Africa. Biomass Bioenerg 2012 (this issue).
[21] Orskov RE, Yongabi KA, Subedi M, Smith J. Holistic Application of Biogas for Small Scale Farmers in Africa and Asia. Biomass Bioenergy 2012 (this issue).
[22] Garfí M, Gelman P, Comas J, Carrasco W, Ferrer I.Agricultural reuse of the digestate from low-cost tubular digesters in rural Andean communities. Waste Manag. 2011;31:2584-9
[23] Titcombe ME, Simcik M. Personal and indoor exposure to $PM_{2.5}$ and polycyclic aromatic hydrocarbons in the southern highlands of Tanzania: a pilot-scale study. Environ Monit Assess. 2011;180:461-76.
[24] Kurmi OP, Semple S, Steiner M, Henderson GD, Ayres JG. Particulate matter exposure during domestic work in Nepal. Ann Occup Hyg. 2008;52:509-17.
[25] Dutta A, Mukherjee B, Das D, Banerjee A, Ray MR. Hypertension with elevated levels of oxidized low-density lipoprotein and anticardiolipin antibody in the circulation of premenopausal Indian women chronically exposed to biomass smoke during cooking. Indoor Air. 2011;21:165-76.
[26] Smith KR, McCracken JP, Weber MW, Hubbard A, Jenny A, Thompson LM, Balmes J, Diaz A, Arana B, Bruce N. Effect of reduction in household air pollution on childhood pneumonia in Guatemala (RESPIRE): a randomised controlled trial. Lancet. 2011;378:1717-26.
[27] McCracken J, Smith KR, Stone P, Díaz A, Arana B, Schwartz J. Intervention to lower household

wood smoke exposure in Guatemala reduces ST-segment depression on electrocardiograms. Environ Health Perspect. 2011 Nov;119(11):1562-8.

[28] Pope CA III, Burnett RT, Krewski D, Jerrett M, Shi Y, Calle E, et al.. Cardiovascular mortality and exposure to airborne fine particulate matter and cigarette smoke: shape of the exposure-response relationship. Circulation 2009;120:941–948.

[29] Kurmi OP, Devereux GS, Smith WC, Semple S, Steiner MF, Simkhada P, Lam KB, Ayres JG. Reduced lung function due to biomass smoke exposure in young adults in rural Nepal. Eur Respir J 2012; [Epub ahead of print].

Figures

Fig. 1 – PM and CO levels in wood-burning home in Malawi over a 16-hour period. The red line represents the CO measurements while the blue line indicates PM2.5 concentrations. Cooking took place in the evening (5-7pm) and morning (7.30-9am).

Tables

Table 1 - Selection of studies that have measured PM and/or CO in biomass burning homes

Table 2 - Examples of data on PM exposure levels in homes using solid biomass fuels compared to LPG.

Table 1 - Selection of studies that have measured PM and/or CO in biomass burning homes

Reference	Country	Exposure	Fuel	Mean concentration
[9]	Malawi	24h Respirable PM	Biomass (wood/charcoal)	226 μg m^{-3}
		24h CO	Charcoal n=31 Wood n=31	7.5 mg m^{-3} 2.3 mg m^{-3}
[10]	Gambia	Cooking area 48h $PM_{2.5}$	Biomass n=13	361 μg m^{-3}
		48h CO		4.7 mg m^{-3}
[11]	Zimbabwe	Cooking task 4h Respirable PM CO	Biomass n=48	2520 μg m^{-3} 23 mg m^{-3}

n= number of samples

Table 2 - Examples of data on PM exposure levels in homes using solid biomass fuels compared to LPG.

Reference	Country	Exposure	Fuel	Mean concentration (μg m^{-3})	Ratio of LPG:biomass exposure
[25]	India	$PM_{2.5}$ (7am-3pm)	Biomass (n=244) LPG (n=236)	156 52	0.33
[23]	Tanzania	Personal $PM_{2.5}$ during cooking	Wood (n=3) Charcoal (n=3) Charocal/kerosene (n=3) LPG (n=3)	1574 588 88 14	0.01
[24]	Nepal	Respirable PM (24h)	Biomass (n=30) LPG (n=23)	792 67	0.08

n= number of samples

20

Figure

Figure 1