WLPGA

Cooking with gas: How children in the developing world benefit from switching to LPG

Report developed for the World LPG Association
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GLOBAL ALLIANCE FOR CLEAN COOKSTOVES

Contents

Executive summary

"Energy is the golden thread that connects economic growth, increased social equity, and an environment that allows the world to thrive."

Secretary-General of the United Nations, Ban Ki-moon

The survival of three billion people, or close to half of the world's population (41%), depends on cooking with polluting solid fuels (e.g. wood, dung, crop waste, coal, and charcoal) and kerosene. It is primarily poor rural women and their children who are exposed to high levels of household air pollution (HAP) as a result of cooking with these inefficient fuels.[2] The intention of this report is to raise awareness about the health benefits for children when transitioning from cooking with solid fuels to liquefied petroleum gas (LPG), a clean cooking fuel.

In 2012, 4.3 million premature deaths were attributed to exposure to HAP, equivalent to one person dying every eight minutes. Thirteen percent, or over 500,000 of these deaths, were among children under five years of age.[3] When comparing the burden of death or disability from exposure to HAP to all other global risk factors (e.g. poor nutrition, lack of vaccination), HAP accounts for about 5% of lost healthy life years.[4]

Section 1: Access to clean cookstove technologies and fuels: Understanding the magnitude of the problem

Despite intense efforts over several decades to transition to cleaner burning solid fuel stoves, very few stoves have reduced HAP sufficiently to protect children's health. Electric, solar and clean-burning gas stoves (piped natural gas, LPG, and ethanol/methanol gas) have the potential to lower disease burden, but piped natural gas is not available in many areas. In addition, electric stoves are not yet a viable option in regions with unreliable electrical power.[5-7] Even if a wood-burning cookstove is efficient at venting indoor air pollution to the outdoors, the problem of community-level air pollution persists. Sixteen percent of the global burden of disease from ambient air pollution is attributed to household pollutants released to outdoor air.[4]

The overarching principle of the 2014 World Health Organization (WHO) guidelines on indoor air quality is that there is no "acceptable" level of air pollution, and even the lowest levels of air pollution are harmful to human health. Cleaner burning solid fuel cookstoves cannot achieve the WHO annual intermittent air quality target-1 (AQT-1) for particulate matter, set at 35 μg/m^3 for $PM_{2.5}$ (particulate matter less than 2.5 microns in aerodynamic diameter). Although testing results from a variety of clean fuel stoves are still ongoing, most LPG, ethanol and methanol, and solar stoves will most likely achieve the WHO's air quality targets. In order to reach the AQT-1 for $PM_{2.5}$ in areas with persistent high background levels of $PM_{2.5}$, where HAP contributes to outdoor (ambient) air pollution, community-level adoption of clean cooking technologies is essential.[8,9]

Section 2: Clean cookstoves and fuels: A key issue for children's health

HAP is especially harmful to children, who breathe more air relative to their body size. Small infants and young girls are at higher risk of exposure to HAP because they spend time with their mothers in the kitchen. Small infants are especially susceptible to the effects of pollutants released by solid fuels because their respiratory and immune systems are developing, which may lead to irreversible lung damage and increased respiratory infections, like pneumonia. There is good evidence of the link between children's exposure to solid fuels and pneumonia; many studies have looked at the relationship between the two[10-12]. Several studies in the past decade found that infants born to mothers exposed to solid fuels during pregnancy had higher rates of low birth weight, still birth and preterm birth[12-14]. Very few studies have examined the impact of HAP on other child outcomes, such as neural tube defects, cleft lip, impaired cognitive function, otitis media, and asthma. In addition to exposure to HAP, children are at increased risk of being burned as many of the rudimentary solid fuel stoves are located on or close to the floor near where they may play.

Solid fuels used for cooking generate copious amounts of kitchen smoke. Contaminants in the solid fuel smoke include carcinogens, such as benzene, formaldehyde, and naphthalene, as well as carbon monoxide (CO) and particulate matter (PM). In low-income countries, children's exposure to HAP is extremely high. In India, the levels of PM that children are exposed to are on average ten times higher than levels known to cause harm to health[3]. Approximately half a million deaths among children under five are from acute lower respiratory infections attributed to HAP[3]. Many of those children are the poorest of the poor, residing in rural areas with limited access to health care. Reducing exposure to HAP through the provision of clean fuel stoves during pregnancy is a promising intervention for improving child survival because it may prevent a substantial proportion of low birth weight, preterm birth and neonatal pneumonia. Few studies have compared the health benefits for children when transitioning from solid fuels used for cooking to truly clean cookstove technologies, such as liquid fuels or electricity. Three studies are being conducted in Nepal, Ghana, and Nigeria, highlighted in this report, are looking at the impact of clean liquid fuels on adverse pregnancy outcomes and child pneumonia.

Section 3: The impact of clean cookstove and fuel transition on women and girls' education and economic development

Clean cookstoves have been identified as one of the four key domains for global investment with a particularly strong potential to transform the lives of girls and women. Girls and young women who cook over fuel-efficient stoves will spend less time gathering fuel and cooking food, which gives them more time to pursue educational and work opportunities. Families are often required to contribute firewood to schools for the lunchtime meal. In some cases, if families are unable to provide wood, their children may be excluded from participating in class. The ability for girls to attend school is directly related to women's decision-making roles and empowerment in the household where these children reside. Empowering women to prioritise girls' education leads to positive outcomes that reach across generations.

Section 4: The barriers and enablers of the clean cookstove and fuel transition

Switching to clean cooking practices and behaviors is dependent on a complex set of barriers and enablers affecting stove acceptance, initial adoption and sustained use. To ensure successful adoption and sustained use of clean cookstoves, it is important to weaken the barriers and strengthen the enablers to clean cookstove use.

Solid fuels are often referred to as "traditional fuels" because they have been used for millennia by humans and fuel preferences are often culturally embedded, which leads to increased resistance to change. Solid fuel stoves are thus "well accepted," and displacing the solid fuel stove in favor of a cleaner stove may be met with a set of challenges. New cooking technologies, such as LPG stoves, require training and education around stove and fuel use, which can be daunting to new adopters. Even if initially adopted, clean fuel stoves, such as LPG, may not meet all of the cooking and heating needs at the household level. Families may continue to use solid fuel stoves, in addition to the clean fuel stoves, a common household behavior referred to as "stove-stacking." Sustained use of the clean stove is dependent on the degree to which the clean stove permanently displaces the traditional stove.

An important aspect of sustained adoption of the clean cookstove is fuel availability. For solid fuel users, there is usually no, or low, financial cost if households are able to gather their own firewood. However, many fuel gatherers, usually women and young girls, experience substantial time and health costs from carrying heavy loads of wood to the home. In many areas of the world, people pay for harvested firewood, which can be as expensive as modern fuels like LPG.

The most commonly cited barriers to sustained use of the LPG stove include tank availability, fluctuating fuel prices, food preparation and taste preferences and safety concerns. The level of adoption and sustained use of gas stoves under real-life conditions is currently being explored in several research studies concerned with improving child survival. Several of these studies are presented here.

Section 5: Policy recommendations for incentivising the clean cookstove transition

To incentivise the full adoption of LPG for cooking, strategies such as generating demand for LPG stoves, strengthening the supply-chain of LPG stoves and fuel, and developing regulation mechanisms to ensure safety of LPG are essential. Creating a supportive infrastructure for operating, inspecting and maintaining LPG and other clean stove technologies are necessary during the transitional period. Fully displacing the use of traditional cookstoves and open fires is a considerable challenge, especially for the poorest of poor who ration their earnings on a daily basis and usually do not have money left over for large household purchases. Policymakers in the energy, health, and environment sectors need to advance strategies to increase affordable and accessible clean cookstoves and fuels for the poorest sectors–those who pay the highest cost for fuel, relative to their income, use the lowest quality stove, and experience the highest costs of poverty in terms of poor health.

If girls and women are released from fuelwood collection, they will be less exposed to the additional risk of physical and sexual violence when scavenging for firewood. Girls and young women who cook over fuel-efficient stoves will spend less time gathering fuel and cooking food, which gives them more time to pursue educational and work opportunities.

Summary

If a concerted effort is made globally to improve access to clean cookstoves, between 600,000 and 1.8 million annual premature deaths from HAP may be averted. Clean fuel stoves include LPG, ethanol, methanol, natural and biogas stoves, solar stoves and electric stoves. When fully adopted, the transition to these stoves can dramatically reduce household air pollution[15]. LPG is currently the most viable fuel option for 15% of the world population that lacks electricity[16]. One of the goals of the WLPGA is to transition one billion people from solid fuels to LPG by 2030. Developing markets for affordable and accessible LPG (and other kinds of clean-burning gas, such as biogas and natural gas) for people at the lower end of the energy ladder needs to be prioritised[8]. In order to make this happen, new partnerships between petroleum, gas and power industries, government energy ministries, NGOs, other micro-institutions, and academia must be developed.

Abundant, clean energy access can have direct health benefits—healthy infants with normal birth weights when mothers are exposed to less HAP, fewer episodes of acute lower respiratory infections when children breathe cleaner air, and reduced rates of diarrhea when children consume boiled water. Other direct benefits of switching to clean cookstoves include safety and efficiency. If girls and women are released from fuelwood collection, they will be less exposed to the additional risk of physical and sexual violence when scavenging for firewood. Girls and young women who cook over fuel-efficient stoves will spend less time gathering fuel and cooking food, which gives them more time to pursue educational and work opportunities.

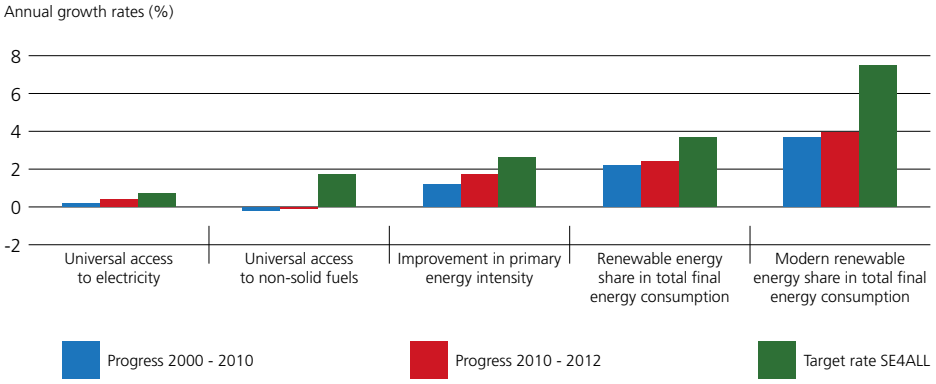
Section 1

Access to clean cookstove technologies and fuels: Understanding the magnitude of the problem

Efforts to cover the world with clean cookstoves

The Sustainable Energy for All (SE4All) initiative was launched by the UN Secretary General in 2011. SE4All is a partnership between governments, private industry, and civil society, which aims to achieve three objectives by 2030: 1) develop universal coverage of modern energy services; 2) double the rate of improvement in energy efficiency; and 3) double the share of renewable energy in the global energy sector. Unfortunately, universal access to clean cooking fuels decreased by 0.1% between 2000 and 2010. This is 1.7% short of the target annual increase to reach universal access to clean fuels by 2030 (**Figure 1**). In absolute numbers, between 2010 and 2012, only 125 million people, mostly in urban areas, gained access to clean cooking fuels and an overall population growth of 138 million people outstripped this gain. In 2012, an estimated ten million dollars was spent on worldwide access to clean cooking energy. Over four billion dollars would need to be invested in this sector to provide universal access by 2030.[16] Understandably, efforts to scale-up in regions that will most benefit from this transition must be strengthened. This scale-up should be focused on concentrating "off the grid" solutions in rural areas with poor electric and piped natural gas supply.

Figure 1: Progress needed to meet the Sustainable Energy for All (SE4All) objectives



Source: World Bank Global Electrification database 2015; IEA, UN and WDI data (2014); analysis by the International Renewable Energy Agency based on IRENA (2014).

Note: Figure shows average annual growth rates for access to electricity and non-solid fuels and compound annual growth rates for renewable energy and energy efficiency.

WHO guidelines for indoor air quality: household fuel combustion

The recently released *WHO guidelines for indoor air quality: household fuel combustion*[9] provides policymakers, researchers, and stove implementers with comprehensive evidence about the importance of assisting households to rapidly adopt clean cookstoves. Not only is adoption of new cookstove technologies important, ongoing efforts must be made to support the sustained use of these cookstoves. The overarching principle behind the WHO guidelines is that there is no "acceptable" level of air pollution, and even the lowest levels of air pollution are harmful to human health. However, in low- and middle-income countries where both outdoor and indoor concentrations are high, the WHO established incremental target levels that were viewed as achievable in these high-exposure areas[17].

Unfortunately, many "clean" cookstoves that use solid fuels cannot ever achieve WHO's least stringent annual intermittent air quality target-1 (AQT-1) of 35 μg/m^3 for $PM_{2.5}$ (particulate matter less than 2.5 microns in aerodynamic diameter). Many stoves, if they achieve that target upon initial adoption, will fail to sustain safe levels over time as the stove deteriorates or is modified by the stove user (see **Figure 2**).

Figure 2 shows a deteriorated plancha stove in rural Guatemala. The stove is missing the chimney and the door at the front of the stove where wood is inserted into the fire. Large pots are cooked over the open fire (to the left) due to concerns that the metal stove surface will crack under the weight of the pot.

In order to systematise claims that a new stove is "clean", the Global Alliance for Clean Cookstoves convened a workshop in 2012 to create interim guidelines for stove performance that resulted in unanimous support among meeting participants. A consensus-based International Workshop Agreement (referred to as IWA 11:2012, published by the International Organization for Standardization[18]) was developed to create objective, performance-based standards for clean cooking technologies. These interim international guidelines are organised into five tiers (0, the lowest performing, four the highest), based on four factors: stove safety, fuel efficiency, total emissions, and indoor emissions. Stoves are tested independently using standard protocols (e.g. water boiling test and emissions tests), which are meant to be flexible for different stoves and performance indicators. Many stove manufacturers are testing their stoves according to these guidelines and are registering stove performance in the Global Alliance for Clean Cookstoves' Clean Cooking Catalog[19]. The next iteration of the Catalog in the autumn of 2015 will also have a more robust framework to allow fuel manufacturers to register their products and test results.

Stoves that meet Tier Four for indoor emissions are the only stoves that can achieve the WHO intermittent air quality target-1 (AQT-1) for $PM_{2.5}$, but meeting emission levels are not the only acceptable metrics of performance. There are a combination of environmental, health, and livelihood goals, as well as different goals for affordability and scale. The tiers provide a flexible framework to evaluate the likelihood of technologies to achieve these goals.

To illustrate the importance of displacing an inefficient cookstove with a clean cookstove, kitchen concentrations of $PM_{2.5}$ over 24 hours will rise above the AQT-1 after one hour of open fire (wood) use, or after three hours of charcoal stove use. Ventilation in the kitchen plays an important role, and homes at high altitude or in cold climates tend to have kitchens with poorer ventilation. Only under the conditions of excellent ventilation can a Tier Three stove meet the AQT-1 for $PM_{2.5}$.[20] Most LPG, ethanol and methanol, and all solar and electric stoves are low emitters of air pollutants, and will likely be classified as Tier Three or Four stoves, although testing results from a variety of clean fuel stoves are still ongoing.

Figure 3: Twenty-four-hour mean kitchen concentrations versus ventilation rate for different indoor emission performance levels

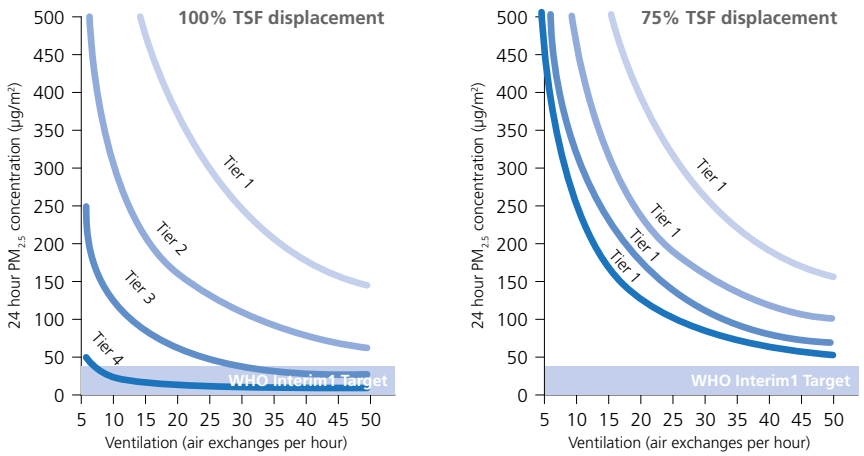


Figure 3 shows the modeling of the effect of 100% versus 75% displacement of the three stone fire by a clean cookstove. Kitchen concentrations of PM2.5 not only change based on the Tier performance level, but also based on kitchen ventilation. This figure shows that the Tier Four stove must be exclusively used.

Source: Johnson and Chiang, 2015.

Contribution of HAP to ambient air pollution: Need for community-wide adoption of LPG [20]

Displacing an open fire with a chimney stove that burns solid fuels simply moves the smoke from inside to outside the home. This can have profound effects on outdoor, or ambient, air pollution; in some parts of the globe, cookstoves contribute to an estimated 37% of ambient PM[21]. At the household level, replacing a wood stove with an LPG stove would reduce exposure inside the home considerably, but not completely. Nearby neighbours who continue to use solid fuels generate substantial air pollution that seeps out of roof rafters and chimneys, increasing air pollution in local environs. "It takes a village" is an essential element in realising the health benefits from clean cookstove adoption[8]. Community-level adoption may be the only way to reach the AQT-1 for $PM_{2.5}$ in areas with persistently high background levels of $PM_{2.5}$. Benefits of community-wide efforts to adopt clean cooking technologies reach beyond the community; soot particles are emitted by inefficient stoves. These combustion byproducts have been shown to be powerful climate change pollutants[22].

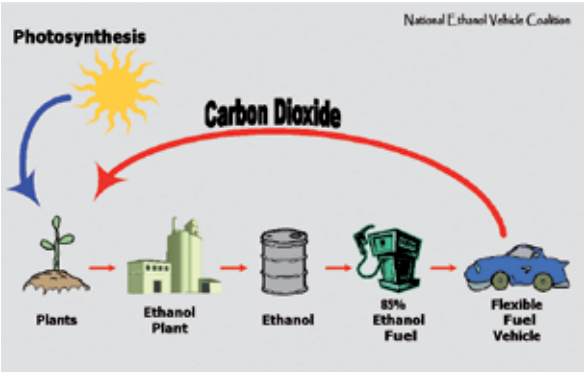
Emission profile: LPG, kerosene, biogas, ethanol, electric and solar stoves

When measuring health effects, solid fuels are often compared to clean fuels, typically liquid fuels and/or electricity. Electric stoves are the cleanest cooking technology, with zero emissions into the kitchen space. Solar stoves, although less commonly used than electricity, are zero emission stoves. LPG stoves emit carbon dioxide and water, but have few other toxic emissions. Several older studies placed kerosene (paraffin) in the clean fuel category, but recent evidence has shown that kerosene exerts toxic effects on respiratory health, and hence should be classified as a "dirty fuel".[23]

LPG is an easily transportable clean-burning fuel that consists of butane or propane or a mixture of the two gases obtained from crude oil during petroleum refining or from the processing natural gas. LPG is stored as a liquid in pressurised cylinders and subsequently transported. It is burned in gas stoves and is cleaner than either solid fuels or kerosene as it burns easily and combusts completely, producing carbon dioxide and water and few other toxic emissions. Although LPG is currently the most viable clean cooking fuel in most areas of the world, it is a non-renewable fossil fuel and therefore its long-term sustainability has been called into question.

Kerosene is a liquid fuel that is used in wick lamps for lighting and is poured into stoves for cooking. It is often stored in containers that can be mistaken for beverages, putting children at risk for poisoning. Kerosene combustion emits many health-damaging pollutants, including PM, CO, nitric oxides (NOx), sulfur dioxide (SO_2), polycyclic aromatic hydrocarbons and volatile organic compounds, sometimes at higher concentrations than solid fuel stoves. Kerosene stoves emit PM that is two to four times higher than LPG stoves and increases indoor concentrations of toxic air pollutants in both laboratory and field studies[23].

Biogas is a methane-rich fuel produced from the anaerobic digestion of organic material, such as animal waste. Digestion requires water and relatively high temperatures, making biogas suitable for hotter regions; family-sized biogas installations have already been promoted in Southeast Asia. The two components of a biogas device are the digester and the gas holder. The main disadvantages of biogas are the cost and technical expertise required to install and maintain the system. Furthermore, to provide enough energy for one household the dung of at least two to three cows and copious amounts of water are needed. The main advantages to using biogas are that it is one of the cleanest burning fuels and a byproduct of digestion is rich fertilizer which can be used for agricultural purposes.



Ethanol The production of ethanol through the fermentation of sugar-rich crops, such as sugarcane and corn, has been done over many centuries for alcoholic drink consumption, but in recent years, ethanol is being used to fuel vehicles and cookstoves. Brazil and the USA are the leading producers of ethanol fuel. The processing of this renewable fuel has become increasingly efficient in recent years, but its production is complex and requires high inputs of energy

and fresh water. The large-scale, modern agricultural processes used to produce crops for ethanol production result in soil erosion, wasteful use of water and soil pollution from the use of pesticides. Ethanol has been shown to reduce emissions of carbon monoxide, particulate matter and nitrous oxides, when compared to gasoline and diesel or biodiesel. However higher levels of ground-level ozone have been reported with the use of ethanol. Switching to ethanol reduces dependency on non-renewable fossil fuels; however costs of conversion from a petrol-based economy are high[24].

Electricity Over one billion people do not have electricity, and when electricity is available in energy-poor parts of the world, including rural areas, supply is often intermittent, with frequent power outages and limited household voltage for high-powered electric appliances25. Connection and monthly costs constrain the poorest from accessing electricity. If poor households do have electricity, they use it for lighting, charging cell phones, or small appliances like electric tea kettles and rice steamers. Rarely is an electric stove used for cooking entire meals. Electric induction cookers are popular in China, and gaining popularity in India and Ecuador (see case study). These cookers do not use high levels of electricity and have lower cooking times.

Solar cookers use the sun's energy to cook food and pasteurise water and come in many different sizes and forms, ranging from individual stoves to cooking capacity for hundreds of people. The main classes of cookers are: the solar oven, parabolic cooker and panel-based cooker. While local women can be trained to build their own cookers, durability comes at a cost. Main advantages include: zero emissions and fuel cost as well as the ability to leave food cooking unattended. On the other hand, switching over to solar implies significant behavior change with respect to cooking practices; solar cookers must be constantly repositioned relative to the sun and food texture and taste are very different. Solar cookers are promising companions to LPG stoves and other clean stoves[26],[27].

Television ad promoting induction cookers. Caption states, "Do you want to receive up to 80 kilowatts free each month?"

Case study: Electric induction cookers in Ecuador

In Ecuador, the Minister of Electricity and Renewable Energy is encouraging citizens to switch from gas stoves to electric induction stoves in order to reduce consumption of government-subsidised imported LPG. To make the transition affordable, the government is replacing LPG stoves with electric induction stoves. Electric induction stoves are more efficient than gas stoves because they transfer all of the heat from the stove to the pot. To incentivise use of these stoves, the government is giving new customers 80 kilowatts of free energy each month. Ecuadorian companies are manufacturing these stoves at a cost of about US$250. To keep up with the increasing demand, China, a major manufacturer and promoter of induction stoves, has agreed to supply Ecuador with 500,000 electric induction stoves.

Section 2

Clean cookstoves: A key issue for children's health

Of all the energy-related household activities, exposure to solid fuel cooking smoke exerts the largest health impact on children[2]. Every year, six million children younger than five years of age die around the world; household air pollution from cooking fires contributes substantially to these deaths, including 534,000 deaths caused by pneumonia[28]. In 2010, HAP was found to be the third leading risk factor for death and disability in children under five following the leading risk factors of being underweight and suboptimal breastfeeding. In terms of global disability adjusted life years (DALYs), a standard metric that includes both premature death and chronic disability, 12.4% of DALYs were attributed to being underweight, 7.6% to suboptimal breastfeeding, and 6% to HAP from solid fuels[4].

Solid fuels used for cooking generate copious amounts of kitchen smoke. Contaminants in solid fuel smoke include carcinogens such as benzene, formaldehyde, and naphthalene, as well as carbon monoxide (CO) and particulate matter (PM). In resource-poor countries, children's exposure to HAP is extremely high. In India, where nearly a fifth of the world's children under five years of age live, children are exposed to PM levels that are on average ten times higher than levels known to cause harm to health[3]. Many of those children are the poorest of the poor, living in rural areas with low access to health care.

There are many reasons why infants and small children are more vulnerable to HAP. Small children breathe more air relative to their body size compared to adults, have immature respiratory and immune systems, are often carried on their mothers' backs during cooking, and spend more time playing in the kitchen. Young girls help their mothers with cooking tasks, such as fueling or fanning the fire. In addition to exposure to toxic air pollution, children are at increased risk of being burned by solid fuel stoves placed close to or on the ground.

Dozens of studies have looked at children's exposure to HAP and resultant pneumonia, and have found a substantial link between the two. Pregnant women who are exposed to solid fuel smoke during pregnancy are more likely to have preterm infants or infants with low birth weight. Stillbirth and child mortality have been evaluated in a handful of studies, and have been associated with the use of solid fuel stoves in the home. Very few studies have examined the impact of HAP on other child outcomes, such as neural tube defects, cleft lip, impaired cognitive function, otitis media, and asthma. Since studies have found these outcomes to be associated with ambient air pollution and/or tobacco smoke, it is not implausible that these could also be related to HAP, which contains many of the same toxic substances as ambient air pollution and tobacco smoke. Few studies have compared the health benefits for children when transitioning from solid fuels used for cooking to truly clean cookstove technologies, such as liquid fuels or electricity. Highlighted below are three ongoing randomized stove intervention studies in Ghana, Nigeria and Nepal that are assessing the effect of clean cooking fuels, specifically LPG and ethanol, on preterm birth, child health and survival.

Child mortality

Neonatal mortality

In 2013, 2.9 million infant deaths occurred in the first 28 days of life. Forty-four percent of total deaths in children less than five years of age occur during the first month of life, indicating the critical importance of reducing newborn deaths. An estimated 100,000 newborn deaths are from HAP-related pneumonia[4]. This number is an underestimate of the global burden from HAP because it does not include deaths among preterm and low birth weight infants born to mothers who cook over polluting stoves during pregnancy.

In a meta-analysis of five studies, pooled together to estimate all-cause mortality for children under five, mortality increased by 27% in children exposed to HAP from solid fuels compared to those exposed to clean fuels[12]. However, the intensity of exposure, and vulnerability of children to these exposures, may be very different depending on the age of the child (see case studies of postpartum practices in Section 3). For example, data from a 2013 Nigeria Demographic and Health Survey showed that younger infants were more heavily impacted by HAP—43% of infant

deaths between one month and one year, compared to 36% of infants between one and five years, were attributed to solid fuel exposure, after controlling for other factors that influence child mortality[29].

In an attempt to look at the effects of solid fuels and kerosene independently against clean fuels, Kleimola et al. (2015) used Demographic and Health Surveys from 47 countries. The authors found that the adjusted risk for neonatal (0-28 days) mortality was 24% higher in solid fuel homes and 34% higher in kerosene homes. Child mortality (29 days to 59 months) was 21% higher in households using solid fuels and 12% higher in kerosene-using homes. Given their findings, the authors pointed out that kerosene should not be aggregated into the "clean fuel" category when analysing the effects of solid fuels. They also concluded that kerosene use during the newborn period was strongly linked to mortality[30]. This conclusion was not born out in another survey-based study that examined kerosene use and neonatal mortality using India's National Family Health Survey. However, study findings are limited because the authors did not look at the use of multiple fuels and stoves, which would lead to exposure misclassification in homes that practice "stove-stacking"[31].

In rural Ecuador, to assess how infant mortality has changed over time at the household level, twenty households were selected based on stove type (LPG only, primarily LPG with some solid fuel use, primarily solid fuel with some LPG use, and solid fuel only). In this area of high infant mortality (29%), households using solid fuel were two times more likely to have had a child die in the first year of life than households using LPG, after controlling for important confounders such as socioeconomic status, mother's education, smoking among household members, and number of people living in the household[32].

Acute lower respiratory infections (ALRI)

ALRI comprises pneumonia, bronchitis, and bronchiolitis, and is the world's largest killer of children. ALRI is estimated to cause almost one million deaths annually in children under the age of five.[33] Solid fuels used for cooking release large amounts of toxic air pollutants; including PM. Inhaling particulate matter from these fires increases children's inability to fight the viral and bacterial infections that cause ALRI. It is not surprising, then, that the most widely studied health risk to children from exposure to HAP is ALRI, specifically pneumonia. More than 50% of premature deaths among children under five are due to pneumonia caused by PM from HAP.

To date, the RESPIRE study in rural Guatemala is the only randomised control trial on HAP and child ALRI. Among 534 children ≤18 months randomised to receive a wood-fueled chimney stove, exposure was reduced by 50% compared to children who lived in households using the traditional three-stone fire. In an intention-to-treat analysis, the relative risk of ALRI decreased by 22% among children in the chimney stove group for physician-diagnosed pneumonia and by 33% for severe pneumonia, as measured by low oxygen saturation. This study demonstrated that reducing HAP levels significantly reduced severe ALRI[11]. One of the key findings was that even though the chimney stove reduced child exposure by 50%, many of the households with chimney stoves continued to be exposed to other cooking fires in or near the home, leading to substantial overlap of exposure between the two groups. These findings point to the need to reinforce messages to avoid smoke from other cooking and heating sources and to consistently use clean cookstoves when measuring the impact of stove adoption.

Dozens of individual research studies conducted in low-resource countries have looked at the association between child ALRI and HAP. Two meta-analysis papers in 2008 and 2013 reviewed the most consistent studies to assess the overall effect of the impact of solid fuel smoke on children's pneumonia. Pooled results from 27 studies showed that children in households using solid fuels were 78% more likely to get pneumonia compared to those in homes using "cleaner" fuels, a mix of fuels which included kerosene[34]. An updated meta-analysis by Bruce (2013) found that when excluding kerosene from the "clean" group, young children were 66% more likely to get ALRI if they were exposed to solid fuel.[12]

Although many of the studies included in the meta-analyses looked at contrasts in exposure between solid fuels and cleaner fuels, like gas and electricity, some studies included kerosene in the clean fuel group, and other studies included both gas and electricity into the clean fuel group. A recent study of 600 households in India directly compared respiratory symptoms among kerosene and LPG users. Children living in a household cooking with

kerosene were almost twice as likely to develop bronchitis compared to children in LPG households. Kerosene was associated with cough and wheezing in children, although findings were not statistically significant[35].

Several studies in middle- to high-income countries looked at the association between gas cookstoves and childhood respiratory health. In these settings, electric cookstoves are typically the "clean" comparison group. A study of over 2,000 infants in Spain found no relationship between infant ALRI and women's use of gas stoves (natural, butane, or propane)[36] . Improper ventilation of gas cookstoves may also increase the risk of children's respiratory symptoms. One large study of over 3,000 children under the age of five found that unventilated gas stoves used for heating homes in the United States were associated with child pneumonia and coughing[37]. Ventilation then becomes an important factor, not only for solid fuel stoves, but also for gas stoves.

Increased maternal exposures during pregnancy and impact on newborns

Harm from air pollutants starts as early as the first trimester of pregnancy. Studies have found that active tobacco smoking, exposure to secondhand smoke, and exposure to traffic pollution are significant risk factors for adverse infant outcomes, including stillbirth, preterm birth, low birth weight, neural tube defects, cleft lip, and neurocognitive impairments. HAP from cooking fires is a significantly higher source of air pollutant exposure than secondhand smoke and ambient air pollution. Cooking smoke contains many of the same pollutants as tobacco smoke, except nicotine[38]. Reducing HAP exposures should begin even before pregnancy, since many women in low-resource countries do not have access to health care, if they do at all, until after they have completed the first trimester. Only a handful of published studies have looked at the impact of HAP on adverse infant outcomes, as described below[12].

Stillbirths

Stillbirth is defined as a fetal death after twenty weeks of gestation. Stillbirth is a relatively rare event, and identifying stillbirths in areas where many women deliver at home is difficult. To achieve an adequate sample size, several studies examining stillbirth have used large national survey data; however, these data are fraught with problems of misclassification of stove and fuel use as well as maternal self-report of stillbirth, which may lead to problems with accurate recall.

Five studies on stillbirth were examined in a recent meta-analysis. Of these five studies, four found a statistically significant effect, with a 29% greater likelihood of stillbirth if the household where the pregnant women lived used solid cooking fuels[39]. The earliest study was conducted in India in 1991[40], and the most recent study was conducted in 2013[41]. The latter study, which included Indian national data on over 188,000 stillbirths, was able to examine a "kerosene effect," which increased the chance of stillbirth by 36%. In this study, wood stove users had a 24% increased chance of stillbirth compared to households using LPG or electric stoves. Wylie et al. (2014) found a higher rate of stillbirth among wood and kerosene users compared to gas users in India, although the findings were not statistically significant[42].

Preterm birth

Globally, preterm birth, defined as a birth before 37 weeks of gestation, is the second leading cause of death among children after pneumonia[43]. Preterm birth is a significant cause of long-term morbidity because infants born too early suffer from breathing, feeding, vision, and developmental problems that can persist for life. Offering clean fuel stoves during pregnancy can be a vital step to reducing preterm birth and subsequent childhood diseases like pneumonia.

Three studies on preterm birth were examined in a recent meta-analysis[44-46]. All of the three studies determined gestational age using last menstrual period, a notoriously unreliable method in areas where women have low levels of numeracy and literacy. While ultrasounds are the most reliable method of dating an early pregnancy, they are often unavailable for poor women. These three studies yielded a 30% greater likelihood of preterm birth among solid fuel users[39].

Low birth weight

Thirteen studies to date have looked at the impact of HAP on newborn birth weight[31,39,41,42,44-52]. Three separate review studies pooled data to measure an overall effect of HAP on newborn birth weight[12-14]. Two of these meta-analysis studies found that exposure to solid fuel smoke reduced newborn birth weight between 86 and 95 grams[13,14.] Both of these estimates fall within the range of active smoking (100-200 gram lower birth weight) and secondhand smoke (10-100 gram lower birth weight). Tobacco is a commonly known toxic substance that definitively causes harm to the developing fetus, and most of the pollutants in cigarettes are also present in wood smoke, except nicotine[38]. All three of the pooled studies were consistent in determining that use of solid fuel during pregnancy increased the likelihood of having a low birth weight infant (defined as birth weight < 2,500 grams) by between 35 and 40%.

Several studies have attempted to measure the impact of maternal exposure to different fuel types on low birth weight. Using over 14,000 births registered in India's National Family Health Survey (NFHS-3), study authors assessed the independent effects of "dirty fuels" on low birth weight and found that each of these dirty fuels significantly decreased mean birth weight: -110 grams for coal; -107 grams for kerosene; and -78 grams for solid fuels compared to gas fuels, even after accounting for socioeconomic factors that could explain low birth weight[31]. In another large Indian study with over 1,500 participants, birth weight was examined between infants in wood stove homes and infants in gas homes. Because women who use gas are likely to be economically better-off than those who use wood, the authors of the study adjusted for dozens of potential factors that were related to poverty using a propensity score[42]. In this analysis, there was no difference in birth weight between the two groups, which suggests that unmeasured factors related to the fuel use are not accounted for in large survey studies.

Randomised stove intervention studies are being conducted in Nepal, Ghana, and Nigeria to assess the links between the use of LPG and ethanol stoves during pregnancy and reduced preterm delivery and low birth weight (see case studies below for description). If these studies prove to be conclusive, then future global burden of disease estimates should include HAP as a risk factor for preterm birth.

Despite the fact that there are consistent estimates showing that solid fuel use contributes to adverse newborn outcomes, none of the studies that examined stillbirth, preterm birth, or low birth weight included measures of maternal exposure to HAP. Instead, they relied on maternal report of stove and fuel use. Given the common use of multiple stoves in a single home for different cooking tasks, and the changes in maternal behavior during pregnancy that may increase or decrease exposure to HAP, the relationship between actual levels of HAP and birth weight is still unknown.

Impaired cognitive development

Carbon monoxide (CO) is a potent air pollutant that can cross the placenta and gain access to the fetus, impacting the developing brain. Inhaled CO binds with both maternal and fetal hemoglobin, preventing the transfer of oxygen to the fetus, which can result in potentially adverse fetal/neonatal outcomes. Even low exposures to CO can significantly reduce the oxygen carrying capacity in the bloodstream[53].

Only one study to date has evaluated the relationship between neurocognitive development in children and chronic, early exposures to solid fuel smoke. This study was conducted with children aged five to seven years who participated in the RESPIRE cohort. Children whose mothers had higher exposures to CO during the third trimester of pregnancy had poorer short-term memory recall, long-term memory recall, fine motor performance, and visuospatial processing[54]. Although this was a small study of only 39 children, the personal exposure assessment during pregnancy was rigorous[11].

A 2012 Spanish study evaluated the use of gas cooking during pregnancy on children's neurodevelopment. Among 1,800 children, exposure to gas stoves was associated with slightly lower mental development scores compared to children whose mothers used electric stoves for cooking; scores were even lower when mothers didn't use extraction fans while cooking[55]. An earlier Spanish study with almost 400 children found that increased exposure to nitrogen dioxide from gas stoves before four years of age was associated with decreased cognitive function in children[56].

Case Studies in Ghana, Nigeria and Nepal

Few studies to date have evaluated the sole use of LPG stoves on adverse infant outcomes. Several ongoing, randomised stove interventions are assessing the effect of clean cooking fuels on preterm birth, child health and survival. These studies are described below:

The Ghana Randomized Air Pollution and Health Study (GRAPHS)

This study seeks to quantify the health benefits from household energy interventions delivered to pregnant women. Women are enrolled through the 24th week of pregnancy, and the study researchers are tracking how clean cookstove interventions affect birth weight and risk of pneumonia during the first year of the infant's life. The study has enrolled approximately 1,415 women from 35 clustered areas in Ghana. The study comprises three arms. In the first arm, women are provided with two BioLite cookstoves, which burn traditional biomass fuels, using a thermoelectric powered fan to blow air into the combustion chamber. In the second arm, women are provided LPG stoves, cylinders, and a free supply of gas. Women enrolled in the third arm serve as the control group, and will receive the BioLite cookstove after the study ends. Personal exposure to carbon monoxide is assessed over 72-hour monitoring sessions at seven time points, four of which occur during the prenatal period. Enrollment ended in early 2015, and as of mid-2015, follow-up is ongoing. GRAPHS is led by investigators from Kintampo Health Research Centre and Columbia University's Mailman School of Public Health.

Improved Bioethanol Cookstoves and Pregnancy Outcome in Nigeria

This study proposes to establish an exposure response relationship for measured household air pollutants and health outcomes for 300 pregnant women in Ibadan, Nigeria. The study hypothesis is that, relative to kerosene and firewood, the ethanol stove will reduce pregnant women's exposures to PM2.5, PAH, and CO, and will thus reduce adverse pregnancy outcomes. Investigators are assessing the ability of ethanol stoves to reduce personal exposures to household air pollution compared to kerosene and wood stoves, and will compare exposure by stove/fuel type with health outcomes. Stove use and acceptability of ethanol stoves is being evaluated using temperature monitors. The long-term goal is that knowledge gained from this study will influence policy that supports the scale-up and adoption of clean stoves and clean fuels in the most affected and vulnerable populations.

Case Study: Child ALRI in Nepal

Few studies have examined the impact of gas stoves on childhood pneumonia in low income countries. One ongoing study in the Sarlahi District of Nepal is conducting a randomized intervention trial in 1,900 homes. Half of the homes are using an Envirofit wood stove and the other half are using an LPG stove. The primary aim of this study is to evaluate the incidence of ALRI among children less than 36 months of age. Home visits are conducted to detect ALRI and measure PM and CO levels before and after stove installation. The main challenges are: household adoption of the Envirofit stove, since it cannot accommodate cooking needs in homes with more than four members, and, the fact that LPG stoves are not affordable to members in the participating communities.

Evidence for understudied conditions

Asthma

Air pollutants, specifically particulate matter, sulfur dioxides, nitrogen oxides and ozone, are associated with the increased development of asthma, illness due to asthma, and reduced lung function in children in high-income countries. Over a dozen studies have measured the association between gas stoves, and/or nitrogen dioxide produced from these stoves, on infants' persistent cough[57], lung function[58,59], childhood wheezing[60], respiratory symptoms61, cough in non-asthmatic children[62,63], and childhood asthma[64,65], including physician-diagnosed asthma[66]. A large United States-based study found that the likelihood of childhood asthma was lower in households that used a vented stove when cooking with gas, compared to households that did not, which indicated the importance of a well-ventilated kitchen[67]. Authors of a prospective study of 1,300 children found a dose-response relationship between indoor levels of nitrogen dioxide in homes using gas stoves and parental report of children's wheeze and symptoms of asthma at night[68], while another study found no relationship between nitrogen dioxide levels and asthma[61], suggesting other pollutants or exposures might trigger the asthma. One study in Germany found persistent cough in infants increased by 50% with a gas stove used for cooking but doubled with a wood stove used for heating[57].

While it is well understood that pollutants from urban and traffic air pollution cause airway inflammation leading to increased asthma exacerbations in children in high-income countries, asthma in low-income countries has not been conclusively linked to increased air pollution from either gas stoves or solid fuel cooking fires. A 2011 meta-analysis[69] of four studies conducted in low-income countries found inconclusive evidence that HAP from solid fuels was associated with childhood asthma. Only one of the studies included in the meta-analysis, conducted in Nepal in 200170, showed twice the likelihood of self-reported asthma in children between eleven and seventeen years of age who were exposed to wood smoke compared to children who lived in homes using gas or kerosene stoves. This study had several limitations, including self-report of both stove use and asthma, and other significant air pollution exposures, including tobacco smoke and traffic in the Kathmandu Valley. Kumar et al. did not find a significant difference in asthma between 900 children residing in households using solid fuels compared to children in households using LPG stoves in urban Delhi[71].

One of the reasons that asthma morbidity may not have been found to be associated with solid fuel stoves is that asthma is not common in low-resource countries that use solid fuels. An early study found that asthma prevalence among indigenous children in rural Guatemala was very low at 3.4%[72]; other low-income countries have similar rates. This may have to do with early exposure to animal allergens as well as exposure to bacterial infections which may have a protective effect against the development of asthma and allergies.

Neural tube defects

Neural tube defects are birth defects of the brain or spinal cord. They develop in the first month of pregnancy, at a time when the pregnant woman may not know she is pregnant. One method for examining risk factors that may be related to rare outcomes, such as neural tube defects, is to enroll cases into a study and then compare their past exposures to a group of healthy participants, known as controls. A meta-analysis of ten case-control studies determined that maternal exposure to secondhand tobacco smoke increased the likelihood of neural tube defect by 82%[79]. Neural tube defects were found to be higher in children exposed to traffic-related air pollution, specifically carbon monoxide and nitrogen dioxide, in a large Central California study[80]. In several Chinese studies, polycyclic aromatic hydrocarbons, pollutants that are emitted from the incomplete combustion of fossil or solid fuel, were associated with neural tube defects[81,82]. However, the study did not find a relationship with different fuels, primarily because almost all of the homes used coal for cooking and heating.

Burns in young children

Burns in young children are a serious concern in homes with open fires as well as in homes using liquefied fuels, such as kerosene and LPG. While there have been case reports of children who have burned themselves when playing near open fires or near pots of hot liquids left on the kitchen floor, there have not been any large field studies that confirm that the risk of burns is reduced by replacing an open fire with a chimney stove that elevates the cooking surface above the young child's reach. During the RESPIRE study in rural Guatemala, over 500 households with young infants participated in an eighteen month trial; none of the young infants or their siblings in either the open fire or chimney stove group reported burns. In this part of Guatemala, young children are carried on their mother's back until they reach two years of age, which keeps them safe when crawling or playing near floor-level fires.

When families transition to new stove technologies that use portable liquefied fuels, burn risk remains a concern. Kerosene is an extremely volatile liquid, and explosions occur when the fuel is stored, transported and transferred to stoves in an unsafe manner. Leaks and subsequent explosions can occur in the LPG stove at three junctures: at the LPG cylinder, along the connecting pipe, and at the stove. Damaged or leaking LPG tanks can cause a pressure drop in the tank that has the potential to release evaporating gas and energy, which can lead to an explosion. If a valve is leaking or left open, air can diffuse into the LPG cylinder, which can form a flammable mixture that can explode. Because LPG is denser than air, leaking gas settles lower to the ground. When an explosion occurs, burns cause more injuries in the lower torso than the upper parts of the body. This may put younger children who are crawling and walking in the kitchen at higher risk for total surface area burns.

In a study of over 700 flame burn patients seen at a hospital in New Delhi, India[83], 54% were due to kerosene, 27% were due to LPG, and 19% were from other sources, such as coal and candles. In a comparison of LPG and kerosene burn patients, mortality was 17% greater in the kerosene group compared to the LPG group. In this study, 70% of the LPG burns were due to gas leaks either in the rubber tubing or the stove valve. The authors point out that the majority of the victims were from single-room households, where cooking and sleeping occurred in the same room, and larger 14.2 kg LPG cylinders were used. As would be expected, the majority of the burn victims were women, over the age of 14 years of age, lower middle class, and with no education. Using kerosene and LPG does not necessarily raise the stove out of the child's reach—100% of the kerosene stoves and 80% of the LPG stoves were level with the floor. In a separate study of 182 hospital patients with LPG burns in New Delhi, 23% of burn patients were pediatric with 18% under the age of ten years. In this study, the stove that was most likely to result in explosions was connected with tubing to a small 5kg tank. Half of the leaks were in the tank and 36% were in faulty tubing between the cylinder and the stove. The authors point out that illegal distributors will refill the smaller tank frequently which can loosen the safety valves, thus increasing the risk of tank leaks[84]. A small Turkish study found that gas leaks from substandard tank manufacturing or failure to close stove valves were attributed to 41 burn patients injured by LPG accidents[85]. These studies address the importance of maintaining strict controls over tank standards, including filling, certifying and removing unsafe tanks from circulation. Home educational programmes should also focus on checking for gas leaks as well as replacing weathered tubing and safety valves. Although small tanks may be an affordable option for low income families, frequent filling and changing of tanks may lead to more leaks between the tank and the stove.

Section 3

The impact of clean cookstove transition on children's education and economic development

"Access to energy must not be taken merely as a goal in itself, but as an enabler of sustainable development overall; it is fundamental for the self-empowerment of the poor."

SE4All Energy Access Committee Report[25]

Close to half of the world's population (41%) uses solid fuel for cooking, and 15% lacks electricity. Access to clean cookstove technology, including electricity for lighting homes, improves children's health and education, as well as gender equality. Women account for half of the potential cookstove market globally (estimated at 2.7 billion), and play a crucial role in the widespread adoption and use of clean cooking solutions. UN Women's report- *The World Survey of the Role of Women in Development*- highlights clean cookstoves as one of four key domains for investment with a particularly strong potential to transform the lives of women and girls. The authors of the report call for expanding access to clean cookstoves because these stoves can improve gender equality directly, and women and girls suffer from their absence. The report emphasises that cookstoves should be at the centre of all policy efforts to achieve sustainable development; investment in cookstoves remains inadequate and must be increased. This report calls for investment at scale in efficient cooking technologies that use cleaner fuels and encourages stove uptake by involving women in stove design, testing, and social marketing. The report also emphasises women's agency, knowledge, and decision-making as critical for ensuring sustainable development, particularly in securing energy services.

Clean energy access can have direct health benefits as described in Section 2. Lower air pollution means pregnant women deliver babies on time and with healthy birth weights, instead of delivering premature infants who may experience cognitive delays later in childhood, leading to poor school performance. Young children exposed to less particulate matter from cookstoves, or kerosene lamps used for lighting, will have fewer episodes of acute lower respiratory infections, and would thus be able to participate in school activities more fully. Households that have an adequate fuel supply will boil their water for longer periods of time, which may reduce the rates of diarrhea from contaminated water, reducing the number of sick days that keep children out of school. Families are often required to contribute firewood to schools using open fires or traditional cookstoves. In some cases, if they are unable to provide wood, their children may be forced to miss class or school meals. An improved cookstove that is 30% more efficient than a traditional stove can potentially save enough money to send two children to school[86].

Other direct benefits of switching to clean cooking stoves include time opportunity costs. Girls and young women who cook over fuel-efficient stoves will spend less time gathering fuel and cooking food, which gives them more time to pursue education and work opportunities. Girls and women are almost always responsible for firewood collection, particularly in humanitarian settings, exposing them to the additional risk of physical and sexual violence when travelling long distances. For example, in the Farchana refugee camp in Chad, 90% of confirmed rapes occurred when women left the camps in search of firewood[87]. In 2014 in Uganda's Nakivale refugee settlement, 41% of households reported incidences of violence during firewood collection[88]. In Doro, South Sudan in 2014, 54% of refugee respondents reported incidents of violence against women in firewood collection places. In emergency and crisis situations, access to fuel-efficient stoves can decrease the protection risks faced by vulnerable populations, particularly women and girls.

Improving health increases girl's literacy rates and educational attainment

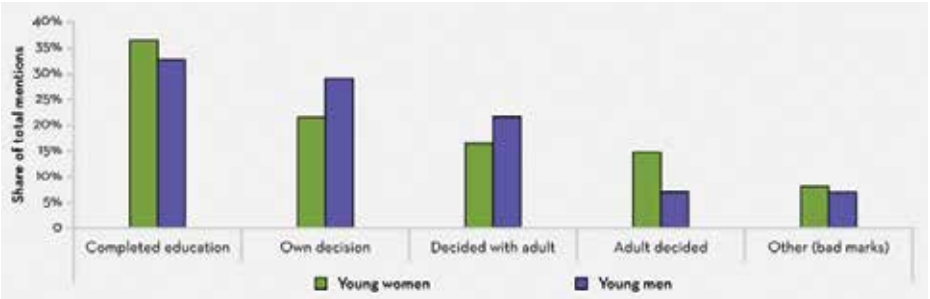
"For children, the most important strategy for ensuring that girls and boys will have equal income earning opportunities as adults is to give them equal access to education."

UNICEF report, 2006[89]

Education

The likelihood that children, especially girls, attend school is directly related to women's decision-making roles and empowerment in the household where these children reside. Gender inequality starts at a young age as traditional domestic roles, starting with cooking, are passed down from mother to girl child. Young girls, starting as early as eight to ten years old, do much of the cooking and therefore experience higher exposure to cooking smoke than their male siblings. This also impacts their school attendance; girls are more likely to drop-out earlier than boys in order to help out with the labor-intensive cooking process, which also requires the collection of fuel. Parents may have to choose between paying school fees and purchasing fuel to cook, particularly in the aftermath of humanitarian crises such as the 2010 earthquake in Haiti. The adoption of LPG alleviates much of the labor associated with cooking and may level the playing field between male and female children; young girls would be able to modify the roles they traditionally play by dedicating more time to other activities, either in school or at work.[89]. Access to electricity can also have a beneficial impact on women and girls' education. A study in Bangladesh found that women's literacy was 22% higher in electrified households than non-electrified households.

Figure 4: Who makes the decision for children to leave school?



Note: Data from young women and men (18-25 years old) in 113 focus groups.

Clean cookstoves save time and impact the "gender-poverty-energy nexus" that women and girls face

> *"Worldwide poor women tend to invest more of any additional disposable income into the health, education, nutrition and welfare of the children and families rather than invest in other "non-productive" activities (sports, leisure, etc.) when compared to men"*
>
> SE4All Energy Access Committee Report, 2014[25]

Women play a significant role in energy systems, including fetching fuel, animal fodder, and water for homes, and using energy for their micro-enterprises. The burden of lack of energy access falls disproportionately on women and girls. Time and effort spent on fuel collection results in missed opportunities for employment, education, and self-improvement. Household air pollution caused by burning biomass directly impacts women and girls. In Sub-Saharan Africa and Asia, the lack of access to clean cooking solutions is particularly significant, with a third of the urban population and the vast majority of the rural poor using solid fuels to cook their daily meals over open fires or inefficient stoves. In some places, women provide 91% of households' total efforts in collecting fuel and water[90], and women have an average working day of ten to fourteen hours, compared to ten hours on average for men[2].

Additionally, reliance on biomass contributes to climate change, deforestation, soil erosion, and 26% of global black carbon emissions[91]. Rural women and children are especially vulnerable to these environmental impacts. As forests are depleted, the energy burden increases, and women and young girls are forced to walk even further to collect fuel or use more toxic fuels, such as dung or trash. This increased labor is almost always unpaid and unrecognised as formal labor.

Access to affordable, quality and safe energy can transform the lives of poor families in multiple ways, including improved efficiency of daily chores. This liberates women and children from drudgery and frees up time for leisure, rest, and self-improvement. A reduction in time spent collecting fuel and cooking enables women to spend more time with their children, complete other household responsibilities, and pursue income-generating or educational opportunities– all of which contribute to poverty alleviation. A recent study in South Asia showed that women who adopted improved cookstoves reported sending their children to school more often[92]. Community, labour-saving, and health benefits are witnessed when electricity becomes available for social infrastructure, including lighting health clinics and schools, and powering grain mills and water pumps.

In the World Health Organization's *Fuel for Life* document, the time savings from immediate access to LPG, for those currently dependent on solid fuel for cooking, was valued at US $44 billion.[93] Transferring the time spent gathering firewood to activities that can generate household income is an obvious economic benefit for the entire family. Since young girls can spend up to twenty hours each week collecting firewood or building and tending the wood fire, prioritising girls' education and homework over necessary cooking tasks is a constant challenge in poor households.

In humanitarian settings such as North Kivu, Democratic Republic of Congo, women and girls report spending a significantly greater amount of time collecting firewood at an average of 5.6 hours daily[94]. A lack of access to sufficient fuel can have direct health and nutritional implications if women resort to undercooking meals, which increases the risk of foodborne illness. Sometimes women are forced to skip cooked meals altogether, which can cause malnutrition, especially in children.

When women have difficulties procuring cooking fuel, a "gender-energy-poverty nexus" leads to an inability to find jobs that will lift them out of poverty[95]. Because women are cooking in smoky kitchens, they are more aware of the need to transition to cleaner cooking technologies than men. Household decisions that do not take into account women's choices about energy, including fuel and clean cookstove purchases, further aggravate gender inequalities among the world's poorest households.

Section 4

The barriers and enablers of the clean cookstove transition

Changing to clean cooking practices and behaviors is a multi-faceted process subject to different barriers and enablers affecting stove acceptance, initial adoption and sustained use[96,97]. A recent systematic review of 57 studies conducted in Asia, Africa and South America[96] found that common barriers to the adoption of new clean cooking technologies were:

- inability of new cookstove to take over all of the functions of traditional stoves and open fires
- poor stove design resulting in low durability and high maintenance costs
- problems related to the availability and cost of new fuels, such as LPG, in rural areas.

Ironically, while decreased fuel collection time and increased cooking efficiency were found to be enablers of new stove adoption and use, larger family size was found to be a barrier to adoption. This may be due to the cheap-to-no-cost labor that children provide in poor households and may be one of the most difficult barriers to overcome. It will be difficult, if not impossible, to dissuade poor households who are struggling to survive to refrain from using children to work on farms and in "cottage industries". It is estimated that child labor impacts approximately 170 million children worldwide, and two thirds of these children are unpaid family members[98].

Other important barriers to the uptake of clean cooking technologies include:

- lack of knowledge of the causal link between smoke and poorer health outcomes, specifically for younger children who are highly exposed to kitchen smoke
- gender inequality in the household decision-making process, leading to women's lack of control over assets and resources
- access to the new stove and fuel in terms of affordability and availability
- constraints for women as clean energy entrepreneurs, such as lack of access to finance, formal education, and training, discriminatory practices that limit business growth, and lack of mobility
- safe LPG use, which includes fear of LPG stoves and cylinders
- underdevelopment of the LPG supply chain, both in terms of production and distribution

Enablers to the adoption of LPG which directly impact children's well-being include:

- ensuring that LPG uptake programmes empower women to be involved in household purchase decisions, as this will determine the prioritisation of purchasing LPG
- integration of health communication interventions focused on children's health with LPG stove uptake
- school-based and extracurricular LPG safety trainings and cooking classes. Afterschool programmes such as the Ghana Girl Guides Association (GGGA) can also be used to educate young girls about clean cooking solutions.

Barrier 1: Tradition of solid fuels used for cooking and heating practices

The development of clean stove technologies that meet emissions performance, and at the same time deliver all the needs and preferences of households that rely on solid fuels for cooking and heating, has not yet been fully realised.[99] The perfect stove, built under lab conditions, may fail to meet the needs of the stove consumer. The consumer may use the stove incorrectly, deliberately modify the stove, or abandon the stove altogether. In order to achieve 100% adoption of LPG stoves, programmes need to integrate technological solutions with educational messages about correct stove use in order to meet the needs of the user. For example, if heating water for bathing is important to a family, a solar water heater may need to be offered to families with LPG stoves so that they discontinue the practice of heating water over open fires.[100] Sustained adoption of LPG stoves and fuel will only work when culturally-specific strategies to displace the use of open fires and solid fuel cookstoves are offered as alternatives.

Traditional cooking practices

One of the most important and easily understood barriers to changing cooking practices is the age-old tradition of cooking food over open fires. People have grown accustomed to cooking with solid fuels, and may prefer the taste and texture of foods cooked in this way. While improvements to the design of LPG stoves do address some of these factors, certain practices cannot be entirely replaced. People who adopt LPG stoves may have to change their expectation about how a food should taste if 100% adoption is to be met. Studies worldwide have documented a clear preference for cooking certain foods over wood despite having an LPG stove in the home. For instance, preparing tortillas in Mexico and Guatemala[101,102]; roasting meat in Nicaragua[103]; toasting chapatti in India[104]; cooking hard beans, stamp, and seswaa in Botswana[105]; steaming rice in Thailand[106]; and cooking stews in China[107] may lead people to use solid fuel fires. While some stove manufacturers have attempted to address these needs (see **Figure 5**), many stoves are not used by low-income households because they do not address consumer preferences.[1]

Figure 5 Guatemalan LPG stove with built-in flat griddle ("comal") for cooking tortillas, a staple food.

Use of multiple stoves, "stove stacking"

Over the past 40 years, efforts to push full displacement of traditional cooking technologies have yet to be successful as households that transition to a clean cooking technology combine it with one or more traditional solid fuel cookstoves or open fires[1,102,108,109]. While the practice of stove stacking in and of itself may act as an enabler, as it demonstrates the adoption of new cooking technologies, it acts as a barrier as it prevents full adoption of the new cooking technology[96]. There are several reasons why an LPG stove cannot fully substitute the role of traditional cookstoves and open fires (see **Figure 6**). While cooking may be the primary function, critical secondary functions include heating and lighting the home, heating water, burning garbage, repelling insects and other animals, as well as smoking foods for preservation[1]. In rural Mexico, the use of wood fuel to heat water for bathing and washing prevailed even after village "modernisation," as defined by widespread uptake of LPG and electricity[110]. Furthermore, the variability of fuel costs and fuel availability, coupled with the fluctuations in household income, promotes stove stacking as a strategy to guarantee that cooking and other needs are met. Households may use the traditional stove when the LPG cylinder can be easily filled and LPG fuel prices are lower[1,102,111].

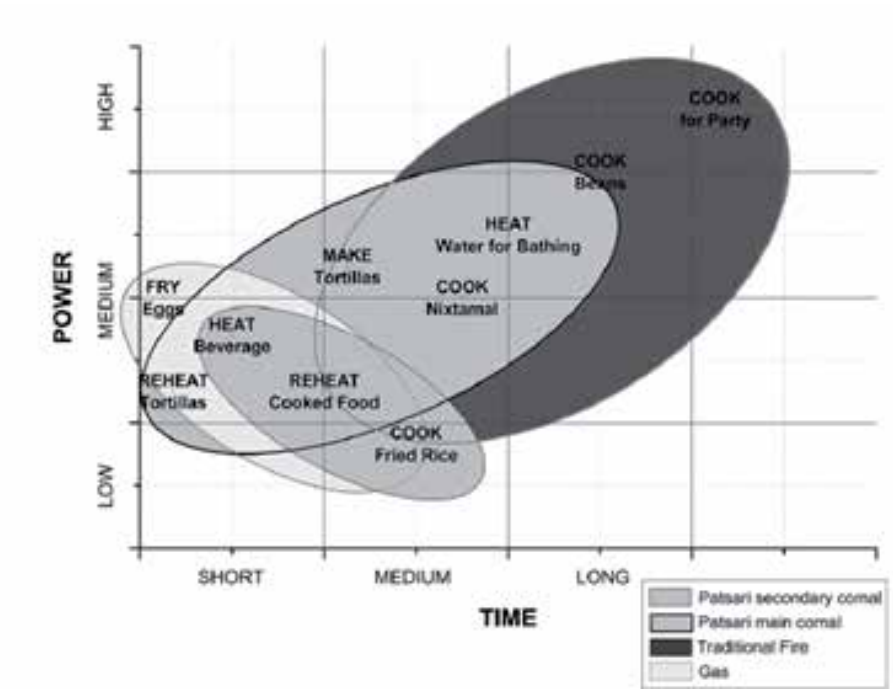


Figure 6 shows the preference for cooking foods on four stoves based on need for high versus low energy and length of time needed to cook food in a typical household in rural Mexico1.

Traditional postpartum heating practices and the impact on child health and well being

Many postpartum traditions worldwide are based on the principle of "regaining heat after pregnancy." Mother and newborn may spend hours each day during the forty-day postpartum period lying near an open fire to restore humoral balance. This often puts women and their newborn babies at high risk of exposure to toxic smoke in the immediate postpartum period when they are most vulnerable. In addition to lying by an open fire inside the home, women and children may go into small wood-fired sauna baths. In Guatemala, these baths had extremely high levels of CO[11,2] LPG stoves do not serve a "heating" function, so many women may choose to lie by open fires during the postpartum period. This significantly increases young infants' exposure to PM, a respiratory irritant, and CO, an asphyxiant gas. If a newborn is premature, or has respiratory distress, exposure to high levels of PM and CO can impair oxygenation that is needed during this critical period. Health communication strategies should prioritise messages about the impact of smoke on children's health from sustained exposure of open fires, even in households that adopt the use of LPG stoves. This may motivate modification of traditional cultural practices that may be harmful to newborns. Families should be offered counseling around alternatives to lying by an open fire, such as moving the mother and baby into a smaller, windowless room with better insulation, and bundling the mother and baby in warm blankets. One study in Guatemala describes the high exposure scenario and another study in Indonesia provides some empirical evidence that when children's health is the focus, women will modify even deeply embedded traditional practices.

Case studies of postpartum practices:

Use of *temazcal* in Guatemala, sei in Indonesia and mother roasting in Lao People's Democratic Republic (Lao PDR)

Temazcal in Highland Guatemala

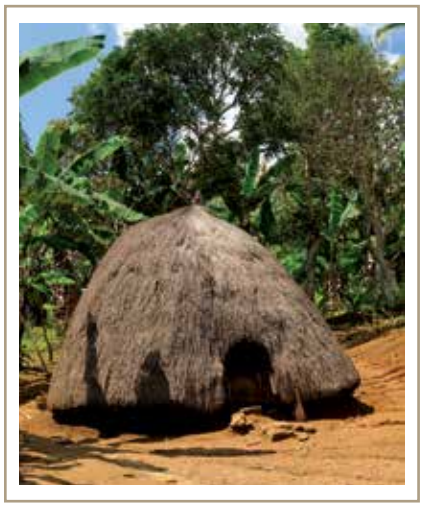
Figure 7 A temazcal in rural Guatemala

The *temazcal*, or *"chuj"* in the Mam language, is a wood fired sauna bath (see **Figure 7**) used in many indigenous communities in the colder climate highland regions of Guatemala. The temazcal is a small adobe or cinder block structure that is used for bathing and healing purposes. A wood fire is built inside the structure, and stones are suspended over a metal grate above the fire. Once the rocks are hot, the family goes into the unvented structure and covers the door with a blanket to prevent heat from escaping. Water is thrown on the heated rocks which produces steam inside the temazcal. Both preparation of the fire, usually by a young woman in the family, and sustained use of the temazcal by mother and newborn during the forty-day postpartum period, are high exposure scenarios. During the postpartum period, the woman and newborn may use the temazcal every day; the newborn may go into the temazcal for five to ten minutes and the mother will go in for longer periods of time to 'heal the uterus,' which aids recovery. Immediately after delivery, the traditional birth attendant prepares the temazcal and helps the woman and newborn for their first bath within hours of delivery[113]. One midwife described taking a very cold, sick newborn that she had delivered into the temazcal to warm it up, but the newborn died the next day. Carbon monoxide levels have been measured in the temazcal and weekly sauna bath activity accounts for 78% of the total weekly carbon monoxide exposure among women who had a well-functioning vented chimney stove intended to reduce kitchen air pollution[112]. The temazcal exposure would be even greater in both absolute and relative terms following childbirth, when women traditionally use the baths more frequently.

Postpartum confinement-to-home practices in Southeast Asia

Many Southeast Asian cultures observe a traditional period of confinement for both mother and child, ranging from 10 to 45 days during the postpartum period.[114] Confinement involves staying indoors near heat, the source of which is often a wood or coal fire. As with the case study described above in Guatemala, pregnancy is seen as a hot state; heat is lost during childbirth, and postpartum practices are believed to return the heat, promote healing[5,114,115].

Sei in Indonesia



Sei ("smoke") is a postpartum tradition of the Timor society of Indonesia which involves confining the woman and her newborn to woodsmoke-filled, unventilated traditional houses (*Ume Kbuku*) for forty days after childbirth. The health effects of these traditions have not been well studied; however, one study observed high levels of indoor air pollution. Mothers reporting that they suffered respiratory health problems during the practice but did not change their behavior due to the importance of the tradition: "…indeed I often had coughing during Sei practice, and my baby did too. However this is our tradition, so we had to do it anyway." To address this issue, a community-based health communication intervention was designed to help women understand the health impacts of Sei practice on their health and the health of their infants. The results of this intervention were encouraging; women decreased the Sei period's length from forty days to four days on average, and improved ventilation by adding windows to their traditional houses [5].

Women in the study stated:

- *"Since I heard about the dangers of Sei tradition to my baby's health, I did Sei tradition for my second child only for four days; I also understand what village midwife had already told me about the danger."*
- *"I follow my priest who told us in church about the effect of forty days Sei smoke tradition to my baby's health, so for my third child I only did three days Sei tradition."*
- *"Since I live in my healthy traditional house, I feel the difference, my house much brighter, we already have two windows, it's not humid anymore, due to this cement floor."*

Mother Roasting in Southeast Asia

Figure 8 Mother roasting in Lao

Mother roasting is part of the *Yu Fai* ("on fire") ritual, a postpartum practice among 90% of families in Laos. The mother lies on a bamboo bed, either over a brazier containing hot charcoal embers, or in close proximity to the embers, for up to 45 days. It is similar to a steam bath, but in addition to steam inhalation, the hot bed of embers acts to vaporise oils in aromatic plants. The mother only leaves the hotbed to bathe, eating her meals and nursing her infant in an environment with temperatures exceeding 50°C and typically around 80-100°C. The purpose of mother roasting is to promote healing of the uterus and alleviate abdominal pain[116]. While the terpene components of the vaporised essential oils have antimicrobial and analgesic properties[117], it is unlikely that they are effective against maternal or neonatal infections.

It is culturally unacceptable to refuse treatment, and refusal is considered to have negative effects to maternal and child health[118]. Ironically, the negative health effects of being exposed to extreme heat and smoke probably outweigh any medicinal effect. There have been no studies quantifying the impact of pollutant levels and extreme heat on maternal and infant health. Lao PDR has one of the highest maternal and neonatal mortality ratios in the Western Pacific region with the maternal mortality ratio at 470 per 100,000 live births, and, neonatal mortality at 27 per 1000 live births, each year[119]; pneumonia accounts for the deaths of approximately 2,800 children each year, or 19% of the country's under-five child mortality[120]. A study taking place in Lao PDR[121] is assessing the effect of the Yu Fai ritual on the health of mothers and infants. Two of the main challenges in this project are to develop a technology that is both smokeless and within a safe temperature range, and to then successfully introduce this technology to communities.

Barrier 2: Lack of knowledge of the causal link between smoke and poorer health outcomes

Reports of adverse health effects related to smoke and fire (specifically reports of burn injuries and house fires) act as deterrents to the adoption and sustained use of clean cooking technologies[96]. "Shocking stories" about a child burned by a kerosene stove can have lasting impact on the adoption or abandonment of a new technology in households. Unfortunately, it is harder to sell the message that chronic exposure to HAP leads to child pneumonia, as the relationship is less obvious, and other risk factors may be blamed. A key problem in resource-poor countries is a lack of knowledge about how cooking smoke impacts health. In a multi-location trial of clean stove technologies in India, where most households knew about LPG, less than half (41%) of all participants were aware that certain fuels produced more smoke than others[122]. This lack of knowledge deters behavior change since household decision-makers do not see the link between adopting a new stove and subsequent health improvement. Other considerations, such as time, cost, ease of use, and traditional cooking practices, are perhaps more important; the stove has inherent value to the consumer besides improved health1[23]. A combination of health and non-health messages should be a part of behaviour change communication. Health messages should target the health of children since women typically place more importance on their children's health and wellbeing than on their own.

The transition to a new technology will always be at some cost to the consumer, so evidently this is in and of itself a barrier; however, focusing primarily on household fuel savings, at the expense of health messages, may in part explain why some stove programmes have not been more successful. Critical to motivating LPG uptake is making the impact of cooking smoke on children's health a key message. In one study in Ethiopia, 90% of the women stated that they would change their cooking fuel if they thought it would improve their children's health[124]. In a large study in China, with high arsenic exposure due to coal stove use, a school-based education programme that promoted lifestyle changes led to a significant decrease in urinary concentrations of arsenic[125]. Health education that links household air pollution to children's health should not be "pushed to the side." Researchers and stove manufacturers are deeply interested in how to sell the stove as a commodity; however, this should also include *why* the stove should be used, which is to protect human health. When benefits of the new stove are reduced to cost and fuel savings, stakeholders ignore the inherent value that all people, no matter how poor, place on their children's health.

Barrier 3: Gender inequality in the household decision-making process

Lack of decision-making power

How a family decides to spend limited income on children's or adults' needs often hinges on who is involved in the decision-making process. Men usually make the decisions about major expenditures in resource-constrained households throughout the world. When women control household income, they reinvest 90% of it in their children, whereas men only reinvest 30-40%[126]. Data from UNICEF Demographic and Health Surveys suggests that a large proportion of women in many countries indicate that their husbands have exclusive control over large purchases (Nigeria, 78%; Egypt, 60%; Bangladesh and Nepal, over 33%). As a result, decisions around cookstove adoption tend to be male-centered and in many countries men are selling the stoves to households, despite the fact that women are the ones who cook. This fundamental disconnect that prevents the uptake of new LPG stoves, as women are often not consulted, despite being the primary end users, and are not empowered to make major purchasing decisions[89,99,127].

Even though stakeholders have decades of implementation experience and hundreds of organisations are active in the sector, enterprises have not adequately leveraged opportunities to empower women throughout the value chain.

Resources are needed to develop effective business models that empower women and utilise women's entrepreneurship in the household energy sector, as well as advance the sector through the exchange of game-changing ideas and lessons learned from successful and failed innovations. Finance and capacity building support for enterprises are also necessary to scale the number of women entrepreneurs and strengthen empowerment impacts. Agency-based empowerment training can significantly increase women's capacity to engage effectively within the clean cooking value chain[128]. Additionally, evaluation and knowledge-sharing are critical in order to ensure the replication of effective business models for creating, sustaining, and scaling gender-informed approaches, women's entrepreneurship, and economic empowerment.

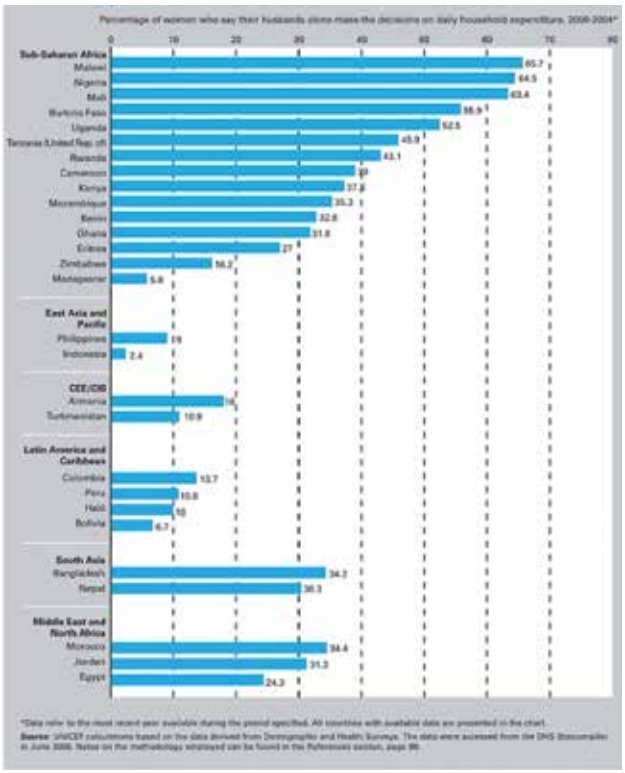


Figure 9 *Many husbands are making the decisions alone on daily household expenditure*

Child Marriage

It is estimated that 34 percent of women worldwide between 20-24 years of age are married before the age of 18; in low-income countries, the number is close to half[129]. The age gap between women and men joined in marriage is one of main reasons that women lack the power to make household decisions. It is most severe in the cases of child marriage (defined as age at marriage before 18 years) when the age gap is most extreme. The burden of housework and childbearing limits the life choices available to child and adolescent mothers and subsequently limits their participation in household decisions, such as purchasing a clean cookstove or clean fuels[89]. When early marriage and childbearing is common, parents and other family members decide when and to whom a girl will marry and make childbearing decisions on behalf of girls.[129] Reproductive choice can be about agency, but it also may be a trade-off for other sources of power-"Bearing the approved number of children will grant a woman the rights and privileges accorded to a fertile woman, but does not necessarily give her greater autonomy in decision-making"[129]. When girls and women are empowered through access to training, education, and reduction of unpaid care work, there is greater potential for them to overcome some of these barriers to using clean cookstove and fuel technologies. For example, in Bangladesh, for each additional year of delay in marriage, a girl will gain an average of 0.22 additional years of school, and her literacy rate increases by 5.6%[52,130].

Transfer of gender inequality from parents to children

Children learn behaviors from their parents, learning at a very early age what it is to be a "good girl or boy," and assimilating the norms they experience[129]. Gender inequalities are passed on generation after generation. Evidence from the Young Lives Study, an international longitudinal cohort study investigating the changing nature of childhood poverty in four low-income countries (Ethiopia, India, Peru, and Vietnam), demonstrates that parents' aspirations for their children's educations and futures are adopted by their children[129,131]. The stereotypes of women being the weaker gender, restricted to domestic tasks, limits girls' life aspirations[129]. Results from 82 focus groups conducted in nine different countries demonstrated that when imagining what it means to be a "good girl", the focus groups of adolescent girls and boys shared similar views, but diverged on the importance of doing household work. A good girl is expected to complete domestic tasks (she helps around the house and is well-behaved, obedient, and respectful) and goes to school. A good boy should go to school, but helping around the house is less important when compared to other tasks (see **Figure below**). Gender inequalities, including household decision-making and the division of domestic chores, are passed down to children who not only do not feel a sense of agency to make choices and take action, but are physically limited by the burden of domestic tasks[89].

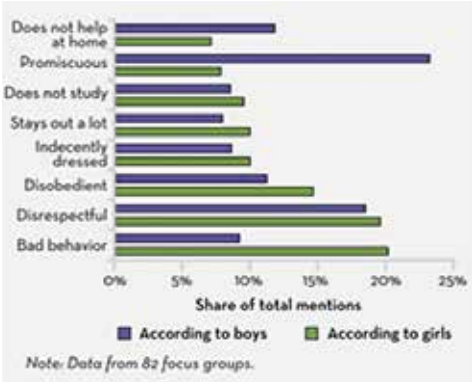


Figure 10 Characterisitics of a bad girl

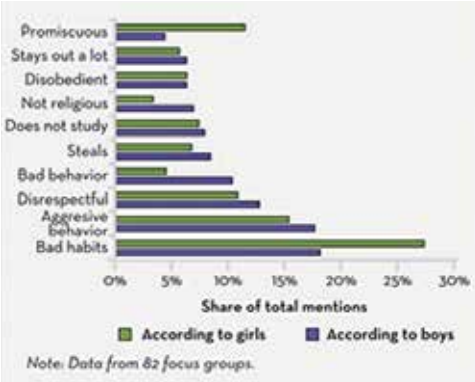


Figure 11 Characterisitics of a bad boy

Enabler 1: Women's participation in the transition to LPG

Gender targeting: Women recognise the health benefits

A review of clean cooking technology programmes stated that "there is a growing recognition of the advantages associated with actively involving women at every stage of the cleaner cooking value chain"[132]. Programmes that have involved women in the transition to LPG have been successful in stove adoption and sustaining usage. An average cost savings of $1.50 in fuel and a reduction in six hours of cooking time was observed in an ongoing community-based initiative that works with women's savings and credit groups to promote LPG uptake and sustained use[133]. Clean stove and fuel technologies provide value-added opportunities for income generation and increase local production of commodities.

Women can catalyse the market as clean energy entrepreneurs by leading efforts that seek to develop effective, culturally-appropriate, and sustainable solutions. A study in Kenya found that women cookstove entrepreneurs sold three times as many cookstoves as their male peers when given the same level of training and support, and woman-to-woman marketing was more effective because consumers were more likely to report consistent and correct cookstove use, as well as the benefits of cookstoves, when sold to them by women[128]. Women distributors have an untapped potential to provide access to consumers in remote and isolated communities, especially in societies where gender inequality limits women's access to markets. Women leaders in Bolivia who underwent empowerment and leadership training were able to engage their community more effectively to expand distribution of improved cookstoves than those who did not receive the training[133]. The same study showed that women in Bolivia who adopted improved cookstoves reported an increase in decision-making, free time, and ease of use compared to users of traditional cookstoves.

Targeted marketing for women users can also increase adoption of clean cooking solutions. In Uganda, an applied research study identified eight strategies for motivating women consumers to purchase improved cookstoves, leading to a 50% increase in weekly sales compared to the previous year[134]. In another research study commissioned by the Global Alliance for Clean Cookstoves, women in South Asia using improved cookstoves saved 70 hours per year as compared to women using traditional cookstoves, leading to a reduction in drudgery through reduced fuel collection; households using improved cookstoves also reported sending their children to school more often[92].

Adolescent girls and young women can also be change agents in their communities and play a crucial role in the widespread adoption of clean cooking solutions. Girls can leverage their networks and peer relationships to promote the adoption of new technologies. Girls can become spokespeople by promoting and encouraging the use of clean cooking products in their own households. The Ghana Girl Guides Association piloted a training curriculum with 200 girls on the negative impacts of traditional cooking practices, the benefits of clean cooking solutions, as well as empowerment and leadership skills to strengthen girls' capacity to become leaders in their communities by promoting clean cooking solutions. Following the training, 85% of girls reported a preference for improved cookstoves over traditional stoves because they are clean, efficient, and easy to maintain; 90% of girls' households adopted improved cookstoves introduced during the pilot as their primary cooking device. The Ghana Girl Guides has a national network of 20,000 members, bringing credibility to social messages at the community level, and will continue to scale the clean cooking curriculum so that it is integrated into all national programmes.

Case study: Women's empowerment through the Jagriti Energy Programme in Jagriti, India

Jagriti is an Indian community-based organisation whose objective is to empower poor, rural hill women in the Himachal Pradesh state in India. Jagriti has helped build women's organisational capacity and economic opportunities by fostering the development of over 140 women's savings and credit groups (WSCGs) with about 1,400 poor women. The WSCGs in turn have helped build women's leadership capacity as well as fund the marketing and promotion of energy-efficient and drudgery-reducing technologies, such as LPG stoves and fuel, pressure cookers, Hamam (water-heating device) and tandoor (metallic stoves)[135]. Prior to the introduction of LPG and Hamam, women, with help from their female children, spent sixteen to eighteen hours a day to complete domestic tasks. This included six to seven hours spent on cooking, utensil washing and fuelwood gathering[136]. Families had little time for anything else to improve their economic and social status.

From 2003 to 2014, 631 LPG connections and 2,486 Hamams were distributed on a cost-sharing plan where 60% of cost is borne by women and 40% by Jagriti. The use of these technologies had great implications for the health and empowerment of women and female children. LPG stoves have reduced smoke exposure, freed up six hours per day in domestic work, and reduced women's daily trips to forests for fuelwood to one to four weekly trips. The typical consumption of 10-12 kg of fuelwood is now reduced to only 2 kg of agricultural waste for heating 25 litres of water. Women's extra time is used to develop skills and generate income through establishing small individual and group enterprises[137].

Enabler 2: Prioritising health communication messages around children

Helping people understand the causal link between switching to clean fuels to improved health outcomes motivates adoption and sustained use[96,99,138,139]. This motivation is amplified when health communication messages prioritise the impacts of cooking smoke on children's health. LPG stove programmes have observed that when mothers became aware of the dangers of smoke, they modified their behavior out of concern for their children's health. Health communication interventions have to be tailored to the local community in order to be effective. Child health-focused communication messages can take the form of focus groups discussing the adverse effects of smoke inhalation (respiratory health, eye problems, growth and development) on newborns and adolescents, and through visually comprehensive promotional materials such as pamphlets, posters, and other visual depictions such as health messages on LPG tanks.

GenteGas educational pamphlet used with potential LPG customers to discuss health effects of woodsmoke exposure on children. This says, in Spanish:

"Carmen never lets Celia help her to start the fire."

Carmen nunca deja que Celia le ayude a hacer el fuego.

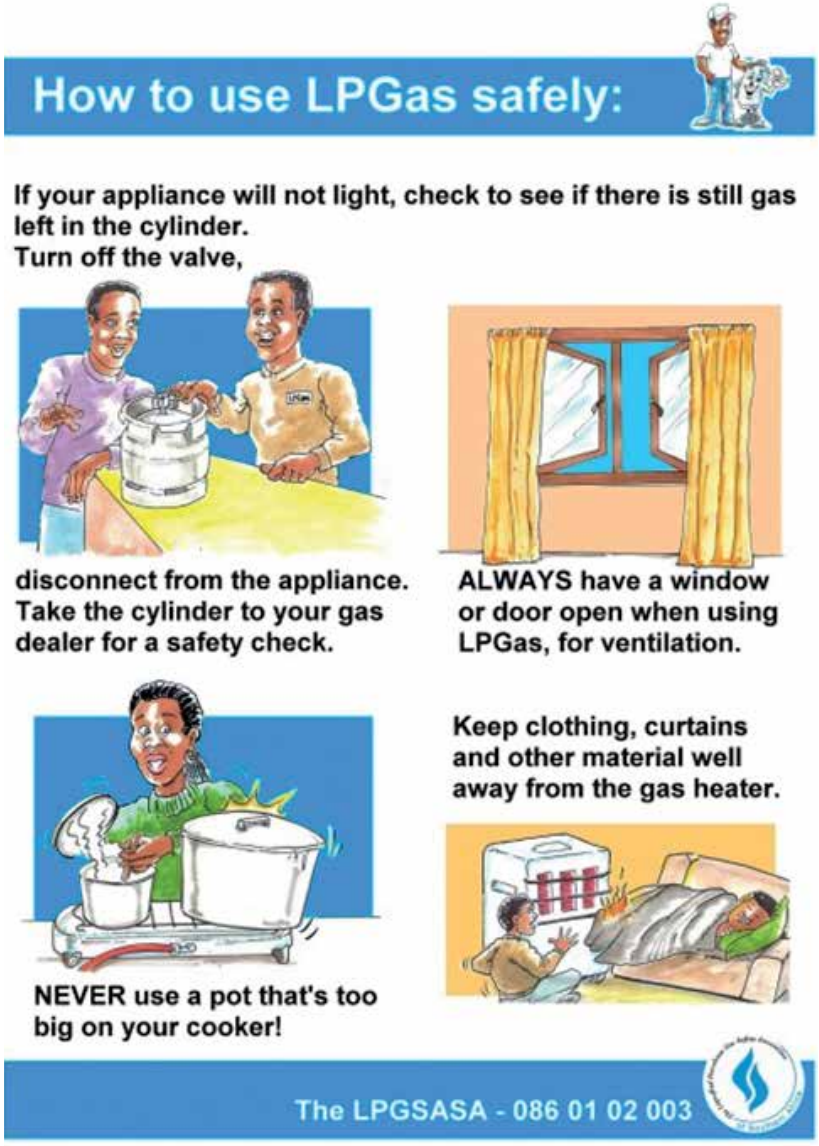
Enabler 3: School-based LPG programmes

Providing food for children in school often involves cooking for children over inefficient stoves. There are few, if any, ongoing initiatives that introduce LPG directly in schools. Even if children have a clean cookstove at home, the principal fuel used for cooking at school may be wood or coal. Switching to a clean fuel has multiple benefits on children's health and well-being. Meals cooked at school with clean cookstoves may place children at lower risk of smoke exposure. Children will also have more time for other school activities, since they will spend less time collecting fuel for school use. Schools are also key contact points with the surrounding communities, which may otherwise be hard to reach, and therefore ideal to introduce new clean cooking technologies and related safety and use trainings. Mothers of children take turns cooking school lunches and can therefore learn about new technologies at the school site. This knowledge can be carried back to their homes.

Young girls carrying wood to school in rural Guatemala

LPG safety trainings

Household LPG use is estimated at 90% in Brazil. More than 30% of homes in the Philippines and China use LPG stoves. In India, estimates vary from 30% nationally to 70% in large cities. As homes move toward the use of LPG stoves in low and middle-income countries, there is a concern for safe use of new stove technologies. Shifting from solid fuels to kerosene, LPG, and electricity inevitably leads to new learned behaviors. Fear of LPG safety is a primary barrier to uptake of LPG; women, the primary cooks, have expressed their concern about gas explosions and associated burns. Recent studies of LPG safety demonstrated that their concerns are not unfounded; several studies have looked into domestic accidents related to liquefied fuel use, including kerosene and LPG. These studies are reviewed in Section 2 and recommendations for safety trainings are discussed in Section 5. School-based trainings around LPG safety that includes mothers and fathers, as well as children, would be an efficient manner to reach many families at once.



Section 5

Incentivising adoption of LPG stoves: Policy recommendations for transition to the modern energy

Over the past four decades, there has been a great deal of discussion about how to get the global poor to transition to cleaner cooking technologies; stakeholders continue to debate on the process of transitioning households to *which kind of stove* and *which kind of fuel.* The Global Alliance for Clean Cookstoves has set a goal of fostering adoption of clean cookstoves and fuels in 100 million households by 2030. With the date fast approaching, there needs to be a major shift in the design and implementation of global and national stove and fuel programmes. There is no "one-size fits all" approach to getting people to use clean cooking solutions like LPG stoves and fuel. Fully displacing the use of traditional cookstoves and open fires is a considerable challenge, especially for the poorest of poor who ration their earnings on a daily basis and usually do not have money left over for large purchases. Given these challenges, policymakers in the energy, health, and environment sectors need to have sustained, cohesive strategies to increase access to clean cookstoves and fuels that are affordable and accessible by those that tend to pay the highest cost for fuel, use the lowest quality stove, and are experiencing the highest costs of poverty in terms of poor health.

Generating demand for clean cooking technologies

Tailored stove design

The use of new LPG stoves will be sustained if, and only if, the stove design and functionality is based upon household needs and preferences. Products should be designed in direct consultation with female end users to ensure acceptability and use[133]. Policy makers, stove manufacturers, and researchers who are working on stove intervention studies must continue to conduct community-based needs assessments, focus groups, key informant interviews, and time-activity studies to see how current stoves are used, and how the new stove performs in a stove-to-stove comparison[1]. If the new stove is to displace the traditional stove, other functions (e.g. heating large quantities of water for bathing) performed by traditional cookstoves and open fires must be addressed. For instance, constructing the stove so that the tubing coils inside the stove heat water for bathing, or, introducing solar water heaters together with new cooking technologies1. While this community-based method has been recognized as essential, very few programmes have managed to integrate this approach 1, and thus fail to ensure sustained adoption. In Guatemala, *Soluciones Apropiadas*, a social enterprise, tested an iterative, woman-centred design process for an improved institutional stove with women tortilla vendors to ensure buy-in and adoption of improved technologies. This is an example of how designers and producers can work with women to meet user needs and increase adoption of clean cooking technologies.

Addressing upfront costs of LPG stoves and fuel cylinders

Stove designs that are compatible with user needs, stove cost, and ongoing fuel costs are barriers to uptake of LPG stoves in low-income and rural areas. Affordability is a key driving principle behind stove uptake and fuel procurement.

Micro-credit loans

To make stoves available to people with little or no access to traditional bank loans, low interest loans should be available through microcredit loan programmes. These loans can be financed through local banks, cooperatives, or nonprofit organisations such as Kiva[140]. Microcredit institutions can serve as bridges between individuals and programmes, and can help families improve their financial literacy. This has been shown to work in areas where people do not typically qualify for bank loans because they do not have collateral and do not work in the formal economy[141]. Access to consumer finance is particularly challenging for women because they often lack control over household finances, making it difficult for them to take out loans that require high interest rates, collateral, and credit histories. For example, women who work in informal jobs, either inside or outside of their homes, will not be able to provide income verification letters from their employers for bank loans. However, women have a strong track record of loan repayment, particularly through women's savings and loans groups that help mitigate risk[133].

Installments

Another strategy that facilitates stove uptake is a purchasing programme that allows households to purchase stove packages (stove and LPG cylinder) over time in installments without interest payments[142]. The obvious benefit of this strategy is that the stove purchaser may pay off the stove sooner, since there is no added interest. Installments are an attractive feature for those who either can't afford, or are wary of, paying full upfront costs for a stove. If the stove is being used to produce food for sale, more income will be retained sooner by the stove purchaser. The downside to this strategy is that stove manufacturers who offer an installment programme do not generate capital that can be used to maintain their inventory, putting them at risk if households are unable to continue payments on a stove that is already in use.

Rebates and returns

Lewis conducted a study where an installment programme was coupled with the possibility of rebates for electric and improved biomass-burning stoves offered to homes in India. When the sales team visited homes to collect installment payments, the household would receive a rebate, which was discounted from the next installment payment, if the team verified that the stove was being used. Installments allowed households to defer initial cost and rebates incentivised sustained use over the installment period. In a subset of households in this study, stove purchasers were offered the opportunity to return a stove they were dissatisfied with it. Future installments were discontinued, although no money was returned to them from previous payments[99].

Stove and tank subsidies

Government subsidies are useful for the initial purchase of the stove or for purchasing LPG fuel, and would therefore speed adoption and sustained use of LPG if these subsidies are consistent and well applied. In the long-term, tank subsidies can help buffer the market variation in the cost of LPG fuel, allowing individual households to plan appropriately, setting aside a fixed amount of money for fuel purchase. National domestic programmes that provide subsidised LPG stoves and smaller 5 kg cylinders will make LPG a more accessible fuel choice for low-income households. Recently, the Cooking for Life[86] innovative distribution model study analyzing programmes in ten countries, found that subsidies can be channeled in correctly to middle-income users instead of the targeted low-income users[143].

Consumer options: Returns, warranties, insurance

Consumer options, such as the ability to return a defective product, warranty, and insurance coverage, are standard in developed countries. These options increase consumer confidence and can act as an incentive for a product purchase. Warranties are very important when consumers view the product as risky or very expensive, and provide the consumer with security that a product can be repaired or replaced. In lower- and middle-income countries, especially in rural areas, these options are practically nonexistent. A multi-location pilot of stove uptake in India observed that the highest sales were achieved (60%) when a stove return option was offered at the point of sale[99]. National policies should prioritise consumer protection, but many low-income countries have an overall lack of resources and competing priorities. This leaves the stove consumer dependent on stove manufacturers and distributors to guarantee their products. With no "return" policy, the stove purchaser is left to bear the cost of maintenance and repair. If the household values the stove and has the money to repair it, the stove is maintained but, as is often seen, the stove is often abandoned. Clean cookstoves, like LPG, will need maintenance and repair. Stove manufacturers and distributors that work with the family after point of sale, make repairs, and ensure safe use of the stove and fuel cylinder will add to the stove value and increase stove use rates.

Case Study: Conditional cash transfer programmes: Brazil's *Bolsa Familia*

Brazil's national approach to tackling the transition from solid fuel stoves to LPG stoves began more than 70 years ago. Today, the primary cooking fuel is LPG. One of the ways Brazil promotes the use of LPG stoves is by providing cash transfers to the poorest households in Brazil so that they can afford to pay for cooking fuel.

Conditional cash transfer (CCT) programmes are government programmes that give cash to eligible participants at or below the poverty line, conditional upon actions that households must take to improve the health or economic wellbeing of family members. Examples of these conditions include keeping children enrolled in school, keeping children vaccinated, and making sure that women attend prenatal care appointments[144].

One of the most comprehensive CCT programmes is the *"Bolsa Familia,"* which is a consolidation of three CCT programmes covering different areas of necessity: *Bolsa Alimentação*, *Auxílio Gás*, and *Bolsa Educação*. Participation eligibility is based upon income below the poverty level, and 99% of beneficiaries are women. When comparing communities with and without the Bolsa Familia, improvements in children's height and weight, lower infant mortality, lower rates of malnutrition, higher prenatal care attendance, lower rates of diarrhea and pneumonia, higher vaccination rates, and higher class attendance have been observed[145]. In this example, the Brazilian government introduced *Auxilio Gas* as a strategy to phase out cooking gas subsidies while still making it possible for poor families to afford gas. Under this programme, the government made an unconditional (not conditional on the use of the stove) transfer to poor families with a monthly per capita income of less than half a minimum wage. The programme was administered by the Ministry of Mines and Energy.

Supply chain development

While clean cooking technologies such as LPG and electric stoves have been available for over 50 years in low- and middle-income countries, the provision of electricity and LPG is not always dependable due to the underdevelopment of the energy supply chain[25]. Potential target markets for LPG are often located in remote areas and lack basic infrastructure such as dependable roads, which hinders the transportation of LPG stoves and fuel.[146] Government subsidised programmes to distribute clean cookstoves are doomed to fail if the production and distribution of clean cooking technologies is not guaranteed[96,127,147,148]. For example, in the 1980s and 1990s, the failure of massive national efforts in India to distribute over 30 million "improved" stoves was largely attributed to the lack of supply chains and inability to fix stoves that failed after two years. A main priority of the Global Alliance for Clean Cookstoves is to strengthen supply chains and last mile distribution models to achieve the adoption of clean cooking technologies and fuels[149].

Regulation of LPG stoves and home safety programmes

While many countries have guidelines for quality control of LPG gas tanks and fuel distribution in target countries, these guidelines are insufficiently enforced. The goal of mass adoption of LPG stoves has to be accompanied by global and national quality control standards for tank design, including the adoption and enforcement of a certification process and the inclusion of factories that manufacture tanks and tank filling stations. Overfilled tanks increase risk of gas leaks and explosion. Literature conflicts about whether larger or smaller LPG tanks increase risk of burn injuries. Quality control of tanks extends past the initial manufacturing and sale as they are reused and therefore undergo wear and tear. For example, steel reinforced rubber tubes used should always be used and replaced when they show signs of cracking or weathering. Clamp devices and safety valves should be used to prevent leaks. Therefore it becomes critical to develop a standardised operating protocol for identifying failing tank parts, repairing or replacing them, as well as removing damaged, dented, or otherwise unsafe tanks from circulation.

Filling stations should be the location for tank quality control as issues can be dealt with on the spot when users bring their tanks to be filled. It is best to avoid leaks all together by ensuring tank quality control as highly noxious substances need to be added to LPG into order to alert users about leaks.

In addition to ensuring tank quality control, safety programmes need to focus on both men and women. While the messages in safety programmes should be standardised, the method of communication needs to be tailored to each user's educational capacity and level of literacy, including visual messages. Since men typically purchase tanks from vendors and install them in kitchens, men and boys must be educated about safely hooking up LPG cylinders to the stoves, detecting leaks in the tubing and at the valves, and what to do if a gas leak is detected. Women and young girls also need to learn how to detect leaks and know what to do when a leak is detected, as they spend most of the time in the kitchen.

Cooking location

Traditional open fires can be used in the kitchen or outside the home. In some homes, traditional open fires are located in kitchen structures that are separated from the main house and sleeping areas. Many of these simple kitchen structures do not have doors. If an LPG stove is purchased or provided, household members may improve kitchen construction, or add a door to the kitchen that can be locked, to keep the stove from being stolen. In some circumstances the household may decide that the stove is safest inside the home, which may mean putting the stove in areas closer to where family members sleep. Households will move LPG stoves away from windows so that the flame does not blow out, so education about keeping windows or doors partially open is important.

The role of micro-institutions in the transition to LPG

Micro-institutions, including NGOs, creditors, and retailers, can help bridge the gaps between evolving market forces, supply chain deficiencies, and the current needs of individuals and households transitioning to clean cooking technologies[99]. Micro-institutions provide loan alternatives through microcredit loan programmes. This can help to develop the local economy through the creation of LPG markets, as well as job creation around the supply and maintenance of stoves. Micro-institutions can create more flexible payment plans for individuals and provide consumer options, such as stove returns and repair services[99], which can generate consumer confidence. Furthermore, because micro-institutions are very close to the community and individual households, they can innovate and tailor safety programmes on a smaller scale.

Case Study: *GenteGas*

Delivering affordable gas stoves and household health education to low-income families exposed to toxic levels of woodsmoke

GenteGas is a local Guatemalan company that has developed a social enterprise model to transition families to LPG stoves, addressing current market failures and incentivising low-income communities in peri-urban areas to switch to LPG fuel. GenteGas evolved in response to the lack of concerted efforts to deliver LPG to households using solid fuels. Their model is a private-academic partnership between GenteGas, the University of California, San Francisco, and the Universidad del Valle de Guatemala, and is funded by Grand Challenges Canada.

The GenteGas model focuses on:

- educating households about the health risks when cooking with wood
- training households on how to safely use LPG
- offering financed starter packages and fuel in smaller quantities for those with limited liquidity to make larger purchases
- creating a community of women entrepreneurs to offer LPG stove packages
- offering a continuing source of fuel cylinder refills, assuring that cylinders are properly filled and maintained

The goal of GenteGas is to distribute LPG stoves through women entrepreneurs at community meetings, festivals, and cooking demonstrations. The ongoing research activities which run parallel to LPG stove sales include monitoring LPG and traditional stove use using stove temperature data; carbon monoxide and particulate matter levels; assessing barriers and enablers for stove adoption and sustained use; and ascertaining household knowledge of the impacts of smoke on family health.

Although the project is in early phases, stove sales are highly dependent on two factors: active, engaged women entrepreneurs and availability of a credit mechanism for consumers. Currently GenteGas is developing additional strategies to recruit and retain a growing cadre of women entrepreneurs. Future strategies will include 1) trainings that focus on women's agency as a means of strengthening women's capabilities to engage with potential consumers; 2) a programme that works with sales goals and provides incentives to promote sales; and 3) ongoing training of women on behavioral messaging around the health benefits of gas stoves compared to the hazards of exposure to smoke from woodstoves. Women entrepreneurs will receive certificates for completion of training.

A second factor that impacts sales is accessible credit for the target market. Families are interested in purchasing gas stoves but many don't meet the bank prerequisites to qualify for credit because they work on their land, in their home or outside of the formal (monetized) economy. A Guatemalan bank is processing credit loans, but credit applications have gotten off to a slow start due to the inability to verify household income. In response to this, GenteGas developed an in-house credit mechanism to offer credit to households, which has shortened time for application processing and stove installation.

Section 6

Summary of Key Opportunities for Promoting Clean Cooking Technologies to Improve Children's Health

"Children drive change. Children are the experts on their own lives. They can contribute valuable knowledge to validate and enrich the evidence base–if only they have a chance to be heard." [150]

If a concerted effort is made globally to improve access to clean cookstoves, between 600,000 and 1.8 million premature annual deaths may be averted. This estimate includes between 400,000 and 600,000 deaths *per year* of children below the age of five in Sub-Saharan Africa, South Asia, and East Asia[151], the areas most impacted by the burden of disease from exposure to HAP.

National and regional programmes should select and distribute options that are rigorously tested, making sure that the stoves reduce total and indoor emissions, save fuel, and are safe. Subsidies, financing options, and community-wide distribution needs to be prioritised to reach households that continue to cook with wood, dung, coal, and crop residues. In order to achieve the WHO air quality targets and reduce poor health, such as ALRI in children under five years of age, households must fully adopt LPG or electricity, and cannot continue to use other polluting stoves ("stove stacking") inside or near the home.

Compared to electricity, LPG is currently the most viable fuel option for 15% of the world population that lacks electricity16. By 2030, it is estimated that 1.2 billion people will lack electricity; of these, 70% would be in Sub-Saharan Africa and 20% in South Asia[151]. One of the goals of the WLPGA is to transition one billion people from solid fuels to LPG by 2030. Developing markets for affordable and accessible LPG, as well as other kinds of clean-burning gas (biogas and natural gas) needs to be prioritised[8]. In order to make this happen, new partnerships between petroleum, gas and power industries, government energy ministries, NGOs, other micro-institutions, and academia must be forged[8]. To incentivise the full adoption of LPG for cooking, complementary strategies such as generating demand for LPG stoves, strengthening the supply chain of LPG stoves and fuel, and developing regulation mechanisms to ensure safety of LPG are essential. Creating a supportive infrastructure for operating, inspecting and maintaining LPG and other clean stove technologies is necessary during the transition to new stove technologies.

Key Lessons Learned in the Promotion of New Markets for LPG in Developing Countries

- LPG can be affordable outside of urban areas, where wood fuel is currently purchased. On the other hand, "for many consumers who do not participate in the monetized economy, it will be premature to promote LPG markets."
- One-time subsidies on appliances could be a good use of government (or other) resources.
- Microcredit initiatives should emphasize the cost-saving and productive potential and should seek to package both the gas (and appliances) and the financing.
- Concerns about safe handling, cylinder refilling, and transportation can be serious barriers to market expansion. These issues need to be addressed by raising awareness among consumers and strengthening regulatory environments.
- Appliances for a range of end uses required by consumers must be available.
- Government leadership is essential, backed up by policy that sets the basic parameters for successful market expansion and avoids conflict between, for example, subsidies on competing fuels that undermine efforts to promote LPG markets.
- Specific initiatives, such as integrated energy centers (as in Morocco and South Africa) offer an effective means of developing markets in rural areas.

Source: Authors, based on McDade 2004.

From Bruce (2006)[148]

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