Household Fuels and Ill-Health in Developing Countries:
What improvements can be brought by LP Gas?

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Kirk R. Smith, Jamesine Rogers, and Shannon C. Cowlin
Environmental Health Sciences, School of Public Health
University of California, Berkeley
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Kirk R. Smith, Jamesine Rogers, and Shannon C. Cowlin
Environmental Health Sciences, School of Public Health
University of California, Berkeley
krksmith@berkeley.edu

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World LP Gas Association, Paris, France

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Executive Summary

Based on available studies, there seems little doubt that large-scale substitution of traditional biomass fuels by LPG presents several advantages. For example, it would:

- Improve health for the many poor people directly affected by the indoor pollution caused by household fuels;
- Reduce emissions of total greenhouse-related pollutants compared to solid fuels, such as biomass and coal used in traditional stoves;
- Reduce pressure on natural forests in some parts of the globe (although it is not known exactly what percentage of wood fuel is harvested non-renewably);
- Increase availability of agricultural wastes for soil enhancement and other purposes in some regions;
- Eliminate time and labor now devoted to gathering biomass fuels and reduce efforts devoted to cooking, and cleaning, potentially benefiting women and children in many regions.

Although many of these same benefits would accompany a large-scale switch to kerosene, the air pollution benefits of kerosene are lower than with LPG, with the added negative point for kerosene of the risks of child poisoning and fire.

As indicated in Figure 1, depending on which fuels and stoves are currently in use, substitution of these in favor of LPG could have significant co-benefits in the form of lower pollution levels in households and lower GHG emissions.

In spite of these significant potential advantages, however, there are two major barriers to any widespread dissemination of LPG to the world’s poor:

- Firstly, LPG is relatively expensive, compared to resources available to the poor from their own income or from current levels of international aid.
- Secondly, the methods to disseminate LPG are not well developed because of the mis-targeting and leakage that occurs with subsidies as practiced to date.

Both of these problems, however, can be potentially addressed by additional efforts to develop...

- A complete cost/benefit calculation that takes into account the following:
  - the value of improved health
  - the value of the significant time savings (no more gathering of biomass fuels)
  - ecosystem protection
  - climate protection

A cost/benefit calculation that includes these points may tip the cost equation in favor of LPG, or at least make the needed residual subsidy affordable.

- Clever and institutionally robust means to promote and distribute LPG and other clean fuels.

- Effective public-private partnerships that engage the local and international LPG industry in the on-going effort to promote and distribute LPG.

It seems clear that additional research and development in these areas would be well rewarded because the lives of hundreds of millions of people could be improved as a result.

Figure 1. Co-benefits for climate and health of changes in household fuels in India. For comparison, the health-based standard for particle air pollution is about 50 μg/m³. The arrow illustrates a shift from crop residues to LPG for one household, which would decrease indoor air pollution by 95% and GHG emissions by 75%. (Data from (Smith, Uma et al. 2000a; Smith, Zhang et al. 2000a))
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1 Introduction

The statements below were made by international organizations in response to recent authoritative studies published by the World Health Organization (WHO) on the health effects of indoor air pollution from household fuel use in the third world. These studies, which are detailed below, show that the use of solid fuels for cooking and heating in simple stoves seems to be responsible for significant ill-health among the poorest and most disenfranchised populations in the world, women and young children in rural areas of developing countries.

The principal goal of this report is to explore the extent to which the substitution of Liquefied Petroleum Gas (LP Gas or LPG) as a household cooking fuel in developing countries can reduce the health burden associated with indoor air pollution and other problems associated with solid fuel use. Solid fuels include biomass fuels, dung, crop residues and wood. We attempt not only to portray the hypothetical impacts of a complete shift to LPG, but also the feasibility of promoting such shifts given past experience and to identify the barriers that have been found.

"Smoke from indoor cooking fires kills one person every 20 seconds in the developing world".

"Smoke in the home kills more people than malaria does, and almost as many as unsafe water and sanitation."

"2.4 billion people burn biomass (organic matter) for cooking and heating, and when coal is included, 3 billion people - half the world's population - rely on solid fuel."

"Smoke in the home is the fourth greatest cause of death and disease in the world's poorest countries, killing 1.6 million people annually. Nearly a million of them are children. Most of the rest are women."

---

1 For brevity and to be consistent with international convention in the energy literature, we use the abbreviation LPG here. See, for example, (IEA 2002).
2 Although much of what will be discussed relates to coal as well, because there are so many different types of coal in use, it is difficult to generalize about its impacts without locally specific information. Some coals burn fairly cleanly, for example, but others contain sulfur, arsenic, fluorne, and other health-damaging contaminants. Coal is discussed briefly in Section 2.1 under lung cancer and in Section 4.3 under air pollution, but the report focuses mainly on the use of biomass fuels, dung, crop residues, and wood in comparison to LPG.
1 Related Issues Addressed

In addition to the health effects, this report examines several other aspects of household fuel use in developing countries.

1.1.1 Women and household fuels

Since household cooking is primarily the responsibility of women in nearly all societies, and the entire household fuel cycle is often the responsibility of women in developing countries whose households rely on biomass fuels, gauging the impacts of household fuel use and the prospects and implications of change requires an understanding of the gender aspects of household fuel cycles in poor countries. Women’s involvement in these fuel cycles, therefore, will be examined in this report as well as their impacts on women’s health and welfare.

1.1.2 Greenhouse pollutants from household fuels

As the evidence has mounted in recent years that use of fossil fuels is the primary source of human-caused greenhouse emissions that increase the risks of climate change, this report examines briefly how household fuels contribute to this problem.

1.1.3 Sustainability and the Millennium Development Goals

The need to find sustainable ways to promote economic and social development among the poorest populations in the world has prompted the creation and promotion of the Millennium Development Goals (MDGs), which include specific targets and timetables as well as indicators for achieving improvements. The report shows how promotion of household LPG fits into these efforts.

1.2 The Household Energy Ladder

LPG and other gaseous fuels, such as natural gas, lie near the top of what has been called the household “energy ladder” or “fuels ladder” (Leach 1992). Observed at large scale and over long periods, there seems to be a relationship between the type of household fuel used and income level or development status. In poor rural areas, people cannot afford modern fuels, such as electricity or LPG, and still rely on biomass fuels at the lower end of the energy ladder (fuels they can harvest on their own), with wood being the most desirable. Where wood shortages exist, the poorest rely on crop residues or animal dung (fuels further down the ladder). Generally, when incomes increase, populations shift up the ladder to liquid fuels (such as kerosene) and eventually to gaseous fuels and, in some cases, electricity for household cooking and heating. Although there are exceptions, in general it is accurate to say that fuel cleanliness, controllability, efficiency in use, and cost all increase as populations move up the energy ladder (OTA 1992). Given what is being learned about health impacts and other effects that lower-quality fuels bring, however, the question this report addresses is what advantages might be gained by accelerating what seems to be, overall, a natural tendency to move up the ladder to LPG and similar clean fuels. See Figure 2 for one representation of the Household Energy Ladder.

![Typical Household Energy Ladder](image-url)
2 Health Effects from Burning Solid Fuels in Households

About half the world’s households cook daily with solid fuels, biomass or coal (Figure 3). Many of these households also use such fuels for household heating during at least part of the year. The simple stoves found in the developing world are often not much more than open fires. Burning these fuels in such basic stoves typically produces substantial health-damaging air pollution, as is discussed below. In many cases, these stoves are not vented to the outside and release their pollution directly into the living area, producing pollution levels often 10-30 times those recommended by health agencies. Even when vented, simple stoves can produce indoor air pollution levels that exceed health guidelines through leakage from the stove and re-entry of the smoke from the outside.

2.1 Principal Diseases

Since the 1980s, there has been a growing international biomedical literature reporting on the results of epidemiological and other studies designed to understand the extent of ill-health from these types of exposures. As women are the primary cooks in nearly all cultures as well as the primary caregivers for young children, women and young children tend to receive the highest exposure to the smoke from solid fuel combustion and have been the focus of the majority of these studies.

The existing literature provides strong evidence that household solid fuel (HSF) smoke is a significant risk factor for three important diseases: acute lower respiratory infections (ALRI) in young children, chronic obstructive pulmonary disease (COPD) in adult women, and lung cancer (for lung cancer the evidence is strong only when coal is used as an HSF).

• **Acute lower respiratory infections**, mainly as pneumonia, are the chief cause of death for children in developing countries. Worldwide, every year about 2 million children under five die from ALRI. Because it affects so many young children, ALRI is the disease with the largest health burden in the world, as measured in lost life years (WHO 2004a). Known risk factors include poor nutrition, crowding, air pollution, and chilling.

A recent “meta-analysis” was conducted of 13 published field studies from around the developing world examining the relationship of household solid-fuel use or other measures of indoor smoke exposure to ALRI in young children. It was found that the best combined estimate of the risk was about 2.3, i.e. children in solid-fuel-using households in developing countries have about 2.3 times the likelihood of developing ALRI as children living in households using cleaner fuels, such as LPG or kerosene (Smith, Mehta et al. 2004).
• Chronic obstructive pulmonary disease, such as emphysema and chronic bronchitis, kills about 2.7 million people each year and is thus the 5th most important cause of death globally (WHO 2004a). Tobacco smoking is the leading cause, although air pollution produces some impact as well. There are elevated rates of COPD in some non-smoking populations, however, that are consistent with exposure to solid-fuel cooking smoke. Current COPD prevention measures focus on reducing important risk factors such as active smoking, passive tobacco smoke, certain occupational hazards, and the rate of acute respiratory infections in early life (Global Initiative for Chronic Obstructive Lung Disease 2004).

A meta-analysis of 10 published studies of COPD and solid-fuel use found a combined risk of about 3.2, i.e., women who had cooked over solid-fuel stoves for many years were about 3.2 times more likely to develop COPD than women using cleaner fuels. Less convincing evidence was found for a smaller effect for men living in these households (Smith, Mehta et al. 2004).

• Lung cancer is the second most important cause of cancer death in the world, killing about 1.2 million annually (WHO 2004a). Again, the chief cause by far is tobacco smoking, although air pollution has been linked to it in developed countries as have a number of occupationally related exposures. Chinese women have some of the highest rates of lung cancer among non-smoking populations globally. The realization that many Chinese women have high exposures to coal smoke from cooking has greatly helped to explain this apparent anomaly (Ezzati and Lopez 2003). A meta-analysis of 16 published studies of lung cancer and solid-fuel use (nearly all analyzed the effects of smoke from coal stove cooking in China), found that women cooking for many years over coal stoves were about 1.9 times more likely to develop lung cancer than women cooking with cleaner fuels. Less convincing evidence was found for a smaller effect in men and from biomass smoke (Smith, Mehta et al. 2004).

Adding considerable weight to the evidence from these relatively small studies are the results from a backwards look at a “natural experiment,” which documented the reduction of lung cancer attributable to the introduction of improved stoves with chimneys in Xuan Wei County in southern China (Lan, Chapman et al. 2002). Xuan Wei has been the site of numerous studies of the relationship of coal smoke and lung cancer due to its high lung cancer rates when coal was burned without venting (e.g., Mumford, He et al. 1987) including one of the studies summarized above (Liu, He et al. 1991). Lung cancer was found to decrease by nearly half after ten years. Household indoor pollution levels apparently reduced by a factor of about three due to the introduction of improved stoves (Lan, Chapman et al. 2002).

Additional Effects

With several published studies in different parts of the world on each effect, the existing epidemiological literature provides moderate and growing evidence that HSF smoke is a risk factor for cataracts, tuberculosis, asthma, and adverse pregnancy outcomes, such as stillbirth and low birth weight for the babies of women exposed during pregnancy. Suggestive evidence also exists of enhancement of trachoma, cervical and nasopharyngeal cancers, and interstitial lung disease (Bruce, Perez-Padilla et al. 2000; Smith 2000). Current literature in developed countries on outdoor air pollution would also suggest that exposure to HSF smoke in developing-world households produces cardiovascular disease, but to date no completed studies exist to corroborate this.

\(^b\) Global Burden of Disease in 2002: data sources, methods, and results. WHO website.
2.2 Total Burden of Disease from Household Solid-fuel (HSF) Use

Even if statistically significant and scientifically valid, disease risks that are derived from epidemiological studies may not have much significance for public health unless some combination of the following three conditions is met:

1. The risk is high.
2. The disease has a relatively high incidence in the population.
3. The exposure factor, e.g. HSF use, is relatively prevalent.

Here, we discuss each required condition in turn with regard to HSF use:

1. Risks found for solid-fuel use are not high by epidemiological standards. For example, for tobacco smoking, the COPD and lung cancer risks are about 4.3 and 20, respectively (Mannino, Gagnon et al. 2000; Vineis, Alavanja et al. 2004). On the other hand, they are not as low as risks for outdoor air pollution and passive tobacco smoke, which are typically around 1.2 or lower (Cohen, Anderson et al. 2004).

2. As discussed above, the incidence of the diseases thought to be exacerbated by HSF use is high and the diseases concerned are some of the most important diseases in the world as a whole and, in the case of child ALRI, strike developing countries in particular.

3. As about half the households in the world use solid fuels for cooking, and even higher proportions in developing countries, the prevalence of the risk factor is extremely high.

Since two of these three characteristics are elevated, it is likely that exposure to solid-fuel smoke is a major contributor to ill-health globally, and particularly in developing countries.

To quantify HSF’s contribution to the global burden of disease, it is necessary to draw from the wealth of health effects studies all the while taking into consideration their varying quality. Previous attempts to combine these studies have lacked the coherent and consistent methods necessary to ensure valid estimates and comparability with other risk factor assessments. (Smith and Mehta 2003). Estimates for other major risk factors, such as tobacco, malnutrition, poor water/sanitation, etc., were conducted separately, therefore creating even less consistency across risk factors and making comparison across risk factors difficult.

To deal with this issue, the largest Comparative Risk Assessment (CRA) exercise ever attempted was initiated in 2000 by the WHO. Burdens of disease for 26 important risk factors were calculated by 100 investigators from about 30 institutions worldwide. Unlike previous single-factor risk assessments, which have been in isolation, the final effort is the first to conduct the analyses in a way that the results - published in final form in 2004 - are coherent and comparable.7

Table 1 summarizes the mortality results for HSF in four major regions of the developing world, plus the world as a whole. Note that the largest effects are in poor Sub-Saharan Africa, South Asia, dominated by India, and middle-income East Asia, dominated by China. Of the total of 1.6 million premature deaths from HSF in 2000, nearly 1 million are due to ALRI in small children. Globally HSF is apparently responsible for one out of every 12 deaths (8.3%) in this group. Most of the rest of the deaths due to HSF are due to COPD, with a relatively small total (16,000) attributed to lung cancer, mostly in China because of heavy use of coal in households. Note the heavy burden of HSF-caused premature death in adult women: 2.5 times that in men. Note also the significant uncertainty still remaining in all these estimates of HSF health effects.

Table 1. Premature deaths from HSF use in major developing regions. The estimates for HSF impacts are uncertain by +/− 50%. (Smith et al., 2004)

<table>
<thead>
<tr>
<th>Region</th>
<th>Age/Sex Group</th>
<th>All Deaths in Age/Sex Groups</th>
<th>Premature Deaths from HSF in each Age/Sex Group</th>
<th>Percent Deaths in Age/Sex Group Attributable to HSF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sub-Saharan Africa (AFRO-D,E)*</td>
<td>children &lt; 5</td>
<td>2,188,000</td>
<td>351,000</td>
<td>16.0</td>
</tr>
<tr>
<td></td>
<td>women &gt; 14</td>
<td>1,600,000</td>
<td>31,000</td>
<td>1.9</td>
</tr>
<tr>
<td></td>
<td>men &gt; 14</td>
<td>1,705,000</td>
<td>10,000</td>
<td>0.6</td>
</tr>
<tr>
<td>South Asia (SEARO-D)*</td>
<td>children &lt; 5</td>
<td>3,034,000</td>
<td>355,000</td>
<td>11.7</td>
</tr>
<tr>
<td></td>
<td>women &gt; 14</td>
<td>4,007,000</td>
<td>130,000</td>
<td>3.2</td>
</tr>
<tr>
<td></td>
<td>men &gt; 14</td>
<td>4,646,000</td>
<td>37,000</td>
<td>0.8</td>
</tr>
<tr>
<td>Southeast Asia (SEARO-B)*</td>
<td>children &lt; 5</td>
<td>269,000</td>
<td>19,000</td>
<td>7.1</td>
</tr>
<tr>
<td></td>
<td>women &gt; 14</td>
<td>868,000</td>
<td>14,000</td>
<td>1.6</td>
</tr>
<tr>
<td></td>
<td>men &gt; 14</td>
<td>998,000</td>
<td>3,000</td>
<td>0.3</td>
</tr>
<tr>
<td>Middle-income East Asia (WPRO-B)*</td>
<td>children &lt; 5</td>
<td>1,045,000</td>
<td>62,000</td>
<td>5.9</td>
</tr>
<tr>
<td></td>
<td>women &gt; 14</td>
<td>4,232,000</td>
<td>335,000</td>
<td>7.9</td>
</tr>
<tr>
<td></td>
<td>men &gt; 14</td>
<td>4,943,000</td>
<td>106,000</td>
<td>2.1</td>
</tr>
<tr>
<td>Total Deaths Worldwide</td>
<td>children &lt; 5</td>
<td>10,900,000</td>
<td>910,000</td>
<td>8.3</td>
</tr>
<tr>
<td></td>
<td>women &gt; 14</td>
<td>20,035,000</td>
<td>490,000</td>
<td>2.4</td>
</tr>
<tr>
<td></td>
<td>men &gt; 14</td>
<td>23,314,000</td>
<td>200,000</td>
<td>0.9</td>
</tr>
<tr>
<td></td>
<td>youth 5 &gt; 15</td>
<td>1,445,000</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>all ages/sexes World</td>
<td>55,694,000</td>
<td>1,600,000</td>
<td>2.9</td>
</tr>
<tr>
<td>Total Deaths: Worldwide Age/Sex Percentages</td>
<td>children &lt; 5</td>
<td>20%</td>
<td>57%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>women &gt; 14</td>
<td>36%</td>
<td>31%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>men &gt; 14</td>
<td>42%</td>
<td>13%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>youth 5 &gt; 15</td>
<td>3%</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>100%</td>
<td>100%</td>
<td></td>
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</tbody>
</table>

* These are the codenames WHO has given subregions in the world. Note that AFRO-D includes one North African country, Algeria. SEARO-D is dominated by India (82%); SEARO-B by Indonesia (84%); and WPRO-B by China (85%). See WHO, 2002, for a listing of which countries are included in each region.

Figure 4. Global mortality by selected diseases and risk factors (data from WHO 2001; WHO 2002).
A burden of 1.6 million deaths is large by global standards. It is nearly 3% of the total 55.7 million premature deaths globally in 2000 and, as shown in Figure 4, is a more important cause of death than some other major risk factors and diseases, but also smaller than many. Since everyone dies and the age of death and the extent of serious illness are also important, however, a better measure for comparison across diseases and risk factors is lost healthy life years measured in "disability adjusted life years" (DALYs), which are shown for the major global risk factors in Figure 5. This measure incorporates the age of death in the form of lost years compared to life expectancy and years lost to illness, with each type of illness having a weight applied according to its severity. Thus, diseases and risk factors affecting children or producing long disabling illness or injury will be counted higher. Note that HSF lies tenth in the world among all major risk factors examined, and among environmental risk factors, is second only to poor water/sanitation. It produces more than four times the burden of disease than what has been estimated for urban outdoor air pollution, for example.

Figure 5. Global burden of disease from major risk factors: Data from (WHO 2001; WHO 2002; Smith, Mehta et al. 2004) * Denotes disease-based risk.
In poor countries, the burden of disease from HSF is even more important as shown in Figures 6 and 7 for China and India. In India, HSF is the third most important risk factor, only exceeded by poor water/sanitation and malnutrition. HSF is responsible for about 17% of all deaths of children under five in India. Note that tobacco actually causes more deaths than HSF, but is still ranked lower in lost healthy life years. This is because tobacco, unlike indoor air pollution, does not directly affect young children, whose deaths count for many lost life years. In China, it is 7th and, along with malnutrition at 5th, is one of the few remaining important risk factors common to underdevelopment in this mid-income country. In contrast to India, most of the effect in China is in COPD, probably because ALRI is already well controlled by antibiotics and better nutrition.

![Chinese Burden of Disease from Top 10 Risk Factors](image)

*Denotes disease-based risk.

Figure 6. Chinese burden of disease from major risk factors: Global data from (WHO 2001; WHO 2002; Smith, Mehta et al. 2004)
Figure 7. Indian burden of disease from major risk factors: Data from (WHO 2001; WHO 2002; Smith, Mehta et al. 2004) * Denotes disease-based risk.

Figure 8. Burden of disease from major risk factors in the twenty most unhealthy countries in Sub-Saharan Africa: Data from (WHO 2001; WHO 2002; Smith, Mehta et al. 2004) * Denotes disease-based risk.

Figure 8 shows the results for the 20 most unhealthy countries of Sub-Saharan Africa, the poorest part of the world. Note the dominance of the HIV/AIDS epidemic, followed by malnutrition. The risk factor of HSF use, nevertheless, is still quite high, ranking 5th overall among risk factors. It is also likely that there are important interactions among these factors, although such interactions are not part of the calculations that went into producing these figures. The impacts of malnutrition and HSF use, for example, are undoubtedly greater among HIV-compromised populations, and vice versa. Thus, even though HSF use is not a direct cause of HIV, a reduction of HSF use could potentially help mitigate the impact of the HIV/AIDS epidemic by reducing the incidence of pneumonia among HIV-compromised children.

2.2.1 What about LPG?

Even non-solid-fuels, such as LPG, produce some air pollution when burned and thus potentially have a health impact, even though it is much lower than with solid fuels. The studies done to date in developing-country households that have included LPG-using households assumed that the health impact of household LPG use was zero and therefore the studies used these households as the reference. Although electric stoves are even cleaner than LPG, they are unavailable in sufficient quantities in such locations to use this technology as the reference. In developed countries, however, many dozens of studies have been done comparing health effects in gas-using households with electric-using households. Although some show a small effect, some do not, and meta-analyses show no overall effect (Basu and Samet 1999). Most of these studies have been done with natural gas, not LPG, but there is little significant difference in emissions between these fuels. Given also that developing-country housing is generally better ventilated than housing in Europe and North America where such studies have been done, the indoor pollution levels in the LPG-using households of interest to this report are likely to be even lower than what has been found in developed countries. For these reasons, it seems reasonable to assume that, for our purposes, there is minimal negative health effect from LPG emissions in most circumstances of interest.

2.2.2 Trends

The current size of the burden from different risk factors is not the only consideration in determining how important the burden is. Among the most important additional considerations are the trends. Some risk factors, unfortunately, are rapidly rising in importance, for example, the burdens from unsafe sex (which is mainly due to HIV/AIDS) and from tobacco. Both of these will continue to grow unless major international efforts are made.

The supposition can be made that, even without outside intervention, HSF use will probably slowly decline on its own during the next decades as households naturally switch to cleaner, efficient, and more flexible fuels as they are made available. This supposition depends, however, on many factors: the regulatory and policy frameworks; the creation of a level playing field for energies; the extent to which economic growth occurs in the poor populations of poor countries and the relative price of alternate fuels (which are all difficult to predict). Furthermore, as part of the comparative risk assessment mentioned in Section 2.2, Total Burden of Disease from Household Solid-fuel (HSF) Use, an estimate was made of the degree to which HSF use might decline on its own in the next decade by assuming economic growth continues at levels predicted by international agencies. It was found that the decline in the fraction of the population

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9 It is estimated that by 2010 or so they will both likely exceed malnutrition, the risk factor that has been at the top of the list for centuries, if not millennia.
using HSF barely kept up with predicted population growth. In other words, the absolute size of the impact may not change much and any significant improvement depends on the rate of population growth of the population segments most concerned. It is thus important to recognize that current best knowledge predicts that HSF use will remain a severe health risk for hundreds of millions of people globally unless actions are taken to accelerate the natural trend to move to improved stoves and fuels (Smith, Mehta et al. 2004).

2.2.3 Conclusion on health effects

One way of looking at the burden of disease is on a household basis, i.e., what is the risk per house or stove of using HSF? This is easiest to determine with ALRI because it is an acute disease, in other words, a change in the risk factor today should result in improvement within a few days or months, and not the years and decades that would be needed to change the rate of chronic diseases such as COPD and lung cancer. It is also difficult to make a global estimate because of the greatly differing background disease rates, age distribution, and HSF use in different parts of the world.

For illustration, it is possible to provide an approximate estimate for a particular region. Take the case of South Asia (which is dominated by India). The annual risk of death due to living with an HSF-using stove for a child under five is about 3 per thousand. Said another way, there is one child death every year for every 300 HSF stoves used in the country.

The difficulty with such an estimate is it suffers from high uncertainty: it simply cannot be as precise as estimates for directly measurable health outcomes as they relate to particular diseases. The reason is the difficulty of linking the lone factor of HSF use to ill-health, because the

variability of household, stove and ventilation conditions across different populations, in different parts of the world, in different seasons, is so great. It is important to remember, however, that whether it is one million or two million premature deaths that occur in women and children annually, the impact is dramatic on a global scale.

3 LPG: an Introduction

Liquefied Petroleum Gas (LPG) is the name given to propane and butane or a mixture of the two hydrocarbons, which are products of the natural gas and petroleum industries.

3.1 Properties of LPG

These gases have the unusual property of becoming liquid at room temperature if moderately compressed and reverting to gases when the pressure is sufficiently reduced. This gives them a considerable advantage over other fuels because they can be easily transported and stored in the liquid state. They can be economically provided in small amounts in tanks at relatively low pressure far from pipelines, unlike natural gas (methane), which does not liquefy unless compressed at high pressures (CNG, compressed natural gas), raising cost and safety issues (Belgueudj and Chantelot 2002).10

LPG burns very cleanly in simple devices, such as household stoves and furnaces, for two principal reasons. Firstly, its properties make it easy to produce in a highly purified state without such intrinsic contaminants, such as sulfur, that would produce health-damaging air pollution. Secondly, being a gas when burned, it is relatively easy to pre-mix with air (oxygen) in simple devices, thereby achieving high combustion efficiency, i.e., nearly complete conversion of the carbon and hydrogen in the fuel to carbon dioxide (CO₂) and water (H₂O) with few products of incomplete

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10 Propane vaporizes at -45°C and butane at -2°C, compared to -162°C for natural gas at atmospheric pressure.
combustion (PIC), many of which are health damaging. This is not easily done with solid fuels in simple devices, as will be discussed below.

Neither butane nor propane is considered toxic and thus, unlike the other major modern household fuel, kerosene, LPG poses no poisoning risk. When leaked into the air, however, LPG can potentially form explosive and/or flammable mixtures and thus poses a safety hazard.

For bulk transport and storage, LPG is normally contained in modestly sized, relatively low-pressure tanks held at near ambient temperature. This is quite different from the very low-temperature (<-162°C) tanks typically used for transporting liquefied natural gas (LNG) where there are no pipelines. LPG transport poses much less risk of large explosions and fire than, for example, LNG tankers.

The burning of LPG, similar to the burning of any other fossil fuel, increases the level of carbon dioxide in the atmosphere. Additionally, although LPG burns cleaner in comparison to most other fuels, its combustion does produce nitrogen oxides fixed from the nitrogen present naturally in air (as does any fuel burned at high temperature). However, household stoves burning LPG typically do not burn at temperatures high enough to produce significant emissions of nitrogen oxides. It is useful to also note that if LPG supply systems leak their hydrocarbon gases into the air, this can potentially add to the amount of ground-level ozone present in urban atmospheres.11

Compared to the other fossil fuels typically used in household cooking, however, LPG produces significantly less (~10%) carbon dioxide per unit of usable heat released than does coal or kerosene, but roughly 20% more than natural gas. Comparisons with biomass fuels are discussed in Section 4.

### 3.2 Production and Use of LPG

LPG is a derivative from natural gas and oil processing and crude oil refining. LPG production has been growing at about 2.9% annually over the past decade. Worldwide, about half is used in the residential and commercial sector, with statistics in most countries not distinguishing the two sectors. Most, however, is thought to be used in households. In 2003, about 103 million tonnes were used in these sectors, which is equivalent to 122 million tonnes of oil, or just 2% of all oil and gas consumption – 1.3% of all primary energy consumption (WLPGA 2004).

It is difficult to obtain data directly about LPG use for household cooking in most countries because sales records are in tonnes without indicating the number of households or the amount used for what purpose in households. By making reasonable assumptions about usage and interpolating among different data sources, however, we have put together a picture of LPG use for household cooking in the 10 largest developing countries in Table 2. These make up about 70% of the population in the developing world, or 55% of the entire world. This table also shows the percent of households relying mainly on solid fuels, biomass and coal, based in these same countries (Smith, Mehta et al. 2004). Note the large differences in per capita consumption among countries, indicating the possibility for large increases in use.

Analyses of current and potential future use of household LPG could be greatly facilitated by cooperation between the LP Gas Industry and international agencies, such as the International Energy Agency (IEA), to collect statistics that allow finer differentiation of LPG use, particularly with regard to residential use.

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11 Ozone is created in urban areas by the action of sunlight on a mixture of nitrogen oxides and hydrocarbons.
3.3 LPG as a Cooking Fuel

Compared to most of the alternatives in developing countries, LPG is a superior household fuel, although not without some potential problems of its own. Table 3 summarizes the principal pluses and minuses of LPG as a cooking fuel compared with the most common cooking fuel, biomass, and the other major fossil-fuel alternative, kerosene.

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Data for percent households using LPG for cooking were available in the literature for only 5 of the 10 countries above (listed in bold). Using data from these 5, residential LPG use per capita was regressed against percent households using LPG for cooking to obtain the following equation: (% HH using LPG) = 13.2049 + 2397.55*(per capita residential LPG use), R^2=0.84. This equation was then applied to the 10 countries above to estimate percent households where LPG is used for cooking (final column).12 Sources (WLPGA 2002; UNDP 2003; IEA 2004; Smith, Mehta et al. 2004)

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12 A more complex model where residential LPG use per capita and percent households using solid fuel was regressed against percent households using LPG for cooking yielded a similar value of R=0.84.
### Table 3. Summary of advantages and disadvantages of LPG compared to biomass and kerosene as cooking fuels.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>LPG compared to Biomass as cooking Fuel</th>
<th>Kerosene compared to LPG as cooking Fuel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ease of use for household cooking</td>
<td>LPG is much easier to light, control, and store than biomass. However, it has to be bought in fairly large amounts.</td>
<td>Kerosene is easier to control and light than biomass, but not as easy as LPG. It can be bought and stored in small quantities.</td>
</tr>
<tr>
<td>Safety</td>
<td>LPG poses some safety concerns in local transport and use. Government attention is required to reduce risks. As it is stored in sealed containers and generally contains odorants to warn of leaks, household risks are low.</td>
<td>Kerosene poses safety concerns in its use and storage, including child poisonings, household fires and burns, whereas safety concerns for LPG stem from leaky appliances to which odorants are added to warn of leaks.</td>
</tr>
<tr>
<td>Ease of local transport</td>
<td>Local LPG transport requires the use of low-pressure cylinders, which are heavy for a woman to handle at refilling time.</td>
<td>Kerosene does not require pressure vessels for transport or storage.</td>
</tr>
<tr>
<td>Health-damaging air pollution</td>
<td>LPG reliably produces much lower air pollution emissions for all classes of pollutants.</td>
<td>Kerosene pollution levels are lower than biomass, but are not as low nor produced as reliably with LPG.</td>
</tr>
<tr>
<td>Greenhouse pollutants</td>
<td>Although always a net emitter, LPG emits far less than poorly combusted and/or non-renewably harvested biomass.</td>
<td>Kerosone produces somewhat more GHGs than LPG.</td>
</tr>
<tr>
<td>Dependence on centralized networks</td>
<td>LPG is a product of the sometimes unstable and unpredictable global petroleum fuel cycle, but locally is independent of pipelines. Local reliability requires smooth operation of rail or road supply chains on a national and local level.</td>
<td>Kerosene is also a product of the international global petroleum fuel cycle and is independent of pipelines. Like LPG, it also requires smooth operation of national and local supply chains. Unlike LPG, however, its production competes with other middle distillates, such as diesel.</td>
</tr>
<tr>
<td>Impact on women’s time</td>
<td>Less reliance on local harvesting of biomass can be positive, negative, or neutral depending on local conditions, such as value of women’s time and alternatives available.</td>
<td>Kerosene may require somewhat more cleaning in kitchens than LPG and, perhaps, more care to keep children safe from burns.</td>
</tr>
<tr>
<td>Impact on demand for children’s time</td>
<td>Less need to harvest biomass can release time (for example, allowing children to attend school).</td>
<td></td>
</tr>
<tr>
<td>Local ecosystem</td>
<td>Less pressure on local biomass resources may reduce deforestation and soil degradation rates and increase availability of biomass wastes for crop enhancement in some regions.</td>
<td></td>
</tr>
<tr>
<td>Daily cost at household level</td>
<td>LPG is generally more expensive in rural areas even where biomass fuels are purchased but is sometimes cheaper in peri-urban areas. Where biomass is gathered, LPG costs (excluding opportunity costs from time spent gathering) are usually substantially more expensive.</td>
<td>Kerosene is often somewhat cheaper than LPG, but prices vary according to a number of local factors. In the long run, the prices of both fuels are closely linked to the international price of crude oil.</td>
</tr>
<tr>
<td>Capital cost at household level</td>
<td>LPG stoves and cylinders are much more expensive than many traditional biomass stoves although not too different in cost from advanced biomass stoves (with chimneys, grates, baffles, dampers and good insulation).</td>
<td>Kerosene stoves cost less than LPG stoves, but cheap ones can be dangerous and can be short-lived. Fuel storage costs are minimal.</td>
</tr>
<tr>
<td>Impact on balance of payments</td>
<td>Most countries import a substantial portion of their petroleum fuels and thus increases in either LPG or kerosene use would put pressure on their balance of payments, assuming all other demands remained unchanged.</td>
<td></td>
</tr>
</tbody>
</table>
4 Indoor Air Pollution from Solid-fuel Use

As discussed in Section 2, current use of unprocessed solids as cooking fuel is thought to result in a significant health burden in developing countries. This is due to the large emissions of health-damaging pollution from use of these fuels such as biomass, coal, etc. in small stoves.

Although wood and many other forms of biomass fuel contain few intrinsic contaminants, they do not burn completely in simple small-scale combustion devices because the partially burnt material escapes the flame zone before combustion is complete. The results are often the products of incomplete combustion (PIC) listed in Table 4.

Table 4. A few health-damaging products of incomplete combustion (PIC) in woodsmoke (USEPA).

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Emission Factor (g/kg)</th>
<th>Chemical</th>
<th>Emission Factor (g/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon Monoxide</td>
<td>80 - 370</td>
<td>Methyl chloride</td>
<td>0.01 - 0.04</td>
</tr>
<tr>
<td>Methane</td>
<td>14 - 25</td>
<td>Napthalene</td>
<td>0.24 - 1.8</td>
</tr>
<tr>
<td>VOCs (C2-C7)</td>
<td>7 - 27</td>
<td>Substituted Naphthalenes</td>
<td>0.3 - 2.1</td>
</tr>
<tr>
<td>Aldehydes</td>
<td>0.6 - 5.4</td>
<td>Oxygenated Monoacromatics</td>
<td>1 - 7</td>
</tr>
<tr>
<td>Substituted Furans</td>
<td>0.15 - 1.7</td>
<td>Oxygenated PAHs</td>
<td>0.15 - 1</td>
</tr>
<tr>
<td>Benzene</td>
<td>0.6 - 4.0</td>
<td>Polycyclic Aromatic Hydrocarbons (PAHs)</td>
<td>7<em>10^-5 - 4.3</em>10^-5</td>
</tr>
<tr>
<td>Allyl Benzenes</td>
<td>1 - 6</td>
<td>Elemental Carbon</td>
<td>0.3 - 5</td>
</tr>
<tr>
<td>Toluene</td>
<td>0.15 - 1.0</td>
<td>Particulate Organic Carbon</td>
<td>2 - 20</td>
</tr>
<tr>
<td>Acetic Acid</td>
<td>1.8 - 2.4</td>
<td>Chlorinated dioxins</td>
<td>1<em>10^-5 - 4</em>10^-5</td>
</tr>
<tr>
<td>Formic Acid</td>
<td>0.06 - 0.08</td>
<td>Particulate Acidity</td>
<td>7<em>10^-5 - 7</em>10^-5</td>
</tr>
<tr>
<td>Nitrogen Oxides (NO, NO2)</td>
<td>0.2 - 0.9</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Leading the list of PIC in terms of total mass and number of carbon atoms is carbon monoxide (CO), an invisible odorless but nevertheless toxic gas with a number of potential short-term and long-term impacts on health. Following are dozens of simple and complex hydrocarbons and organic compounds, some in gaseous and some in solid form. In addition, a portion of the PIC is released as elemental carbon, or “soot,” in the form of small particles (PM). The chemical mixture of soot and organic carbon particles varies by combustion conditions, phase of the burn, fuel type and condition, and other parameters, but the particles tend to be small, i.e., smaller than the threshold of a few microns (millionths of a meter) in diameter thought to be most dangerous because they penetrate into the deep lung. Larger airborne particles, for example from a non-combustion source such as a dusty road, are not thought to be as important for health because they do not penetrate deeply into the respiratory system.

Although by no means representing the entire panoply of chemicals, CO and small particles have come to be considered as reasonable indicators of the relative health risk from combustion smokes that do not contain toxic chemicals such as sulfur, fluorine and lead (as is found in some types of coal, for example). As a result, the carbon compounds in the fuel go through substantial modification through complex and not fully understood combinations of oxidation, reduction, pyrolysis, and other chemical processes to be emitted as the mixture of gases, particles, and droplets we call smoke.

13 To illustrate this point, the outcome of tens of thousands of health studies of the most well-studied form of biomass combustion, that of tobacco, has been to designate emissions of “tar” and CO as the major indicators of risk for cigarettes. What the tobacco research community calls “tar”, the air pollution research community calls particulate matter (PM), and both tar and PM refer to what is found on a filter after passing the smoke through it.
Figure 9 shows the pollution in the form of the three major categories, CO, total hydrocarbons, and particles emitted by other major household fuels compared to LPG per unit energy delivered to the cook pot. This includes consideration of the energy efficiency of the fuel/stove system and is probably the most descriptive illustration of the potential health implications of switching fuels.

4.1 Testing Considerations

Before discussing the results in Figure 9 it is important to note several limitations of such data. First, emissions depend not only on the fuel itself, but also on the combustion conditions, i.e., the stove and the way it is used. This is particularly important for solid fuels, which will have different emissions depending on the phase of the burn, whether the fuel is added in large amounts or a little at a time, and on whether the pieces of fuel are large or small. In addition, the moisture content and species of wood or crop residues will affect the results. Systematic measurements have not been made of the dozens of different types of agricultural residues (dung and crop residues) and wood species, and thus the results should be considered typical, rather than average.

4.1.1 Advantages/Disadvantages of Standardized Use Cycles

More fundamentally, for many consumer devices it is necessary to establish a standardized use cycle in order to fairly compare emissions, efficiency, and other characteristics. This is also the case for stoves because they are not used the same way all the time by everyone who has one. This is why, for example, government agencies have established standard driving cycles for comparing the fuel use and air pollution emissions of vehicles. Otherwise, results would depend not only on the characteristics of the fuel and vehicle, but also on the exact mixture of slow and fast driving, braking, starting and stopping, and other aspects of driving. As much as possible, these standard driving cycles try to mimic typical consumer patterns, but of course, any individual is likely to find somewhat different results in actual usage.
The data in Figure 9 were taken using a standard cooking cycle, which was developed originally for comparing energy use by different fuel/stove combinations. In order to make it possible to repeat tests in a reproducible way, it essentially duplicates rice cooking, ie., bringing a standard amount of water to a boil and simmering it for a standard period. This is a common cooking task around the world, but hardly the only one or even the most important one in many areas. Thus, like driving tests, it cannot exactly indicate energy use or emissions in the real world.

### 4.1.2 Understating solid fuel pollution

All these testing issues are much less important for stoves powered by gaseous or liquid fuels (e.g., LPG or kerosene), because the fuel characteristics and combustion conditions do not change nearly as much as with solid fuels. Thus, the uncertainties regarding the pollution caused by their burning are less with these fuels. In addition, these fuels are much more controllable than solid fuels, e.g., they can be lit and extinguished instantaneously.

This is simply not the case with a solid-fuel stove. Furthermore, this characteristic is not taken into account in typical simulated cooking tests nor the standard cooking cycle used to produce the statistics used in Figure 9.\(^{15}\)

In the tests, all the fuel/stove combinations are stopped (fires put out) at the end of the cooking cycle in order to keep the tests as similar as possible and to avoid taking many hours per test. In actual households, however, solid fuels such as wood typically smolder long after cooking is finished, producing smoke and using up fuel. The contribution of this non-cooking phase to overall emissions and health impacts has not yet been well measured.

However, whether understated or not, the simple truth is that solid fuels are highly polluting in the kind of simple stoves used for cooking in developing countries.

Keeping these caveats in mind, the results in Figure 9 are nevertheless still striking. Emissions per meal of CO and PM, as well as total PIC generally follow the so-called Energy Ladder (see Figure 2), with solid fuels producing much more emission per meal than kerosene and gaseous fuels. Gaseous fuels produce the least, by far, due to their general lack of contaminants and high combustion efficiency. This supports the epidemiological results reported in Section 2, most of which were done with just simple binary distinctions such as use of solid fuels or not. It also supports the comparative risk assessment reported in Section 2.2, which estimated the total burden of disease stemming from the results of a model estimating household use of solid fuels around the world.

### 4.2 Biomass

As shown in Figure 10, in a traditional Indian wood stove 10% of the carbon in the fuel is diverted into PIC instead of burning completely to non-toxic carbon dioxide and water, which are essentially the only outcomes of complete combustion. Some traditional stoves using crop residues divert 20% or more of the fuel carbon to PIC. As shown in Table 1, a vast range of carbon-containing PIC is typically produced, dozens of which are known to be health-threatening. As shown in Figure 11, however, because the fuel and air can be premixed before combustion, the conversion of fuel to carbon to CO\(_2\) in an LPG stove is more than 99%, producing relatively little PIC. Note also the large difference (more than eight times)\(^{15}\)

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\(^{15}\) This has the effect of understating, perhaps greatly, the pollution levels attributed to biomass fuels as they are used in the household and therefore penalizes an appreciation of the actual benefit the use of gaseous or liquid fuels would provide solid-fuel using households.
in the amount of useful cooking energy obtained per kilogram of fuel for the LPG stove compared to woodstove in Figures 10 and 11.

Emissions per meal reflect this great difference in energy efficiency as well. (See Figure 9.)

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**Carbon Balance in Traditional Indian Wood Stove**

Acacia wood
90% combustion efficiency

- **Wood:** 1.0 kg
  - 420 g Carbon

- **PIC Carbon:**
  - CO: 29 g
  - CH₄: 3.0 g
  - TNMOC: 5.2 g

- **Char/Ash Carbon:** 1.6 g

- **Particle Carbon:** 0.9 g

In this improved stove, 1.0 kg fuel would deliver 2.7 MJ energy to the pot.

**Figure 10. Efficiency and carbon balance of a typical Indian wood-fired cookstove (data from Smith, Uma et al. 2000a)**

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**Carbon Balance in Typical LPG Stove**

99.4% combustion efficiency

- **Wood:** 1.0 kg
  - 825 g Carbon

- **PIC Carbon:**
  - CO: 1.1 g
  - CH₄: 0.4 g
  - TNMOC: 3.3 g

- **Char/Ash:** 0 g

- **Particle Carbon:** 0.1 g

1.0 kg of LPG in this stove would deliver about 23 MJ to the pot.

**Figure 11. Efficiency and carbon balance of a simple LPG cookstove (data from Zhang, Smith et al. 2000; Pennise 2003)**
4.3 Coal

Household coal use is common in China (up to 15% of total households) with significant use also in South Asia and South Africa (Sinton, Fridley et al. 2004). A further large number of households heat with coal, particularly in Eastern Europe and the former Soviet Union (Smith, Mehta et al. 2004).

As with biomass, coals that are free of contaminants still produce pollution in small-scale combustion because of their PIC levels. Typical household coal cookstoves in China, for example, divert more than 10% of their fuel carbon into PIC (Zhang, Smith et al. 2000). Blowers, fluidized beds, pelletization, and other means to achieve reliably good combustion are relatively uncommon in poor countries. In addition, unlike biomass, some coals contain intrinsic contaminants such as sulfur, arsenic, silica, fluorine, lead, etc., that are not destroyed in even good combustion conditions, but instead are released into the air (Finkelman, Belkin et al. 1999). Flues (chimneys) to vent smoke outdoors are apparently nearly universal in home-heating systems in Eastern Europe and the former Soviet Union, but are absent in a large percentage of households using coal for cooking in China, India, South Africa, and elsewhere. As a result, household members are exposed to significant indoor concentrations of PICs and coal contaminants. Even where vented outdoors, however, local (“neighborhood”) pollution levels of coal smoke can sometimes be significant because of the high emissions from residential coal use, particularly in winter (Smith, Apte et al. 1994).

Previous to the middle of the last century, household coal use was common in the currently developed countries of Europe, North America, and East Asia (Japan), but has been nearly entirely eliminated due to air pollution regulation and an increased availability of more convenient and cleaner fuels. The infamous killer London Smog of 1952, which heralded the modern era of pollution control, was nearly all due to emissions of coal smoke from household heating (Brimblecombe 1987). In the UK, as elsewhere in the developed world, such use in cities is almost non-existent today.

China, in which the bulk of global household coal use continues, is also experiencing a steady reduction of household coal use in urban areas due to policies to substitute gas and other cleaner fuels (Sinton, Fridley et al. 2004). In rural areas, however, household coal use seems to be increasing as it substitutes for biomass, which nevertheless still currently dominates. There do not seem to be clear trends elsewhere in the world, where household coal use tends to be confined to coal-mining areas. There have, however, been proposals by national and international agencies to promote household coal use, often in the form of “clean coal,” as a way to use domestic fossil energy supplies and/or relieve the pressure on biomass resources.

Before moving to the stage of actually banning coal in cities, the UK and other former household-coal-using countries, developed and deployed a range of clean coals for small-scale use. Eventually, however, it was realized that in simple household combustion, even these processed forms of coal or cleaner natural forms, such as anthracite, could not be burned cleanly enough to use in urban areas and still meet health-related pollution standards. China and South Africa today are now promoting clean forms of coal for urban use, but their sustainability is uncertain. In addition, few of these clean coal fuels are required to undergo standard emissions testing and there is even less regulation of what is actually sold in the market place. In rural China, little attention is placed on clean coals and coal used in households also varies dramatically across the country according to the character of local coal deposits.
Systematic measurement of household indoor pollution levels from coal use have not been done, but it seems likely that average levels are high, particularly where the ubiquitous unvented coal bucket stove is used. A 1996 database of all available studies, published in English and Chinese, identified 100 separate studies of typical household situations, both urban and rural, using coal fuels (Sinton, Smith et al. 1996). Particle levels were commonly 100 to 2000 µg/m³, compared to health-based standards of about 100 µg/m³. Although such stoves are becoming much less common in Chinese cities, they seem to be increasing in rural areas (Sinton et al., 2004). A recent rural monitoring study in three provinces (Sinton, Smith et al. 2004) found that such stoves produce small particle levels well in excess of the new Chinese indoor air standard (SAQSIQ 2002).

5 Greenhouse-related Pollutants

The potential impact on climate from the release of global warming (“greenhouse”) pollutants is an additional criterion related to the choice of household fuel type. Many people believe that any fossil fuel is worse from a greenhouse standpoint than any renewably harvested biomass fuel. After all, it is reasoned, burning fossil fuel must lead to a net addition of carbon to the atmosphere (mainly as carbon dioxide, the principal greenhouse gas). Although fossil fuels are actually renewed (made continually on Earth), the natural processes that do so are vanishingly slow compared to current burn rates.

In contrast, a renewably harvested biomass fuel (such as wood from forests that are managed to ensure that they can grow back as much biomass each year as is cut down for fuel), or agricultural residues [dung and crop residues, which are grown and harvested on annual cycles], have the benefit of being carbon neutral. In the case of vegetation, this means that as much carbon is captured from the atmosphere through photosynthesis each year as is put into the atmosphere from burning.

The carbon neutrality of wood is dependent, however, on whether the forest regenerates sufficiently each year to make up for the harvested and burned wood fuel. If it does not, then it too is operating in a “fossil” or “mined” mode and the difference in carbon flows in and out becomes a net increase in atmospheric carbon.

Even though agricultural residues are not considered subject to regeneration restraints the same way as forests are (and so are considered renewable for most fuel-cycle analyses), in reality, however, the situation is a bit more complicated for biomass fuel cycles.

Carbon neutrality (renewability) turns out to be a necessary, but not sufficient condition of “greenhouse neutrality” of the biomass fuel cycle: an additional condition must also be met, that of high combustion efficiency. As illustrated in Figure 10, typical simple biomass-burning household stoves in developing countries do not convert all the fuel carbon into carbon dioxide, which is the implicit assumption in discussions that equate carbon with greenhouse neutrality. A significant fraction of the carbon, sometimes as much as 20%, is diverted into PICs, which are, in total, a vast array of non-CO₂ carbon containing gases and particles. Although most of these probably eventually turn into CO₂ in the atmosphere, the majority have an impact on global warming while in their original form.

Per carbon atom nearly all forms of PIC are likely to have more impact on global warming than CO₂. Thus, surprisingly, if one has to put carbon into the atmosphere, the least-damaging form is CO₂ from a global warming standpoint. The only way to reduce this atmospheric PIC is to not produce it in the first place, i.e., to have higher combustion efficiency.

As photosynthesis captures only CO₂, the result of a significant fraction of fuel carbon being converted to PIC is that the atmosphere contains a larger amount of PIC than it otherwise would, no matter to what degree the CO₂ is recycled through renewable harvesting.
5.1 GWCs of fuel stove combinations

To compare the Global Warming Commitment (GWCs) of fuel/stove combinations requires multiplying the emissions of individual GHGs by their global warming potentials (GWP) and combining into an overall GWC. By definition, the GWP of CO₂ is 1.0. On the other hand, methane, one of the other major GHGs, has a much higher GWP per unit of carbon emitted. How large, however, depends on the choice of time period. If considered over the next 20 years, the GWP of methane per carbon atom, including indirect effects, is 23, but over 100 years it is just 7 (Seinfeld and Pandis 1998).

Choice of time horizons is not entirely a technical one, however, because it indicates the trade-off being made between available resources today and future benefits, and therefore different analysts use different numbers. For calculating warming, the Kyoto Protocol specifies 100-year periods, but many analysts believe that this time-period is too long and fails to account for the needs of developing countries to allocate resources carefully to their many current needs for health, environmental protection, and development. A 20-year time horizon much more closely represents the kind of time perspective taken in normal analyses about allocation of current resources to today’s problems (Hayes and Smith 1993). It optimizes resource use today and creates confidence in having the resources later on to deal with future problems.

Based on the available scientific knowledge and the state of political negotiations in 1997, only 5 other gases were included along with CO₂ in the Kyoto Protocol, which, with the ratification by Russia, entered into force internationally in February 2005 (United Nations Framework Convention on Climate Change 2004). Of the five, only two are relevant to household stoves: methane and nitrous oxides. For some other PICs, however, there is also considerable evidence of warming effect, particularly CO and total hydrocarbons (Smith, Zhang et al. 2000b). Partly because their GWPs vary somewhat by time of year and place on the globe it is difficult to agree on standard values for international negotiations.

5.1.1 Energy absorbed by the cooking pot: comparison

For most policy purposes, the best comparison of stove emissions is by energy absorbed by the pot, which includes correction for the energy efficiency of the different fuel/stove combinations. Figure 12 describes the quantity of Kyoto-listed greenhouse gases (GHGs) released for biogas fuel/stove combinations in India (based on measurements done in the 1990s). It shows the difference between wood and root fuels harvested renewably and non-renewably.

The figure shows that the GWCs tend to follow the energy ladder concept, with solid fuels producing more global warming impact than liquid and gas fuels. There may be an increasing trend from wood to crop residues to dung as well, but there are so many different types and conditions (e.g., moisture content) of these fuels that it is hard to know what the overall picture might be in the field.

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17 The GWP is the amount of warming per carbon atom (or kilogram of carbon) of the gas in question compared to CO₂.
18 This is because methane has a much shorter lifetime in the atmosphere than CO₂.
19 Although without participation by the largest GHG emitter, the USA.
20 Measured in Global Warming Commitments (GWCs).
There are some caveats that should be mentioned with regard to Figure 12, however.

- Crop residues and dung contribute the most Kyoto-listed GHGs. The low combustion efficiency and low thermal efficiency of stoves using these HSFs ensure that they are generally worse than LPG despite the fact that these HSFs are always renewable.

- Wood and root fuels do better if renewably harvested and are roughly even with LPG using the narrower Kyoto definition of GHGs. For wood, if any appreciable fraction is not harvested renewably or if a broader definition of GHGs is allowed, however, it is generally worse than LPG.

- LPG and kerosene are products of a long and complicated fuel cycle including oil or gas wells, refining operations, storage, and transport. There are GHGs released in the operation of these facilities, a portion of which should be accounted to each meal cooked with the final fuel. It seems, however, that the accountable GWC from operation of petroleum fuel cycles is probably no more than 15-20% extra (Wang 2002; Pennise 2003).

- Biogas, renewable when harvested and gaseous when burned, beats everything from a GWC standpoint and, as seen in Figure 12, is also equal to any in terms of health-damaging pollutants. However biogas contains much methane, one of the powerful non-CO₂ GHGs.

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Figure 12. Global warming commitments of different household fuels with typical stoves in India: Kyoto GHGs only (Smith, Zhang et al. 2000b)

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21 This should be compared to actual HSF use, where solid fuels such as wood typically smolder long after cooking is finished, producing smoke and using up fuel, a factor that is not fully included in the values shown in Figure 12, since these values are based on a standard cooking cycle, see section 4. Emissions per unit fuel burned, however, take this usage partly into account.
It's advantage will disappear if even a small percentage of the biogas leaks from the facility into the air before combustion. Few measurements have been done, however, to discover typical biogas leakage rates. The best from a global warming perspective, therefore, would be biogas or the high-combustion-efficiency options for renewably harvested biomass, such as pellet stoves. However, as mentioned in Section 4.3, pelletization and other means to achieve reliably good combustion for biomass are relatively uncommon in poor countries.

5.1.2 Black carbon emissions and the LPG advantage

In recent years, there has been growing interest in the "black carbon" emissions coming from biomass combustion that can add to regional and global warming. Although there is no easy way at present to predict the GWC per stove from black carbon, it is clear that a large fraction, perhaps nearly two-thirds, of the particles from household biomass stoves would classify (Venkataraman, Habib et al. 2005). Although much shorter lived than GHGs, black carbon particles can travel far enough to affect warming levels far from their source.22

This is the reason, therefore, that, counter-intuitively, even renewably harvested biomass can produce more GWC per meal than the fossil fuel LPG. Put another way, LPG could be promoted as a GHG control measure if it were to directly replace these inefficient solid-fuel/stove combinations.

Of course, given the scientific uncertainties about the global warming potential of some of the major non-methane PICs in solid-fuel smoke and given the political implications of the undoubted fact that fossil fuels overall are the chief cause of human-engendered global warming, it seems unlikely that LPG would ever be successfully promoted as a GHG intervention. After all, it cannot actually eliminate GHG emissions.

Still, given the much higher combustion and thermal efficiencies of LPG fuel/stove combinations, it is quite possible to argue that there is no increase in GWC from the introduction of LPG as a replacement for typical solid-fuel stoves. In fact, in some cases this replacement would lead to a reduction.

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22 For example South Asian particles in the Arctic (Koch and Hansen 2005).
6 Safety

When LPG energy supplants wood fuel use in the home, there is a shift in the risks and the groups affected. This shift reflects the changes in how a family obtains fuel, the nature of the fuel being kept and utilized in the home, and the different design of the new stoves being used. Hazards involved with fuel collection are eliminated when there is no longer a need for solid fuel, and different safety issues arise with storage and distribution when fuel needs are transitioned to LPG. There are hazards associated with storage and transport of LPG, but most accidents occur close to the point of consumption (UNEP and WLPGA 1998), and the change in risks inside the home necessitates knowledge of storage and operation to minimize risk. The addition of odorants reduces this risk, when combined with warning labels and education.

6.1 Risks of Fuel Collection Versus Distribution

For the many people currently reliant on biomass fuels, fuel collection efforts comprise a significant fraction of total household work. As discussed in Section 7.1, this work often falls primarily to women and can involve traveling large distances while carrying heavy loads. It can also increase women's exposure to other hazards, such as violence and snakebite. In many households, biomass fuel collection occurs solely to meet cooking needs and a transition to LPG cooking fuel could reduce or perhaps eventually eliminate the need for biomass fuel collection and the associated risks.

Storage and distribution networks that reach remote rural locations are required in order that LPG fuel can be brought to these households. The containers necessary for transport of LPG are unique to that fuel and cannot be used to transport or store other fuels (Bizzo, de Calan et al. 2004). The primary risk involved in storage and transport of LPG is of explosion followed by fire. This can occur under various circumstances, but historically the most property damage and loss of life has been a result of Boiling Liquid Expanding Vapor Explosions (BLEVEs) and Unconfined Vapor Cloud Explosions (UVCEs) (Davenport 1988). In the case of a BLEVE, a ruptured pressurized container results in rapid release, vaporization, and misting of LPG, which then mixes with surrounding air and results in the formation of a fireball. Fireballs several hundred feet in diameter have been reported, and the fire can burn for several minutes. In that time, the fire may weaken adjacent storage containers leading to further BLEVEs. UVCEs occur when large quantities of LPG are released and subsequently ignited. These risks do not exist at the household level but do exist for storage facilities, rail and truck LPG transport systems, and transport/storage of more than 40 cylinders at a time. Insulation and shielding has helped to minimize the risks associated with overheating and puncture. Risks associated with cylinders can be minimized by ensuring that they are not overfilled and that pressure release valves are functioning properly.23

6.2 Cooking with LPG: How does it change household risks?

LPG minimizes certain important risks when compared to other energy types, while at the same time introducing new risks of its own. Cooking with solid fuels over an open fire presents a major safety concern of accidental burns, especially for children. These open fires are often left with coals smoldering throughout much of the day, which can increase the risk of such burns, in addition to increasing the general risk of fire. LPG cooking devices need only be ignited during the actual cooking event, which

23 Not all cylinders have pressure release valves, however. Cylinders without valves are stronger, and thus there is a trade-off, i.e., they are not necessarily safer than those with valves.
limits the time of burn risk to the duration of cooking and subsequent cool-down period (Bizzo, de Calan et al. 2004). The important risk of an unattended open fire is avoided entirely.

A new element of risk that is introduced by the LPG stove is that of the gas leak. Even though LPG is non-toxic and produces only dizziness, even at concentrations of 10%, it is classified as an asphyxiate and will displace oxygen in confined spaces (Bizzo, de Calan et al. 2004). The most vulnerable component of the LPG cooking system is the hose, which can leak if improperly connected or weakened due to prolonged exposure to high heat. To reduce this risk, the addition of highly pungent warning odorants is compulsory worldwide. Cylinder deposit schemes can reduce risk when combined with regular inspection, and maintenance at the filling station can be mandated so that unsafe cylinders are taken out of circulation. Typical cylinders are made of steel, and the weight and bulk of a full cylinder can pose a hazard to those who must carry it (ESMAP 2004c). This issue has been addressed, in part, by the introduction of smaller cylinders (but these require more frequent refilling).

Another household-level risk of LPG cooking devices is due to high emissions of CO due to improper maintenance of equipment, particularly the burners. As discussed in Section 4, LPG stoves typically emit much lower levels of CO then most alternatives when operating under optimal conditions; however, in sub-normal conditions CO can be emitted at unsafe, high levels. A study in India comparing the carboxyhaemoglobin (COHb) levels of women using kerosene, biomass, and LPG showed no statistically significant differences between stove types. The COHb levels of LPG users were higher than expected, and this was attributed to insufficiently cleaned burners (WHO 1994). In a more recent study that compared COHb levels in members of households using LPG and biomass, those using LPG had average COHb levels below the average of biomass users (Behera, Chakrabarti et al. 2001). Though CO exposure is expected to be less among LPG users than in users of biomass fuels, CO is not eliminated entirely, and the WHO study illustrates the importance of equipment maintenance in the protection of health.

### 6.3 Hazard Mitigation

The primary hazards associated with LPG, as noted above, are due to mishandling or misuse of LPG and associated equipment. Risks to those in the distribution and supply chain and to end users can be minimized through education and adherence to safety guidelines. Internationally recognized standards and codes are made available through a joint UNEP/WLPGA publication (UNEP and WLPGA 1998). These guidelines call for appropriate management and emergency planning and response. For these guidelines to be successfully implemented it requires both innovation and cooperation by industry and regulation by government.

### 7 Gender Benefits of Cleaner Fuels and LPG

Women benefit the most from improved access to cleaner cooking fuels, because they almost always have the role of being responsible for cooking. As a consequence, they - together with their children - are also the ones most exposed to indoor air pollution. In the rural areas of developing countries (and many peri-urban areas as well), women are also often responsible for fuel procurement and processing. LPG as a cleaner and more efficient cooking fuel...
hence has the potential to directly improve these women’s lives.

Perhaps the most poignant aspect of the rural energy crisis is the demands made on rural women’s time. Women usually work longer workdays than men and provide many survival activities such as fuel and water carrying, cooking, food processing, transport, agriculture, and small enterprises that do not appear in the national labor force and economic statistics. LPG can save them significant amounts of time, which will allow them to better manage their household and their work.

Many income activities of women in the urban and rural informal sector - often critical to family economic survival - are fuel intensive, and the viability and safety of these activities is affected by energy prices and availability. LPG offers a clean and safe fuel for women’s income-generating activities. Electrification has also been shown to produce such benefits to women, although electricity is rarely used for the principal cooking tasks in poor areas (Porcaro and Takada 2005).

The segment of the global population continuing to use solid fuels overlaps significantly with those living on less than $1 per day. As women constitute 70% of the world’s adult population that meet this definition of poverty, moving from solid fuels to gaseous fuels such as LPG would have a substantial positive impact on them (Cecelski 2001).

Skutsch (Skutsch 2004) identifies three primary ways in which energy transitions can impact the lives of women:

- General well being,
- Economic productivity,
- Empowerment.

Changes in each of these three categories can be brought about by:

- Modified fuel collection requirements.
- Cooking conditions.
- Resources for income-earning enterprises.
- Availability of information and education.

There are varying degrees of overlap in these three categories and also, in some cases, the strategies to implement intervention can be more important than the actual change in energy source and pollution, a phenomenon labeled as “Improved Stove as Trojan Horse.” (Smith 2001). To the above points should be added the importance of involving women in the process: there are clear cases in which their involvement has improved the success rate of rural energy programs (Bhogle 2003).

The introduction of LPG as a cooking fuel has the potential to:

- Improve women’s health and that of their families by reducing indoor air pollution.
- Reduce risk by eliminating the need to travel long distances with heavy loads.
- Save significant time in gathering and preparing fuel and cleaning. The time saved can be used for activities that generate income, improve education, or simply to enhance people’s quality of life through greater opportunity for community or leisure activities.
- Increase the probability that young girls and boys remain in school (since they no longer need to help collect solid fuel for cooking), which should help to improve the scope of opportunities available to future generations.

Since the potential health benefits for women have already been discussed, the remainder of this section focuses on the benefits, in the form of time 

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27 It is beyond the scope of this report to detail the extent to which women’s work, monetized or not, contributes to family survival in these rural economies. However, reducing the load associated with meal preparation (both fuel acquisition and cooking time) should in the long run provide real economic benefit to many families in these communities.
savings and income generation, from the adoption of cleaner and more efficient cooking fuels.\textsuperscript{28}

### 7.1 The Burden of Fuel Collection

In many households that currently use biomass fuels, the introduction of LPG could reduce the significant burden of fuel collection that is largely the responsibility of women. In some areas, where firewood is used, women must travel for distances of up to 20 km to collect fuel and then transport loads of more than 20 kg on their backs (Clancy, Skutsch et al. 2003).\textsuperscript{29} Fuel collection on this scale requires a significant time commitment, and repeatedly carrying such heavy loads can put women at risk of strain injuries or even of miscarriage. In some regions, women must overcome the additional risks of crossing dangerous terrain and of suffering violence in the form of rapes and beatings (Cecelski 2001). Those who collect fuel are also at increased risks of leech, snake, spider, and insect bites, including those of malaria-transmitting mosquitoes (Moeung 2001). As problems of deforestation become more widespread, the distances traveled are greater, thereby increasing the risks and the effort associated with firewood collection. When these collection efforts of the adult women are still insufficient to meet household needs, young girls are sometimes taken from school to aid their mothers (Agarwal 1986).

Deforestation has also resulted in greater numbers of households using dung as a significant fuel source. Often when dung is collected, women need not travel such great distances since they can collect the excrement from their own animals. However, for poor families who do not own animals, they must forage for this unreliable fuel source. Though collection may not take as long as does firewood, mixing of dung, straw, and mud to make dung cakes can take up to two hours a day (Jeffery, Jeffery et al. 1989).

### 7.2 Cooking Advantages of LPG

In communities where LPG cooking stoves have been introduced, women have reported decreases in time preparing meals due to greater stove controllability. Users of LPG cook stoves in the Lag valley in India report that the pots and other utensils are much less soiled as a result of burning the cleaner fuel, and, as a result, they are able to save between 15 and 30 minutes per day (Chandar and Tandon 2004). Analysis of the Nepal biogas program (transition from wood) showed that more time was saved in cooking and cleaning (2.25 hours per day, combined) than in the collection of wood (1.4 hours per day) (Mendis and van Nes 2001). Table 5 shows the result of a 1996 survey of 5000 households in six states of India (ESMAP 2004a). Note the significant numbers of hours per week spent by women collecting biomass fuels: more than 14 hours a week in those one-third of households that do so.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Average hours per week</th>
<th>Percent of households doing activity</th>
<th>Hours per week for households doing activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collecting fuel</td>
<td>4.8</td>
<td>33%</td>
<td>14.4</td>
</tr>
<tr>
<td>Fetching water</td>
<td>6.5</td>
<td>93%</td>
<td>7.0</td>
</tr>
<tr>
<td>Cooking</td>
<td>19</td>
<td>97%</td>
<td>19.7</td>
</tr>
<tr>
<td>Food preparation</td>
<td>12.5</td>
<td>89%</td>
<td>14.1</td>
</tr>
</tbody>
</table>

\textsuperscript{28} For some interesting short case studies, see (UNDP 2004b).

\textsuperscript{29} Additional studies treating this point: (Clancy, Oparaocha et al. 2004) and (Chandar and Tandon 2004).
In areas of fuel scarcity, family diets can be obliged to shift to higher consumption of less-nutritious but faster cooking foods, and the risk of infectious disease transmission can increase due to insufficiently cooked food and improperly boiled water ([Agarwal 1986] and [Clancy, Skutsch et al. 2003]). If LPG conservation is not a concern, its use could result in improved nutritional intake for all family members.

As discussed in Section 4, LPG emissions of health-damaging pollutants are considerably lower than from solid-fuel combustion, and the use of LPG cook stoves significantly reduces indoor air pollution and its associated disease risks. Women and young children are usually the family members with the highest smoke exposure and would benefit the most from its use. Although no studies seem to have been done, it is also highly likely that there is a greatly reduced risk of accidental burns when cooking with LPG in comparison to cooking with solid-fuel.

Unlike solar stoves, another important clean-cooking option in many areas, an additional benefit of LPG is that it does not require that cooking be done outside the kitchen or at certain times of the day. The failure of some solar cooker programs is often attributed to the requirement that they be used outdoors during daylight hours. The disruption of traditional kitchen dynamics can lead to breakdown in social networks, and daytime cooking can be far removed from the primary consumption times [Clancy, Oparaocha et al. 2004]. Solar box cookers can be left out during the day to slowly cook certain types of foods for eating at regular mealtimes, but require a secure spot in the sun to leave them while the family is away working. Many poor households have no such place. LPG stoves do not place these restrictions on the operator and are easier to use than even improved solid-fuel stoves, which can mean better performance regarding efficiency and complete combustion, which ensures that the intended benefits are achieved (ESMAP 2004a).

This increased control over their time can give women in modernizing societies more options and possibilities – to improve the welfare of their family in various ways, to rest or socialize hence building their own social capital, or to earn much-needed income.

### 7.3 Women’s Earning Potential

In addition to the increased earning potential of women resulting from decreased time collecting fuel and cooking, LPG availability presents other opportunities in women-run micro-enterprises. Although other fuels, such as diesel, can of course be used to energize women’s income generation activities, LPG offers unique advantages, and its higher cost can be more easily justified in a commercial context.

For example, in Ghana, an improved fish smoker fueled by LPG has improved the quality of the output to meet export standards, and the emissions from the LPG smoker are significantly less than the traditional wood-fired model (Mensah 2001).

In addition, several commercial projects have been developed as part of the United Nations Development Program’s LPG Applications for Rural Development project. LPG fired dryers are being promoted for use in curing leather, textiles, cement, food, to list but a few examples (UNDP and WLPGA 2003). There are LPG applications in place to aid in the processing of shea butter, a women-driven industry. The result is increased extraction from the nuts at a lower human energy output. The UNDP program is also promoting a multifunction platform that is fired by LPG that will provide lighting and energy for several tasks that will aid in the completion of household duties, such as oil presses, cereal grinders, and water distributors.
These LPG applications are a few examples of ways in which the use of a transitioning fuel can ease the burden of women’s household duties as well as increase their economic potential in small-scale industries. The entrance of women into the market can have a positive feedback effect whereby money earned will be invested in household items to further aid in the completion of household tasks, freeing more time for money-generating or leisure/community activities (ESMAP 2004a).

7.4 Women’s Status and the Success of Rural Energy Programs

Where the opportunity cost of labor, particularly of women and children, is perceived to be low, gathering of biomass for fuel remains “cheap” (ESMAP 2004a). In such circumstances, the rational economic response for many households is to sell their subsidized LPG at a profit and keep using biomass fuel.

For example, it has been argued that the rural regions of China in which improved stove programs have had the most success were those in which women could participate in income-earning activities. These regions have high levels of commercial production of vegetables and livestock and village-level industry. The opportunity cost of women’s labor is therefore high enough to justify the purchase of fuel-saving technologies, such as improved cookstoves, thereby allowing them more time to participate in income-generating activities (Nathan 1997).

8 Alternatives to LPG for Reducing Indoor Air Pollution

There are several technical approaches to reducing air pollution exposures from the continued use of solid fuels that could potentially compete with changing to cleaner fuels such as LPG. As summarized in Table 6, these alternatives range from short-term relatively inexpensive options to longer-term more expensive approaches.

Table 6. Summary of approaches to improved use of biomass fuels

<table>
<thead>
<tr>
<th>Action</th>
<th>Degree of reduction possible</th>
<th>Constraints</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Behavioral changes to reduce exposures</td>
<td>Can lower exposures but probably not enough to meet typical guidelines for protecting health</td>
<td>Little is known about potential, means to achieve, or durability</td>
<td>Uncertain, perhaps low</td>
</tr>
<tr>
<td>Better household ventilation through windows, gaps in the eves, etc.</td>
<td>Can reduce pollution levels but not enough to meet guidelines</td>
<td>Security needs and architectural limitations can be limiting</td>
<td>Relatively low</td>
</tr>
<tr>
<td>Hoods</td>
<td>Can reduce pollution levels but not enough to meet guidelines</td>
<td>Examples are known, but there are architectural limitations</td>
<td>Low to intermediate</td>
</tr>
<tr>
<td>Chimney stoves</td>
<td>Can reduce pollution substantially in low density settlements, perhaps to near guidelines levels</td>
<td>Long-term reliability and acceptability difficult to achieve, but there are successful examples</td>
<td>Cost for long-lived, reliable devices, is intermediate</td>
</tr>
<tr>
<td>Increasing combustion efficiency</td>
<td>High, probably to near guideline levels</td>
<td>Technology shown in developed countries, but not yet in developing world context</td>
<td>Uncertain, but probably intermediate to high</td>
</tr>
<tr>
<td>Charcoal</td>
<td>High for particles and hydrocarbons, but not CO, which can pose risk of acute poisoning</td>
<td>Well-established technology, although polluting at kiln</td>
<td>Inefficient use of wood resources, but workable in some areas</td>
</tr>
<tr>
<td>Biogas</td>
<td>High, although leaks during production can reduce this</td>
<td>Millions of units in place, but limited by needs for proper resources</td>
<td>Intermediate</td>
</tr>
<tr>
<td>Other biomass-based liquid and gaseous fuels</td>
<td>Would seem high potential at the household level, although can be polluting to make</td>
<td>Technically possible, but no working examples at scale</td>
<td>Uncertain but probably high</td>
</tr>
</tbody>
</table>

30 The recent special issue of the journal, Energy for Sustainable Development (Vol 8 #3, September 2004) devoted to household fuels in developing countries has many useful articles on this topic, some of which are cited here, and other subjects related to this report. See http://www.ieiglobal.org/esd.html
Although these technical approaches can potentially improve the performance of biomass fuels and reduce levels of indoor air pollution, their implementation does not bring biomass indoor air pollution levels down to LPG’s level\(^31\), nor is the reduction as consistent as that obtained from LPG.

### 8.1 Changes in Behavior

As health effects depend on whether people actually spend time in polluted parts of the house when HSF is used (exposure), there is scope to reduce impacts by educating households to change behaviors, for example to reduce the time spent by pregnant women, young children, and other vulnerable groups where the smoke is greatest. Exposure might be reduced by changing the way existing doors and windows are used, putting out fires more quickly and using dry fuel. Relatively little is known about the best way to conduct such education, however (Barnes, Mathee et al. 2004a). One study in South Africa did find that efforts to educate households to keep children away from the fire and to open windows and other openings seemed to be most effective (Barnes, Mathee et al. 2004b). In another approach, comic books were produced for Kenyan schools in the early 1990s that emphasized the value of using dry biomass fuels for reducing smoke.

Because they tend to exercise purchasing power within families, it is important to educate men regarding the benefits of cleaner technologies and safer behaviors as well. Research in South Africa and Asia demonstrates that men will often spend expendable household income on their pursuits of leisure, such as radios and cassette players, rather than on household improvements such as piped water or improved stoves (Clancy, Skutsch et al. 2003). Efforts to increase the number of households utilizing cleaner technologies must therefore also be spent educating men regarding the benefits of cleaner technologies so as to influence these spending patterns. In at least one case, involvement of women shifted emphasis from fuel savings to smoke reduction, thereby turning a failed stove improvement program into a success (Bhogle 2003).

Promotion of behavioral changes is, however, only one component of an effective intervention to protect women and children from the worst exposures to dirty fuels. In fact, sole reliance on behavioral change without access to cleaner technologies may not be an acceptable (ethical) approach for widespread public policy. It is not an outside agency’s place to tell people how they should spend their time, but rather to help provide clean households and other environments so that people can spend time safely in the ways that meet their own perceived needs.

### 8.2 Better Household Ventilation

Household changes like adding windows, creating gaps between the top of the wall and the roof, etc., can reduce indoor concentrations and human exposures, although these sorts of changes do not directly affect emissions. However, the need to maintain household structural integrity and family security, for example, can make such changes difficult and the potential degree of improvement does not approach that available from other approaches.\(^32\) Studies have shown, for example, that even routine cooking outdoors on open biomass stoves produces air pollution exposures for the cook well above health guidelines (Uma, Smith et al. 2004). This is consistent with the standard rule in industrial hygiene that general ventilation (ventilating the entire factory) is nearly always an inferior approach compared to task ventilation (ventilating at the source of pollution).

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\(^31\) Biogas can challenge this assertion but only if Biogas production facility leakage is strictly controlled.

\(^32\) Chimneys to vent smoke outside, for example (although see section 8.3 Chimney stoves).
Gender roles may also influence decision-making, as men are often solely responsible for roofs and house repairs. In one village in India, for example, women were reluctant to make holes in roofs for chimneys because their men were away and were likely to object, so chimneys vented directly into the kitchen instead of outdoors (Cecelski 2004).

8.3 Chimney stoves

The household equivalent to industrial task ventilation is to enclose the fire and guide the smoke outside with a chimney. Studies have shown that a properly designed, built, maintained, and operated vented stove can reduce indoor pollution levels by a factor of nearly 10. Considering the normal variations in these characteristics and their inevitable decay over time, good improved stoves probably can still reduce exposures by a factor of 3-5 for years, although this is not known well for many populations. Unfortunately, however, there are also many examples of vented stoves that, with time, declined in performance sufficiently to eliminate any statistical difference in indoor concentrations compared to the open-fire stoves they replace (Ramakrishna, Durgaprasad et al. 1989).

The largest success story by far with improved cook stoves is the Chinese National Improved Stove Program (NISP), which is given credit for introducing 180 million vented stoves in rural China from about 1981-1995, a remarkable result, one achieved without any foreign assistance. Focused mainly on energy efficiency, but also on incorporating chimneys, nearly all of these stoves were designed to burn crop residues or, in a smaller number, wood (Sinton, Smith et al. 2004). Although information is scarce on what indoor pollution levels existed throughout rural China before this program, it seems clear that NISP produced a significant drop in indoor pollution levels for hundreds of millions of people.

A recent independent household survey of pollution levels in rural China (Shaanxi, Hubei, Zhejiang), however, shows that in spite of widespread dissemination of chimney stoves, indoor pollution levels still typically exceed Chinese and international health pollutant guidelines (Edwards, Smith et al. 2004). Thus, as China modernizes and expectations about pollution control rise, the NISP results no longer match needs.

The most successful current example of a national improved cookstove program is that run by Nepal’s Alternative Energy Promotion Centre, funded by the Danish foreign aid agency, DANIDA and others. Since 1999, it has introduced more than one hundred thousand improved stoves with chimneys in the middle hills area of the country. Another quarter million stoves are planned over the second phase of the program until 2009, as well as an expansion to the lowlands (Terai) and to the mountain areas of the country. Evaluations have shown that the stoves are well accepted and have reasonable lifetimes, but have not, to date, included air pollution measurements (Sapkota 2005).

There are two basic sets of reasons why a chimney stove would produce more indoor pollution than might be expected:

- Failure to operate as desired (thus amenable to improvement).
- Intrinsic characteristics of the technology that are not easily fixable.

Chimney stoves can leak smoke into the room because of holes and gaps around the fuel door and pot holes, plus many chimneys could be improved. The necessity of periodically opening the fuel door may limit a chimney stove’s ultimate achievable cleanliness.

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33 Ventilating at the source of pollution.
34 The set of materials from an independent evaluation of NISP and dissemination of the results is found at http://ehs.sph.berkeley.edu/hem/page.asp?id=29
35 http://www.aepcnepal.org/esap/ics.php
More fundamentally, chimney stoves do not actually reduce pollution but, at best, vent it outside.\textsuperscript{36} Once outside, however, the smoke can come back indoors, both in the same house and in nearby houses. Indeed, this so-called “neighborhood” pollution from households can produce rather large amounts of outdoor pollution in residential areas where much solid fuel is used in both developing and developed countries, the latter usually from wood-burning fireplaces or heating stoves.

This implies that only in situations where households are widely spaced can chimneys be considered a long-term solution for substantial reduction of pollution exposures. Even though there are probably tens of millions of candidate households around the world, still the overwhelming majority of households that use solid fuels for cooking live in villages or cities and for these populations a method of actually reducing emissions is needed.

8.4 Increasing Combustion Efficiency

As wood and most other biomass fuels have few intrinsic contaminants, if burned completely they pose little health hazard. Thus, if combustion efficiency for these fuels could be reliably improved to 99% and higher, as is common with gaseous and liquid fuels, pollution emissions\textsuperscript{37} would be dramatically reduced.

Although such combustion efficiency is commonly achieved in large-scale (industrial) wood combustion, to achieve it in small stoves is not easy. The principal methods to do so are fluidized bed combustion, reliable secondary combustion of PIC escaping the primary combustion zone and catalytic converters, in automobiles. These all work but are far too expensive in the context of a typical cookstove in a developing country in which the total cost should rarely exceed a few tens of dollars. Such approaches are more often used, for example, to bring metal wood-burning heating stoves in developed countries into compliance with environmental standards, but at costs typically starting at $500 and higher.

The most well-demonstrated high-combustion-efficiency solid-fuel technology for potential developing-country applications are pellet stoves, in which the biomass is processed into uniform small pellets for which the combustion chamber of the stove can be optimized for high efficiency. To work well, such stoves also usually use electricity, for pellet handling and air blowing. Electric wood-pellet heating stoves in the US, for example, produce less than 8% of the emissions of an open fire (USEPA).

Although not required in large amounts, the need for electricity can be a severe drawback in many countries where it is not available in rural areas or is quite unreliable. In other regions however, such as much of rural China, electricity is available and the combination of pellet processing technology and pellet stoves may come to play a major role, not only because of low emissions but also because of the high energy efficiency it offers (Sinton, Smith et al. 2004).

There are stove technologies now being developed that can achieve high combustion efficiency of biomass through a partial gasification process (Lou 2005). Although not yet widely tested or disseminated, such technology would be a welcome addition to clean rural energy options. As gasification is difficult to maintain reliably across all the conditions likely to be experienced in a house (fuel of different moisture contents, sizes, compositions), it is important that such stoves still use chimneys to vent the smoke when the gasification function is interrupted.

\textsuperscript{36} Indeed, although beyond the scope of this report, many chimney stove designs change combustion characteristics in such a way that they actually increase total emissions, even though improving energy efficiency and, if operating properly, venting the smoke outside.

\textsuperscript{37} Including a great reduction in PIC levels.
8.5 Processed Biofuels

In contrast to pellets, which still have the same chemical structure as the original biomass, there is a range of technologies available for producing cleaner fuels with substantially different chemical structures from the original biomass.

8.5.1 Charcoal

The oldest and most widespread processed biofuel is charcoal, which is produced by heating wood in an air-deprived chamber, or kiln. In developing parts of the world, such as Africa, charcoal is often made in simple temporary earth-mound kilns with low efficiency and high pollution emissions (Pennise, Smith et al. 2001; Karve and Smith 2003). It can be produced much more efficiently with more advanced technology. Compared to wood, charcoal burns with much less production of PM and hydrocarbons, but similar emissions of CO.

This produces the difficult to assess change in which long-term health impacts mainly due to PM are reduced, but the hazard of short-term acute poisoning is increased. This is not due to production of more CO, but rather to the great reduction of PM and such irritating hydrocarbons as formaldehyde, which in woodsmoke act as a natural warning because they normally wake up householders and drive them from the room before they absorb lethal levels of CO. Overnight CO poisoning from use of "clean" solid fuels, charcoal and some coals, therefore is a serious concern. This characteristic, and the necessary substantial loss of total energy value in the charcoal-making process compared to using the wood directly, makes it problematic to promote expanded use of charcoal in most parts of the world as a cooking fuel.

8.5.2 Biogas

Biogas, made by microbiological processes in air-free tanks, or digestors, is most easily made using animal waste, but can also be made with certain other agricultural residues. Large programs disseminating biogas plants to millions of households have existed in many countries, including India and China, and, with an even higher degrees of success, more recently in Nepal. As shown in Figure 10, burning biogas produces quite low emissions per meal, potentially even below those of the other major household gaseous fuel, LPG.

Attractive as it is as a renewable and clean-burning fuel, biogas is not appropriate for much of the developing world because of its requirements for water, animal dung, and relatively warm temperatures. In addition, its construction is relatively capital-intensive and its maintenance is relatively labor-intensive in many areas. Thus, it tends to have a small niche of attractiveness overall.

Poor people often do not have access to enough water, dung and capital to consider biogas, and at a certain level of income people would rather purchase LPG or other easier to handle fuels. Nevertheless, as shown in South Asia and China, even though the potential size of the niche may be modest in terms of percentage of total households, it can still be attractive for tens or even hundreds of millions of people.

In addition, there are encouraging signs that biogas may be produced economically from less valuable and more widely available forms of biomass than dung, namely certain types of crop wastes (Goldemberg, Reddy et al. 2000; Karve and Smith 2003). If these systems are proven out, the size of the niche could increase significantly.

Among the most successful recent efforts is The Biogas Support Program in Nepal, which resulted in wide dissemination of biogas plants in rural homes through a system of targeted subsidies, financing, quality control of plants, and education. A key component was provision of information accurately outlining the benefits and
limitations of the biogas plants, with the aim of customer satisfaction resulting in increased word of mouth promotion. This program targeted the approximately 1.5 million households that were determined as suitable for biogas plant installation by having sufficient cattle or buffalos and other characteristics. Availability of financing ensured that biogas was available to those unable to meet the capital costs beyond the subsidized amount. In addition, there are signs that a number of households are connecting human latrines so that biogas production serves a secondary role of sanitation (Mendis and Vander Hoorn 1999).

8.5.3 Other gases and liquids

A highly attractive cooking fuel would be biomass-based liquids or solids. If renewable when harvested and liquid or gas when burned, the combination of carbon recycling and high combustion efficiency would result in an extremely low impact fuel from both health and climate considerations.

Although there are a number of available fuels in this category, including ethanol, methanol, and producer gas, and some exotic fuels being researched, including di-methyl-ether (DME) and synthetic LPG, none currently offer much prospect as an affordable and available cooking fuel for widespread use in developing countries in the near future (Goldemberg, Reddy et al. 2000; Goldemberg, Johansson et al. 2004; Larson and Yang 2004).

8.6 Kerosene

The first modern household fuel to be taken up in many countries was kerosene (or paraffin), which is a colorless flammable hydrocarbon liquid obtained from the fractional distillation of petroleum. Table 3 compares the use characteristics of LPG to kerosene and biomass. Like LPG, kerosene has high energy density for transport and can be burned much more efficiently in simple stoves than solid fuels. That it does not require pressure vessels for transport and storage is an advantage over LPG, also making it easier to buy and sell in small amounts as well. Like LPG, kerosene is a product of the petroleum fuel cycle and thus requires reliable supply chains and, in many countries, imports. Unlike LPG, kerosene can easily be diverted to other uses, for example mixed with diesel fuel (another middle distillate) for vehicles. As discussed in Section 9.1, this makes it difficult to target subsidies to the household sector.

Chief among its disadvantages are the poisonings, burns, and loss of property that are associated with kerosene use in many areas of the world. Poisoning applies particularly to children, as they are more likely to drink kerosene stored in the household in small containers, or be trapped in kerosene-related fires. Although most reports of child poisonings have been from Africa (Reed and Conradie 1997; Orisakwe, Egenti et al. 2000), they are a concern in other areas as well (Gupta, Govil et al. 1998). Kerosene seems also to be associated with more household injuries and deaths due to burns than LPG (Singh, Singh et al. 1997; Mabrouk, Badawy et al. 2000). Most of the poisonings seem to occur because the fuel is stored in soft-drink bottles or other inappropriate containers. It is possible that a concerted effort to reduce poisonings by education and dissemination of childproof containers could be a cost-effective way to increase its safety factor.

38 In South Africa alone, the Paraffin Safety Association estimates that 80,000 children ingest kerosene every year and between 40,000 and 80,000 households experience kerosene related fires a year and roughly 43% of these households experience 2 or more fires a year (Markinor omnibus surveys, January 2004, unpublished).
8.6.1 Kerosene air pollution emissions

With current knowledge, it is difficult to generalize about the air pollution implications of household kerosene use. Unlike LPG, there are wide variations in kerosene quality and types of stoves used. In addition, kerosene is a much more complex mixture than LPG. In poor countries, where refining capability is low and/or suffering from variability, it sometimes contains sulfur and other contaminants. Furthermore, it can change quality with refining conditions and types of crude oil utilized. All of these factors will affect its air pollution emissions.

There is a wide variety of kerosene stoves, from pressurized devices (using hand pumps) in which the air and fuel can be reliably premixed, to simple wick stoves with more variable combustion conditions. Thus, it is much more common that a kerosene stove will have low combustion efficiency than an LPG stove, although even LPG stoves can pollute if poorly made or maintained.

The few studies of kerosene stove emissions show, in general, that they are lower than solid fuel stoves, but higher than LPG [Smith, Khalil et al. 1993; Smith, Uma et al. 2000a] (as shown in Figure 10). Quality varies widely, to the point that the worst kerosene stoves are just as bad as some solid fuel stoves and the best are as good as the worst LPG stoves. Along with better understanding of the quality and consistency of kerosene fuels sold in developing countries, more and more systematic emissions measurements are needed, along with household surveys of the types of stoves used and their condition.40

Kerosene is also commonly used for lighting in many developing-country households, usually in simple wick lamps. Although having the advantage of being able to purchase fuel in small amounts, these lamps are very inefficient as light sources and can be quite polluting (Schare and Smith 1995).

8.6.2 Kerosene and LPG prices41

It is difficult to generalize about the relative prices of kerosene and LPG experienced by households, as there is much local variation due to taxes, subsidies, and other factors. Along with many other products (e.g., gasoline and diesel fuel), kerosene is produced in petroleum refineries. There is no uniform or entirely objective way for outsiders to assign relative production costs to such co-products in refineries for they are usually run in a proprietary manner, leading to differences in estimated costs, even before taxes or profits.41

In addition, the quality of the crude oil used for refining will have an effect on the relative amounts of co-products and change the pricing calculus. Furthermore, depending on the equipment it has and the crude oils it uses, each refinery has some capability to adjust the relative amounts of different co-products it produces, according to market demand. Thus, being a “middle distillate”, the degree to which the refinery is set to produce cooking kerosene and its price are influenced particularly by the demand for the other major middle distillates, diesel fuel and jet fuel. With the expected rapid increase in vehicle use (and to a lesser extent air travel) in much of the developing world, particularly Asia, it is probable that cooking

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40 A substantial amount of emissions data is available from the US on kerosene space heaters, but the combustion conditions and fuel qualities are too different to apply the results to developing-country cookstoves (Pacific Environmental Services 2002).
41 For a good discussion of the LPG and kerosene markets in two different countries, India and Guatemala, including the impacts of prices and subsidies, see (ESMAP 2003a; ESMAP 2003b).
kerosene will be disadvantaged in this regard and prices will rise. A further consideration, of course, is that both kerosene and LPG have uses in other (non-household) sectors and prices will depend on the overall demand growth. The degree that this is an issue, however, will depend on crude oils used and investment in advanced refining technology by the petroleum industry.

Over the long term the prices of both LPG and kerosene must rise and fall more or less in step with international petroleum prices, with local variations, apart from government regulations or subsidies, only existing in the short term.

9 How Can LPG be Promoted? 

Although sharing some advantages and having some disadvantages compared to kerosene, LPG is generally considered the most superior available household fuel. A multi-criteria evaluation of cooking alternatives in India, for example, evaluated nine cooking options including traditional and improved biomass stoves, biogas, and solar, across 30 different technical, economic, environmental, social, behavioral, and market criteria. LPG came out on top by a large margin, following by kerosene (Pohekar and Ramachandran 2004).

The advantages of LPG have been noted by many observers and development agencies over the years, including the World Bank. Thus a number of attempts have been made to promote greater usage in households that currently use biomass fuels. Unfortunately, however, there has not been a great deal of success in many such efforts, which have also sometimes been costly and inefficient.

9.1 Subsidies

The basic problem is that LPG is more expensive in terms of financial costs compared to self-gathered biomass fuel in rural areas, where the principal population of concern lives. Although there are many complexities, it is generally true that over time as household incomes rise, people tend to turn away from solid toward cleaner fuels. Subsidy of LPG and kerosene has thus been attempted as a means to encourage poor households to move to these cleaner and more efficient fuels at lower levels of income than they otherwise would, but such efforts have not generally progressed as planned. Three major problems generally limit the viability of such subsidy schemes (ESMAP 2003a):

- Firstly, they are expensive in the local context. India's LPG subsidies, for example, cost more to the government than it spends on all education in the country.
- Secondly, they are inefficient. In India, again, much of the subsidized LPG ends up being used by middle- and upper-income Indians who do not need the subsidy.
- Thirdly, like kerosene, its use may be diverted to non-household needs, in vehicles, irrigation pumps, restaurants, etc., for which the subsidy was not intended (this is a much bigger problem with kerosene subsidies). Even when effort is made to make sure that only the poorest households actually have access to the subsidized LPG, there is no way to keep them from selling it to others for needed cash rather than use it for their own cooking.

Ironically, therefore, some of its very best advantages, portability and ease of use, make LPG an unsuitable commodity to subsidize in a way that efficiently assists the targeted groups, the rural poor. It is just too easily diverted to (sold for) other uses.
On the other hand, there would seem to be a better case for targeted subsidies in peri-urban and urban areas where, perhaps surprisingly, there is still much use of purchased biomass in many developing countries. Perhaps even more surprisingly, some studies show that the cost of purchasing the biomass fuel can sometimes actually be higher than the equivalent amount of LPG would cost (ESMAP 2003c). The main reasons people do not switch on their own seem to be (ESMAP 2003a):

- The upfront cost of the stove and cylinder keep poor people out of the market because they cannot put together the sufficient capital and have no access to the micro-credit needed to borrow it.
- Supply of LPG is not reliable, forcing people to maintain backup cooking arrangements, since cooking must be done every day.
- Access to LPG equipment is inadequate and the distribution network for LPG is insufficient.

These three problems in biomass-purchasing urban areas seem more tractable to government policy interventions than in the rural areas where biomass fuel is gathered (ESMAP 2004d). Low interest loans targeted for purchasing stoves and cylinders and development of smaller cylinders with lower upfront cost are realistic and efficient ways to deal with the first problem. Even direct subsidies of the stove and cylinder would not have the major disadvantage of subsidizing the fuel, as there are no other major uses of a small cookstove except for household cooking. The second and third problems, unreliable supplies and inadequate infrastructure, are also at least theoretically amenable to government action to encourage fuel markets to operate more smoothly. It is important to note that the LPG industry must also be engaged in these efforts and, indeed, may be able to initiate many of these improvements on its own in many areas.

9.2 Practical Difficulties with the Energy Ladder framework

Although it is clear that the household energy ladder framework (Figure 2) reasonably describes situations at large scale (regional, national, and historical), it often does not do well at predicting what will happen in individual households and neighborhoods (ESMAP 2003c). In particular, although rising incomes and other factors can lead households to adopt LPG (or kerosene, depending on local availability), they rarely do so in a step-wise fashion. In other words, they maintain use of biomass fuels, slowly substituting LPG for more and more tasks over time and with further rises in income, what has been called “stacking” (ESMAP 2003b). Even when LPG might be reported as the principal cooking fuel, therefore, there still may be significant use of biomass for other purposes, or for certain types of cooking (for example, long-term cooking of beans or the making of animal fodder).

This is particularly dramatically evident in transitional middle-income countries like China. A recent study of rural areas in two provinces, for example, found 37 different fuel-stove combinations in use in summer and 28 in winter (Sinton, Smith et al. 2004). The population was straddling several steps of the energy ladder at once, but with seasonal changes. In rural India, middle-income households use LPG for preparing meals quickly, such as breakfast or for guests, and the heating of beverages. Meals that require more time are cooked using fuelwood (Sinha 2005 forthcoming).

It is perhaps not surprising that old habits die slowly and that expensive new devices are reserved first for the subset of tasks that they do best. It does have important implications for predicting the advantages of LPG introduction, however. Even when ways are found to encourage formerly biomass-using households...
to adopt LPG, unfortunately, there is likely still to be some air pollution and other problems due to residual use of biomass fuels.

It does seem clear, however, that urban households, which cannot gather their own free biomass fuels, are much less likely to stack their fuels, i.e., are more likely to adopt LPG more completely when they switch. This characteristic is another reason why such groups would seem to be the best initial targets of programs to promote movement up the energy ladder to achieve air-pollution-reduction and other social benefits (ESMAP 2003a). Determining the total air pollution benefit, however, may be more difficult as such groups tend to live in parts of cities that have the worst outdoor air pollution.

An intriguing association between household electrification and switching away from HSF use to LPG and kerosene has been identified in a number of studies in recent years (ESMAP 2003c). Even when analyses try to eliminate the effects of education, income, and other potentially confounding factors, this intriguing association remains in the data. In such cross-sectional studies, it is difficult to prove that electrification causes or triggers cooking fuel switching, but this is the implication. More work is clearly needed to understand this effect, which might have important policy implications (Heltberg 2004).

**9.3 Case Studies of LPG Promotion**

There has been some encouraging progress in LPG promotion efforts around the world. The extent of success varies with local circumstances.

**Senegal:** Government may address insufficient progress in switching from HSF use to LPG through the implementation of policies that create incentives for its LPG industry to invest in infrastructure while at the same time limiting availability of depleted resources, such as wood fuel. In the 1970s, Senegal introduced an aggressive LPG program to alleviate deforestation partially due to the high consumption of biomass energy (wood-fuel and charcoal). The government gave the private sector a key role in the distribution, packing and storage of LPG right from the program's genesis. It also created subsidies to alter the price structure and thus encourage adoption, while limiting access to wood through increases in the license fees for cutting wood and revisions in charcoal extraction quotas and sale prices. With significant political will behind it, the LPG program significantly increased LPG use in Senegal. There are, however, serious limitations in the program's success. As is often the case, the subsidies primarily benefited middle- and higher-income groups, whereas low-income groups still could not afford LPG. A price differential also existed across the rural and urban groups, with LPG much more affordable in Dakar than rural areas. Lastly, Senegal's LPG program was 'gender-neutral'; women were not part of the distribution chain and it did not consider the broader spectrum of women's energy needs beyond cooking. It is important to note that this program's goal was not social justice, but rather environmental (preventing deforestation) and this influenced how policies were set (Denton 2004).

**Brazil:** LPG is widely used as a household fuel source in Brazil with access in approximately 98% of households. A history of governmental subsidies is probably the principal reason for its widespread use (Jannuzzi and Sanga 2004). From 1950 to 2001 the Brazilian government utilized subsidies to control the market price of LPG, while unintentionally curbing investment and the entrance of additional distributors into the market. Subsidized LPG began to be used for

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45 Taken in large household surveys in a number of countries.
46 See also http://sparknet.info/home.php for other examples from Africa.
unintended purposes such as heating saunas and swimming pools and powering vehicles. In January 2002, these subsidies were removed, resulting in a doubling of prices and increased use of alternative fuel sources, such as fuelwood. Residential use of fuelwood is free of cost, while industrial and commercial fuelwood demands a price that is significantly less than current LPG costs. The Brazilian government has maintained a subsidy for low-income families to encourage residential use of LPG. Some additional reasons for the high penetration of LPG in the residential sector include: (1) the low cost, availability and ease of maintenance of LPG cookstoves; (2) a well-established infrastructure to deliver LPG throughout Brazil; and (3) no infrastructure for delivery of gas via pipes to households. The National Petroleum Agency (ANP) is undertaking a two-pronged program to address the inefficiencies of LPG use in Brazil through fuel standard revisions and a campaign aimed at educating consumers to buy more efficient products and use LPG more wisely (Lucon, Coelho et al. 2004).

Sudan: Although still small, a promising community-based approach by the Intermediate Technology Development Group (ITDG) in Sudan utilized a revolving fund to distribute small loans for the purchase of smoke reduction technologies in a peri-urban area where households spend a considerable portion of their daily expenditures on the purchase of biomass. The 30 study participants chose to purchase LPG appliances after discussions with ITDG regarding their needs and the health effects of smoke and the benefits of smoke reduction technologies. Reasons for LPG preference included LPG’s relative abundance and availability in the locale and its clean burning and short cooking time relative to biomass. Perhaps more importantly, the government widely encourages its use through incentives such as an LPG subsidy of 50% and an exemption on import taxes for LPG appliances. ITDG-Sudan’s local Women’s Development Association managed the revolving fund from which women could borrow capital to purchase appliances and then repay over time. Few women defaulted on their loans, and the possible involvement in the revolving fund attracted the interest of other women who wanted to participate as well. Due to the success of this initial project, ITDG-Sudan and its partners are preparing to scale up other LPG activities (Hood, Ahmed et al. 2004).

10 LPG and the Millennium Development Goals

In 2000, the 191 United Nations Member States adopted the Millennium Declaration and resolved to achieve 8 development goals by 2015, called the Millennium Development Goals (MDGs). These goals aim to:

- Eradicate extreme poverty and hunger.
- Achieve universal primary education.
- Promote gender equality and empower women.
- Reduce child mortality.
- Improve maternal health.
- Combat HIV/AIDS, malaria and other diseases.
- Ensure environmental sustainability.
- Develop a global partnership for development.

No causal link has yet been established, but a positive correlation has been observed between increased access to clean energy services and increases in the Human Development Index (HDI) (composed of health, income, and education indicators) (McDade 2004).
Under MDG 7, **Ensure Environmental Sustainability**, there are five indicators, one of which is **“Proportion of population using solid fuels,”** promoted by the WHO because of the close link to air pollution and health (WHO 2004b). Increased access to residential LPG, however, can assist in several of the other MDGs as well, as summarized in Table 7.

**Table 7. How LPG can aid in achieving the Millennium Development Goals (modified from (Havet 2004))**

<table>
<thead>
<tr>
<th><strong>Millennium Development Goal</strong></th>
<th><strong>How LPG contributes to achieving goal</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Goal 1: Eradicate extreme poverty and hunger</td>
<td>Use of more efficient fuels can reduce the share of household income spent on household energy needs.</td>
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<td></td>
<td>Reliable and efficient energy delivery can improve enterprise development.</td>
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<td></td>
<td>Reliable fuel access increases the range of staple foods available to a household.</td>
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<td></td>
<td>Improved fuel and stove technology can improve food preservation thereby decreasing the proportion lost to spoilage.</td>
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<td>Goal 2: Achieve universal primary education</td>
<td>Transition away from biomass fuels reduces the need to withhold children, especially girls, from school to help with domestic duties, such as fuel collection.</td>
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<tr>
<td>Goal 3: Promote gender equality and empower women</td>
<td>Cleaner burning, efficient, and reliable fuel availability means that the amount of time that women must spend in collecting fuel, cooking, and cleaning is decreased. This time can be spent on leisure or income-generating pursuits.</td>
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<tr>
<td>Goal 4: Reduce child mortality</td>
<td>Improved cooking technology with cleaner-burning fuels will reduce the morbidity and mortality associated with indoor air pollution.</td>
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<td></td>
<td>Improved fuel availability can improve water boiling and food preparation practices, leading to increased nutritional health.</td>
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<tr>
<td>Goal 5: Improve maternal health</td>
<td>Reductions in levels of indoor air pollution (IAP) will result in decreased maternal exposure to IAP, reducing the incidence of fetal and maternal morbidity associated with these exposures.</td>
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<td></td>
<td>Women must often continue to collect biomass fuel wood throughout their pregnancy; transitioning fuel will reduce the strain on expectant mothers.</td>
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<tr>
<td>Goal 6: Combat HIV/AIDS, malaria, and other diseases</td>
<td>When fuel collection responsibilities of women are reduced, associated risks of rape and infectious disease transmission are also reduced.</td>
</tr>
<tr>
<td>Goal 7: Ensure environmental sustainability</td>
<td>Degradation of land due to biomass fuel gathering can be halted or reduced by supplanting the need with gaseous fuels.</td>
</tr>
<tr>
<td></td>
<td>Proportion of households using solid fuels is established as one of five indicators under this Goal.</td>
</tr>
</tbody>
</table>

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*This is under Target 9, “Integrate the principles of sustainable development into country policies and programmes and reverse the loss of environmental resources.” The proportion of household using solid fuels is Indicator #29 of the total MDG set of 48, see: [http://millenniumindicators.un.org/unsd/mi/mi_goals.asp](http://millenniumindicators.un.org/unsd/mi/mi_goals.asp).*
Young girls would also benefit from a transition to LPG, as decreases in biomass fuel availability can result in their being kept home from school to aid in fuel collection. With some of the household energy needs being met by alternative fuels, fuel collection requirements will be decreased, and the goal of universal education has one less impediment (McDade 2004). The greatest benefit of decreased fuel collection time will be realized by women, who can use this liberated time for leisure or income-generating activities (Havet 2004). As discussed in previous sections, the decreased need to gather fuel will improve the health of women who would otherwise need to cover great distances with heavy loads, a fact which puts them in a vulnerable position (risks of violence or infectious disease transmission). The increasing distances traveled for fuel collection itself speaks volumes on the impact fuel collection has on ecosystem health. Decreasing forest degradation that results from fuel collection moves us forward in the goal of working towards environmental sustainability.

Transition from biomass to use of cleaner burning fuels in the home will benefit maternal and child health. These are the two groups most impacted by the high levels of smoke produced by biomass home heating and cooking stoves, and this is strongly tied to adverse health outcomes, as was discussed in the section on indoor air pollution. By reducing IAP levels in the home, the mortality and morbidity associated with these exposures would decrease (WHO 2004b).

11 Data and Monitoring

Finally, needed for any coordinated effort to improve household fuel systems in poor countries, is systematic attention to gathering local and national data on fuel use. Consider the international data gathering jointly implemented by WHO and UNICEF on access to clean water and access to sanitation (www.wssinfo.org). These water/sanitation indicators are widely used around the world and commonly cited by those concerned with development and health. They are the only environmental health indicators available in essentially every country, a result of the long-term efforts of UNICEF/WHO to promote their collection and reporting in systematic ways. Although far from perfect, these indicators are relatively easy to determine because they do not require measurement. Importantly, in addition, studies show that they relate directly to the risk of diarrheal disease, still a major killer in the developing world (Pruss-Ustun, Kay et al. 2004).

In parallel to the household water/waste indicators, there also needs to be systematic collection of information on household air quality indicators (Smith 2002a). Although the simple metric of the proportion of solid fuel used has been shown to be a reasonable indicator of the health risk of indoor air pollution, it would be improved by information on ventilation, the use of stoves with chimneys and the location of kitchens (Smith 2000; Smith 2002a; Smith, Mehta et al. 2004). Questions on household fuel use are becoming more common on national censuses and other large-scale household surveys around the world49, but for it to be done consistently, regularly, and sustainably will require additional resources be allocated to WHO and other international bodies to continue their promotion. Ventilation questions are today rarely found on national household surveys.

Following the principle that you cannot know how to move forward until you know where you are, one of the first steps in implementing the Millennium Development Goals [including the reduction of household solid fuel use] should be to establish a systematic international monitoring system. Like the water/waste indicators,

49 An example can be seen in the immensely valuable series of Demographic and Health Surveys done in many countries (www.measuredhs.com).
systematic data on fuel/ventilation gathered by household sample surveys, even without measurements, would greatly improve our ability to understand the extent and trends of unhealthy exposures, the impact of interventions, and where to target measurements and improvements.

As noted at the beginning of this report, current LPG sales statistics are not currently broken down into commercial and household end-use sectors. This hampers understanding and planning for household fuel transitions.

The LPG industry should help quantify solid fuel use by distinguishing between sales of LPG for household use from sales for commercial use. This action would greatly facilitate the efforts of international agencies to promote LPG as a cleaner household fuel.

12 Conclusion: The Implications of LPG for Sustainability

In preparation for the World Summit on Sustainable Development, a number of reports addressing how to put “sustainability” measures into operation were authored. One example is the well-written and widely disseminated position paper, “Power to Tackle Poverty: Getting Renewable Energy to the World’s Poor” (Greenpeace and T. B. Shop 2001). It dealt with the issue being addressed in this report: how to bring modern energy services to nearly half of humanity whose development and survival requirements suffer for lack of them. These people have little access to electricity and depend for their household cooking and heating requirements on local biomass in the form of wood, crop residues, and dung.

A premise of this position paper, as in many other such discussions, is that sustainability in energy can only be applied to renewable sources. After all, fossil fuels are in principle limited, and the fossil carbon they contain is a threat when released rapidly into the atmosphere. With this starting point, often the next logical step is to promote various forms of renewable energy to provide the sustainable energy services to those that need them most, the rural poor of the third world.

There are several questionable assumptions, however, hidden in the premise that widespread household use of fossil fuels in poor countries would be unsustainable:

- That the major alternative, local use of biomass fuel, is, by comparison, sustainable. The fact is that in many cases it is used inefficiently, which:
  - contributes to local depletion of biomass resources including forests and soils.
  - produces serious health impacts in the local population because inefficient use results in high emissions of pollutants.
  - can add to net CO$_2$ emissions and global warming if it is not renewably harvested.

- That provision of household fuel to the world’s poor would appreciably add to the greenhouse burden of fossil fuels. The fact is that:
  - Even if the 2 billion poorest people shifted to LPG for household fuel it would add less than two percent to the global greenhouse-gas (GHG) emissions of fossil fuels (Smith 2002b).

- That it would replace biomass fuels that are greenhouse neutral. The fact is that:
  - If methane and other non-CO$_2$ greenhouse pollutants are taken into consideration, a switch to LPG for household cooking would probably actually produce a net decrease in global warming impacts, even in comparison to renewably harvested biomass.
- That being a fossil fuel, it produces health-damaging pollutants when burned. The fact is that:
  - In terms of human health, a shift to LPG would actually result in a substantially larger net reduction of human exposures to major air pollutants than today’s total exposure from all fossil fuel emissions.

- That, being non-renewable, petroleum cannot be relied upon to serve household needs into the future. The fact is that:
  - Petroleum resources, however, are more than sufficient to supply all conceivable household needs far into the future. It is demand from other sectors that depletes supplies, stresses balance of payments, and threatens international security as nations seek to protect their energy interests.

- That available means to supply high-quality renewable energy services for cooking and heating will be affordable, reliable, and suitable for the rural poor. True sustainability needs to consider these factors as well. However:
  - Unfortunately, few of the widely available renewable technologies to replace household fuels with high-quality substitutes meet these requirements today.

Asking the poor to take on novel devices and fuels that have never been used anywhere else in human history because, if they do not, we may add fractionally to GHG emissions or shorten the petroleum era by a few months is a bit strange. Why ask them to take on this difficult task, when the rest of the world will not? Who should be shouldering the burden of finding and using new low-GHG high-efficiency technologies? It seems difficult to resist the argument that those who produce the most GHG now and who have the resources and technology to do something about it are precisely the ones who should be the first to take the risk of trying the alternatives.

To illustrate, an extra annual increase of efficiency in the world automobile fleet of just 0.5% (5.1% over 10 years – about one-half kilometer per liter) would “free” sufficient fuel energy for the cooking needs of the poorest 2 billion people well before the year of the next Earth Summit (Rio + 20). In addition, by Rio + 30 (2022), even though providing cooking fuel in the interim, enough extra petroleum would have been saved for a household fuel reserve of 10 years to be put aside for these people (Smith 2002b).

Put another way, no matter how the rural poor do their cooking, the GHG production and petroleum demand battles that count will be fought in Detroit, Yokohama, and Stuttgart (as well as Shanghai, Sao Paulo, and Mumbai).

There has always been difficulty in treating non-renewable resources, such as petroleum, in a sustainability framework. However the original definition, “Sustainable development meets the needs of the present without compromising the ability of future generations to meet their own needs” (United Nations World Commission on Environment and Development 1987), does not mean non-use, rather careful use for the highest possible generational gain. What possible better use for the low-cost, high-efficiency, clean-burning fossil fuels such as LPG than providing high-quality energy services for poor households?

As noted in the Millennium Development Goals, reducing the fraction of households relying on solid fuels is an important indicator of improvement in people’s lives.

There remain serious cost and administrative constraints to putting LPG in this role, of course, but there are no realistic resource or greenhouse constraints to keep us from targeting the needs of the poorest with LPG or other clean fossil fuels in those places where renewable technologies are not yet appropriate or sustainable. In addition, there are clear health and environmental benefits of doing so. Far from petroleum being excluded, some of this one time gift from nature ought actually to be reserved to fulfill our obligation of bringing the health and welfare of all people to a reasonable level – an essential goal of sustainable development, no matter how defined.
13 Glossary

ALRI – Acute Lower Respiratory Infection.
ALRI describes respiratory tract infections in the lower lung and includes pneumonia.

BLEVE – Boiling Liquid Expanding Vapor explosions. BLEVEs occur as a result of release of a flammable gas from ruptured pressurized containers, which then mixes with the atmosphere and forms a fireball.

CHILLING – Becoming too cold to maintain proper health from lack of proper clothing, housing, fuel, etc.

CO – Carbon Monoxide. CO is a colorless, odorless and toxic gas, for which standards are set to protect human health.

COHb – Carboxyhemoglobin. COHb is formed when CO enters the body and binds with hemoglobin molecules in the blood, which preferentially bind with CO over oxygen.

COPD – Chronic Obstructive Pulmonary Disease. COPD is a disease where the airflow is limited due to chronic disease such as bronchitis or emphysema.

CRA – Comparative Risk Assessment. A CRA examines the health outcomes associated with risk factors taking into account exposure prevalence to determine the attributable burden of ill health.

DALY – Disability Adjusted Life Year. DALYs measure the years of healthy life lost to both premature mortality and morbidity.

DME – Dimethyl ether. DME is a gas at ambient conditions but can be compressed and used as a fuel for both residential and mobile applications.

ESD – the journal, Energy for Sustainable Development.

ESMAP – Energy Sector Management Assistance Program. ESMAP is a program sponsored jointly by the World Bank and UNDP to provide technical assistance for environmentally responsible growth.

GHG – Greenhouse Gas. GHGs are those that impact the earth’s radiation balance. Anthropogenic GHGs which strong global warming potential include carbon dioxide and methane.

GNP – Gross National Product. The GNP is the gross domestic product plus the income accrued to residents from investments abroad minus the income accrued to non-residents from domestic investments.

GWC – Global Warming Commitment. GWC is a metric combining the total emissions of a source and the global warming potential of each pollutant.

GWP – Global Warming Potential. GWP describes the radiative forcing of a compound relative to a reference compound and includes both the strength of impact and the atmospheric persistence.

HDI – Human Development Index. The HDI is a measure meant to quantify and rank countries based on achievements life expectancy, literacy, and standard of living.

HIV/AIDS – Human Immunodeficiency Virus/Acquired Immunodeficiency Syndrome. HIV is a virus that results in gradual deterioration of the immune system. AIDS is the most severe manifestation of HIV where immune function is sufficiently depressed to allow introduction of opportunistic infections.

HSF – Household Solid Fuel. Solid fuels, including biomass and coal, used to meet household energy needs.
IAP – Indoor Air Pollution. IAP is pollution emitted to the indoor environment from sources in that environment.

IEA – International Energy Agency. IEA is an intergovernmental body committed to advancing security of energy supply, economic growth and environmental sustainability through energy policy co-operation.

ITDG – Intermediate Technology Development Group. ITDG is an international NGO, based in the UK, and working in the household energy field (ITDG has recently changed its name to "Practical Action").

LPG or LP Gas – Liquefied Petroleum Gas. LPG is a mixture of propane and butane, which is liquid when moderately compressed and gaseous when the pressure is reduced, and can be combusted for usable energy generation.

Meta-analysis – A statistical technique to combine the results of many studies of the same relationship, for example air pollution and a particular disease, to derive an overall quantitative estimate.

MDG – Millennium Development Goals. The MDGs are 8 goals that UN member states have pledged to meet by 2015. These goals focus on health, environment, equality, poverty eradication and global partnerships.

MJ – Megajoule. A MJ is a unit of energy equivalent to 1 million joules.

NISP – Chinese National Improved Stove Project. A program in China between 1981 and 1995 aimed at introducing stoves with increased energy efficiency and designed to be used with biomass fuels.

PIC – Products of Incomplete Combustion. When fuel is completely combusted, all carbon and hydrogen in the fuel will be released as carbon dioxide and water. When combustion is not complete, intermediate carbonaceous compounds are released; these intermediate compounds are PICs.

PM – Particulate Matter. PMs are microscopic particles in the air. They are the result of natural forces and human activities and are grouped into two size ranges (in micrometers): PM_{2.5} and PM_{10}. The smaller can penetrate deep into the lungs whereas the "coarser" PMs (from 2.5 to 10 micrometers in diameter) don’t generally penetrate deeper than the upper respiratory system.

TNMOC – Total Non-Methane Organic Carbon

UNDP – United Nations Development Program. UNDP is a United Nations agency working to ensure countries have the resources necessary for meeting global development goals.

UNEP – United Nations Environment Program. UNEP is the United Nations agency working towards environmental care and conservation in all nations.

USEPA – United States Environmental Protection Agency. The USEPA was established by the US Congress to protect human health and the environment.


UVCE – Unconfined Vapor Cloud Explosion. Explosions resulting from release of large quantities of gas that are subsequently ignited.

WHO – World Health Organization. WHO is an agency of the United Nations that focuses on worldwide attainment of health by all people.

WLPGA – World LP Gas Association. WLPGA is a non-profit business association that represents the global LP Gas industry, with the mission to promote the use of LP Gas as a clean, all-purpose and efficient fuel.
14 References


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