Market Barriers to Clean Cooking Fuels in Sub-Saharan Africa: A Review of Literature

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An SEI Working Paper

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ACRONYMS AND ABBREVIATIONS

ARI	Acute respiratory infection
ALRI	Acute respiratory infection
CCFB	Clean Cooking Fuel Bureau
CDM	Clean Development Mechanism
CHAPOSA	Charcoal Potential in East Africa
EAC	East African Community
GCCFI	Global Clean Cooking Fuel Initiative
HDI	Human Development Index
IPCC	International Panel on Climate Change
IEA	International Energy Agency
LPG	Liquid petroleum gas
MDGs	Millennium Development Goals
MGI	Millennium Gelfuel Initiative
NMHC	Non-methane hydrocarbons
ODA	Official Development Assistance
PIC	Products of incomplete combustion
ProBec	Programme for Biomass Energy Conservation
UN	United Nations
UNDP	United Nations Development Programme
USD	United States dollars
WHO	World Health Organization

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ABSTRACT

In the developing nations of sub-Saharan Africa, providing households with modern energy services is a critical step towards development. A large majority of households in the region rely on traditional biomass fuels for cooking, which represent a significant proportion of energy used in the domestic setting. The disadvantages of these fuels are many: they are inefficient energy carriers and their heat is difficult to control; they produce dangerous emissions; and their current rate of extraction is not sustainable for forests. Transition to clean cooking fuels such as liquefied petroleum gas (LPG) or ethanol would resolve many of these issues as they do not produce dangerous particulate emissions, and are commercially viable, offering a number of socio-economic advantages over traditional options.

Despite the benefits of fuel switching, clean cooking fuels are rarely used in households in sub-Saharan Africa. Their failure to attain widespread use can be attributed to a number of market barriers. One of the major issues is cost: clean cooking fuels are prohibitively expensive for many households, and the high price of compatible stoves further discourages their use. Besides the expense, many consumers are hesitant to adopt the new technology, reflecting the lack of public awareness of the relevant issues. At the same time, Africa's underdeveloped infrastructure prevents these fuels from being made available in many local marketplaces. To date, this combination of factors has largely stifled the transition to clean cooking fuels.

National governments can adopt a number of strategies to address these issues. The creation of clean cooking-fuel initiatives at the national level would be an important first step, after which governments can begin to address the issues more effectively. The introduction of relevant financial instruments would help to tackle the economic barriers to clean cooking fuels, and public outreach and education could overcome socio-cultural obstacles. Through such a policy framework, national governments can play a significant role in encouraging the transition to clean cooking fuels.

Key words: *clean cooking fuels; energy consumption; ethanol; LPG; gelfuel; biogas; woodfuel; reduced emissions from deforestation (RED); climate change*

1. INTRODUCTION

The provision of modern energy services to the developing world is an issue that is critical to metrics of international progress. The role of energy services in achieving the Millennium Development Goals (MDGs), while not explicitly referred to in the goals, has been clearly established (Modi et al. 2005; Axberg et al. 2005). Scaling up modern energy services in developing countries will boost efforts to reach MDG targets for poverty and hunger reduction, education, health, gender equality and environmental sustainability. Access to modern energy services will also increase quality of life as measured by the Human Development Index (HDI) (Reddy 2002). Because of the low levels of per capita energy consumption in developing nations, even small increases in energy consumption by individuals—which cleaner and more efficient energy sources provide—result in dramatic increases in the HDI.

Lack of access to modern technologies and fuels is thus a major impediment to development and underpins serious problems of poverty and health in developing countries. Household cooking, which accounts for a considerable amount of household energy use, is a clear example of this problem. A large majority of households in many countries depend on inefficient and primitive fuels and technologies, particularly biomass resources, to provide energy for cooking. Not only are these fuels inefficient, but their heat is difficult for the user to control and their supply subject to disruption. They also result in harmful emissions when used indoors. As efforts such as the Global Clean Cooking Fuel Initiative (GCCFI) suggest, this is a global problem. Worldwide, the number of people who depend on traditional biomass fuels is close to 2.5 billion, slightly more than half the population of the developing world. However, nowhere is this issue more pressing than in sub-Saharan Africa, where 76% of the population relies on traditional biomass fuels for cooking (IEA 2006).

Since the late 1970s, when it was first widely recognised in research literature, the issue of household cooking fuels in Africa has been addressed from many perspectives (Goldemberg et al. 2004). Initially, the prevailing approach was to try to introduce improved stoves that used traditional biomass fuels more efficiently, and there have been many studies exploring the feasibility of improved stove-dissemination programmes as well as efforts to put them into practice.

In recent years the focus has shifted away from traditional fuels towards modern alternatives, and ultimately to the cleanest of those alternatives—liquefied petroleum gas (LPG) and biofuels. Many governments have set targets to reduce dependence on traditional cooking fuels. For example, the East African Community (EAC), comprised of Burundi, Kenya, Rwanda, Uganda and the United Republic of Tanzania, has set a target of providing access to modern cooking fuels by 2015 for half of the households currently dependent on traditional fuels (GTZ, UNDP 2005).

With the assistance of international agencies such as the United Nations and GTZ (a German sustainable development enterprise), African nations are beginning to take interest in the promotion of clean cooking fuels. However, in spite of the many benefits that would be derived from a shift to cleaner fuels, they are scarce in African markets and failed to gain widespread use.

1.1 Objectives

This paper provides an overview of the social, economic, and political factors that act as market barriers to clean cooking fuels in sub-Saharan Africa. A qualitative assessment of these barriers is made through a general overview of clean cooking fuels, as well as through examples of specific fuels and countries. The barriers are then evaluated within the broader policy context in terms of the factors that have affected expanded use of clean fuels.

Of course, the large geographic area and the number of countries encompassed by this analysis limits how far barriers can be examined in specific locations. Furthermore, the barriers do not necessarily apply to all sub-Saharan countries: each country's geographic, demographic and economic circumstances uniquely affect the demand for clean cooking fuels. This analysis presents the framework required to determine the roles of social, economic and political institutions in existing and potential national markets for clean fuels.

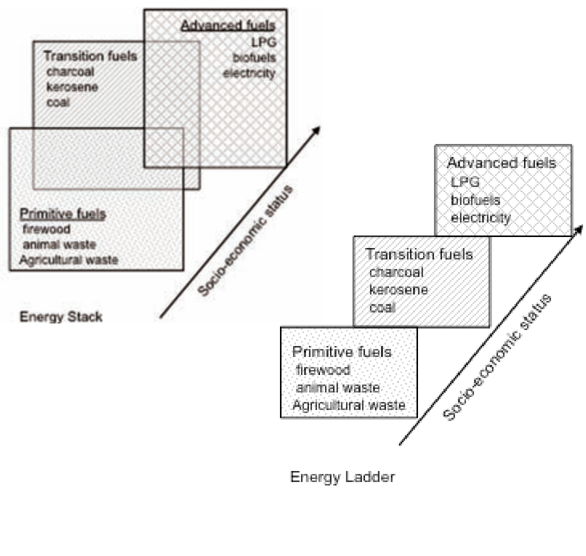
1.2 Framework

This paper draws on a broad review of literature relevant to clean cooking fuels in sub-Saharan Africa (and globally, where applicable). It is largely a qualitative analysis of market barriers to clean fuel, focusing on identifying and describing the barriers rather than measuring their effects. By synthesising the data and results of the many applicable studies, this paper describes the barriers in detail and provides insight into the mechanisms that drive them.

2. HOUSEHOLD ENERGY CONSUMPTION IN DEVELOPING COUNTRIES

In exploring the changing patterns of energy use in the household, researchers have traditionally turned to the "energy ladder" model (see figure 2.1), in which different fuels represent the "rungs" of the ladder. At the bottom are the least efficient, most polluting fuels. As a household gains socioeconomic status, it ascends the ladder to cleaner and more efficient forms of energy. The ladder model divides energy-use patterns into three stages of fuel choice. In the first and lowest stage, households depend solely on solid biomass, deriving energy from the combustion of firewood and animal wastes. In the intermediate stage households shift towards fuels that burn more efficiently but still have notable emissions, including charcoal, kerosene and coal. In the

Fig. 2.1. The energy ladder and energy stack models



most advanced stage, households move to a dependence on the cleanest forms of energy, usually LPG, electricity, or biofuels. The crux of the energy ladder is that it presumes a perfect substitution of one fuel for another: households do not mix fuels but instead choose only the fuel that best fits their socioeconomic position. Following the model, as their income increases one would expect households to completely abandon the inefficient, lower-tier fuels in favour of the higher-tier fuels that they can afford. It is thus implicit in this model that income has a uniquely important role in determining a household's fuel choice.

However, empirical data have shown that fuel substitution is not perfect and that households often use multiple fuels alongside one another. Recently, many researchers have supplanted the energy ladder model with what has become known as the "energy stack" model, proposed by Masera et al. (2000) (See fig 2.1). This model rejects the linear simplification of the energy ladder, suggesting that households do not wholly abandon inefficient fuels in favour of efficient ones. Rather, modern fuels are integrated slowly into energy-use patterns, resulting in the contemporaneous use of different cooking fuels. This model is supported by empirical data presented by Masera et al. (2000) and has been confirmed by further studies of the dynamics of fuel switching (IEA 2002; Pachauri and Spreng 2003). The complexity of fuel switching in the developing world suggest that there are many factors besides income that determine fuel choice. Social, economic and technological barriers all prevent the linear progression towards clean cooking fuels represented by the energy ladder.

The diversity of fuels used in household cooking in sub-Saharan Africa is representative of the complexities of the market. While a large proportion of households rely on traditional sources of energy (those that the energy ladder would describe as primitive or, in the case of charcoal, transition fuels), a small percentage of households have begun using advanced fuels for cooking. The following section describes the current patterns of fuel consumption in sub-Saharan Africa, a prerequisite to understanding the barriers to clean cooking fuels.

2.1. Traditional biomass cooking fuels

Some 575 million people in sub-Saharan Africa—76% of the region's population—depend on traditional biomass as their primary energy source (IEA 2006). By far the biggest source of biomass energy is woodfuel (firewood and charcoal) but agricultural residues and animal wastes are used where woodfuel is unavailable. The reliance on traditional biomass fuels is magnified in rural areas, where more than 90% of the population in many countries depend on these fuels.

Firewood

In most sub-Saharan African nations, firewood is the predominant fuel in the majority of households (see table 2.1). In rural settings, the proportion of the population that uses firewood is fairly consistent across countries—a result of its low cost and the lack of available alternatives. In urban areas, use of firewood as the primary fuel varies according to factors such as differences in price and availability of alternatives. Firewood

Table 2.1. Use of firewood as a household cooking fuel in selected sub-Saharan African countries

	Percentage of total population living in rural and urban areas		Percentage of rural, urban and total population dependent on firewood		
Country	Rural	Urban	Rural	Urban	Total
Tanzania[a]	76.9%	23.1%	95.6%	26.7%	77.4%
Uganda[b]	87.7%	12.3%	91.3%	22.1%	81.6%
Senegal[c]	59.3%	40.7%	89.1%	15.9%	54.7%
Zambia[d]	65.4%	34.6%	87.7%	10.1%	60.9%
Malawi[e]	85.6%	14.4%	98.5%	69.0%	94.3%
Kenya[f]	64.1%	35.9%	88.4%	9.6%	68.8%

Sources: [a]TNBS 2006; [b]UBS 2006a, UBS 2006b; [c]ANSD 2006; [d]CSOZ 2000; [e]NSOM 1998; [f]KNBS 1999, UNCDB 2007 is often burned in open stoves resulting in low energy density and low total energy efficiency on combustion, often between 10% and 20% (Bailis 2004). Furthermore, the difficulty of controlling heat levels in an open stove means that large masses of fuel must be burned.

The prevalence of firewood in the energy economy of sub-Saharan Africa follows both from its widespread availability and its low immediate cost to the individual—in fact in rural areas it can be collected for free. However, this low or non-existent immediate cost does not reflect the lost opportunities and external costs associated with its collection and combustion. Use of firewood as fuel is also a gender issue, as women spend by far the most time collecting the wood (see section 2.3).

Charcoal

Charcoal is another important fuel currently used for household cooking in developing nations. While its role in meeting the energy needs of rural communities is typically small, it is often widely used in urban areas (see table 2.2). In many respects its characteristics as a cooking fuel make it more desirable for household use than firewood as it emits fewer pollutants, has a higher energy content and is simpler to transport. Because of its advantages over firewood there have been a number of efforts to promote its use; nonetheless, in comparison to clean cooking fuels it remains inefficient and less than ideal for household cooking.

The processes involved in producing charcoal and using it as a cooking fuel are tremendously inefficient and resource intensive. Charcoal is often manufactured in rural areas where wood is more accessible. Wood is heated in earth kilns that restrict air flow, resulting in a product with a high carbon density that can be used as a cooking fuel. During the conversion process up to three quarters of the energy in the original biomass is lost. The efficiency of charcoal stoves commonly found in urban households is approximately 25%, so the overall system efficiency is quite low: about 5% of the energy in the original biomass is converted to useful energy for cooking (Davidson 1992). As a result, large quantities of biomass must be used to manufacture enough fuel to meet the energy demand of the urban population. In Nairobi, for example, it is estimated that a household that relies exclusively on charcoal will consume between 240 kilograms and 600 kg of charcoal annually. Between 1.5 and 3.5 tons of biomass is required to produce this amount of charcoal (Kammen 2006).

Table 2.2. Level of charcoal use for fuel in selected African nations

Country	Rural	Urban	Total
Tanzania[a]	3.6%	52.9%	16.7%
Uganda[b]	7.0%	66.8%	15.4%
Senegal[c]	1.8%	12.1%	6.6%
Zambia[d]	9.5%	52.1%	24.3%
Malawi[e]	0.4%	15.5%	2.5%
Kenya[f]	6.0%	20.8%	9.7%

Sources: [a]TNBS 2006; [b]UBS 2006a, UBS 2006b; [c]ANSD 2006; [d]CSOZ 2000; [e]NSOM 1998; [f]KNBS 1999, UNCDB 2007

2.2 Modern cooking fuels

Modern cooking fuels are considered to be those that have a high energy density, high combustion efficiency and high heat-transfer efficiency with sufficient heat-control characteristics. Biogas and LPG are commonly used gaseous fuels, and ethanol, kerosene and jatropha are the more familiar liquid cooking fuels.

Kerosene

Kerosene is a petroleum-based fuel produced in oil refineries. It is used almost exclusively in urban areas of Africa, though its level of urban use varies greatly across national borders. In Kenya, for example, it is used by 57% of urban households; in Tanzania by 15%; and in Uganda by 4%. Because it produces soot and other particulates when burned it is not considered a clean cooking fuel; nevertheless, it is potentially an improvement over woodfuel.

Two types of stoves are used for cooking with kerosene: wick stoves and pressurised stoves. Both have high total energy efficiencies of between 40% and 60% and are simple to use (Bailis 2004). However, there are numerous hazards associated with the household use of kerosene because of its toxicity and flammability. In 2000 in South Africa, kerosene ingestion was cited as the cause of death of 4,000 children; in addition, there were at least 46,000 fires resulting from household kerosene use (Bizzo et al. 2004). Such hazards make kerosene less desirable than other options.

Jatropha oil

Jatropha curcas is a small bush-like plant often used by farmers in rural villages as a means of protecting crops, preventing erosion, and demarcating property lines. Originating in Central America, the plant is now found in large areas of Southern and Eastern Africa. The oil extracted from the seeds of the jatropha plant has a wide range of possible applications: besides its potential as a cooking fuel, it can be used in soap production or for medicinal purposes and could become an important feedstock for biodiesel.

Because of the benefits derived from both the jatropha plant and its oil, Reinhard Henning (2004a) has put forth a model for rural sustainable development, termed the Jatropha System, in which rural communities would cultivate the plant for the various uses described above. Although the idea offers clear benefits for rural development, current technology for plant-oil stoves does not limit emissions enough to make jatropha an attractive alternative as a cooking fuel. The extent of pollutant emissions from use of jatropha oil is currently comparable to those from woodfuel stoves (Mühlbauer et al. 1998). However, with improved stove technology it is possible to reduce emissions, and with such improvements jatropha oil would be an attractive alternative to traditional fuels.

Biogas

Biogas is a clean cooking fuel that is produced through the anaerobic digestion of various organic wastes; the most commonly used feedstock is animal waste. The digestion process, which takes place in sealed airless containers called "digesters", produces a mixture of methane and carbon dioxide gases from which the carbon dioxide can be separated to further increase the energy density of the gas. The result is a clean fuel that produces no smoke or particulate matter on combustion. With a high total energy efficiency on combustion of nearly 60%, biogas is well suited to household cooking (Smith et al. 2000a).

One of the most important advantages of biogas is its feasibility in rural areas where it offers the potential for sustainable development projects. The scale of digesters can vary to suit the energy needs of a household or small community, and the only input required—organic waste—is readily available in rural areas. Modern biogas digesters designed to produce energy for a household can function on the waste produced by four humans, or one to two cows. Several countries have made efforts to introduce digesters to rural areas, but biogas remains an untapped energy resource. In Tanzania, which had an ambitious programme to disseminate biogas technology in the 1980s, only 200 digesters were operating as of 1991 (Rutamu 1999). However, biogas has been much more successful in China and India, which have approximately 11 million and 2.9 million digesters, respectively (Bizzo et al. 2004). The widespread use of biogas in these nations is evidence that it is a viable energy resource for household cooking.

Liquefied petroleum gas

LPG is a mixture of propane and butane. Despite the fact that it is a fossil fuel, LPG is considered to be clean because it can be burned very efficiently and emits few pollutants. Its use as a cooking fuel in Africa varies significantly across national borders and is highly dependent on government policy. For example, Senegal, which began its "butanisation" programme in the 1970s, has had the greatest success in integrating LPG into household cooking through fuel subsidies. LPG is the primary fuel for 37% of Senegal's population, including 71% of urban households (ANSD 2006). Other Western African countries have followed suit with subsidies of their own, but none have so far achieved Senegal's success. By contrast, in many Eastern African nations the market for LPG is almost non-existent and the fuel has little commercial value. At Tanzania's major petroleum refinery, half of the LPG produced is flared (Hosier and Kipondya 1993).

Where it is used in household cooking, though, LPG is a popular fuel. It is non-toxic, and the specialised stove required for its combustion is simple and easy to use. The fuel has a high energy density and a total energy efficiency of between 45% and 60% (Bailis 2004). In Senegal, it is dispensed from centralised facilities in 2.5kg and 6kg bottles for household use.

Ethanol and gelfuel

Several countries in Africa are currently distilling ethanol at significant scales, including Ethiopia, Kenya, Malawi and Zimbabwe. The ethanol produced is mainly used as an additive in transportation fuels. However, as the industry continues to expand, ethanol could offer the prospect of meeting household cooking needs.

Ethanol is produced by fermenting the sugars in various types of biomass feedstock. It can also be produced from starches if they are first converted into sugars. The resulting mixture is then distilled to yield a high concentration of ethanol. There are a wide range of crops that can be used as feedstock, including sugarcane, cassava, sweet sorghum, maize and wheat. The ideal feedstock for the production of ethanol is dependent on regional climate and soil conditions, the crop's annual cycles, and available technology.

Ethanol can be burned directly in specialised stoves, but further conversion to gelfuel is a simple process that offers notable advantages over the liquid form. For example, where liquid ethanol has been used for cooking, a high number of burns have been reported, and for this reason Brazil, which has been experimenting with household ethanol use, prohibited liquid ethanol and began marketing gelfuel instead (Bizzo et al. 2004). Gelfuel has a much higher viscosity, making it easier to handle and a safer alternative.

Despite the fact that ethanol is not yet widely available in sub-Saharan Africa, several projects have attempted to introduce it into specific communities. The Millennium Gelfuel Initiative (MGI), which began in 2000 as a public-private partnership, has marketed gelfuel with some success. Having demonstrated the household acceptability of gelfuel, MGI has established production facilities in Malawi, South Africa and Zimbabwe, and has plans to expand to other African nations (Utria, 2004). Another independent effort in Malawi, led by D&S Gelfuel Ltd. in partnership with the Government of Malawi, reported a wide acceptance of ethanol gelfuel in urban areas (Wynne-Jones 2003). Project Gaia has led an experimental effort in Ethiopia, installing ethanol stoves in 850 households in Addis Ababa (see box 1). The results of this project are still being evaluated (Lambe 2006).

Ethanol is well suited to meeting the energy needs of urban populations because of the large output of ethanol distilleries. There has also been discussion on introducing ethanol production into rural communities on a smaller scale through micro-distilleries. A recent proposal (OECD 2004) offered a model on which such a system could operate using sweet sorghum as the feedstock. The heat needed for ethanol production would be supplied by a cogeneration unit powered by biomass fuel pellets, meaning that production would be sustainable. Though such a system has not yet been implemented, it offers the prospect of providing clean and renewable cooking fuel to rural communities.

Electricity

Electricity is a clean and efficient source of energy but because the grid in most sub-Saharan countries is so poorly developed few households have access to it. Indeed, South Africa, the only sub-Saharan nation with a substantial number of connections to a national grid, accounts for 50% of all electricity generated in the entire continent. Northern Africa accounts for 20%, with the rest of sub-Saharan Africa generating 30% (Karekezi 2002). Most of the electricity that is generated in sub-Saharan Africa is used for industrial and commercial purposes. Even in urban settings where grid connectivity is substantial, use of electricity for cooking is not feasible because its prices are so high compared with traditional fuels. As a result, only wealthy households benefit (Karekezi and Majoro 2002).

Because of the tremendous capital investment needed to develop grids to the point where a significant number of households could have access to electricity for cooking, it is unlikely that electricity will account for any significant proportion of cooking energy in sub-Saharan Africa (except for South Africa) in the near future. Besides the costs of grid connection, further costs would be incurred for many householders because of

Box 1: Project Gaia in Ethiopia

While ethanol is still in development as a cooking fuel in many African countries, Project Gaia has taken the lead in Ethiopia to make it commercially available to urban households. A large number of stakeholders have contributed to the effort.

With respect to ethanol production, Ethiopia's position among sub-Saharan African nations is unique: already, eight million litres of ethanol are produced from waste products at the Finchaa Sugar Factory each year, and none of this ethanol currently has a market.

Because of this great potential, in 2004 Domestic AB (a major Swedish producer of alcohol appliances) introduced the ethanol-compatible CleanCook Stove and conducted a pilot study among 850 Addis Ababa households. The study confirmed the stove's popularity among users, who cited a number of benefits.

After the pilot study, the not-for-profit Gaia Association was formed with the mission to encourage the project's expansion and widen its scope. The project has since begun to formulate a business model to address issues of fuel retail and stove production and importation.

Project Gaia is planning a broad public awareness campaign to increase awareness of the fuel. and to finance the commercialisation project the association is seeking government subsidies and CDM funding. With this business plan the project has high hopes of making ethanol a feasible option for household use in Ethiopia (Kassa, 2007; Lambe, 2006; Stokes and Ebbeson, 2005).

the building work needed on their homes to make electricity use safe (Murphy 2001). Consequently—and because of the unique issues that apply to electricity generation—this energy currency is not explored in this analysis. Nonetheless it should be noted that where it is used in South Africa its benefits to users are substantial.

2.3. Benefits of clean cooking fuels

Reduced deforestation

The loss of the world's forests is a pressing environmental issue: the global forest area is decreasing by 0.2% per year. The rate of deforestation is greatest in Africa, where the area of forested land decreases by about 0.6% per year (FAO 2006). Researchers have pointed to numerous causes for this high rate of loss, including agricultural expansion, firewood collection, charcoal production, timber harvesting, and development of infrastructure.

Despite the difficulties inherent in measuring the extent to which these factors contribute to deforestation, a number of studies have attempted to do so. The findings of these studies vary depending on their regional focus. For instance, the Charcoal Potential in Southern Africa (CHAPOSA) project reports that agricultural expansion has been the primary cause of deforestation in Zambia (Chidumaya et al. 2001) and Mozambique (Ellegård et al., 2001), while charcoal production has been a major contributor to Tanzania's forest loss (Malimbwi et al. 2001). A more recent study of Tanzania's charcoal production industry confirms this conclusion, citing it as "a real threat to the long-term persistence of forests in Tanzania" (Mwampamba 2007). Despite regional differences there is a clear link between woodfuel extraction and deforestation: a statistical analysis that includes data from 40 African nations reports a strong correlation between the rate of deforestation and the rate of woodfuel production (Tole 1998). A transition to clean cooking fuels has the potential to reduce the rate of sub-Saharan deforestation as households would depend less on woodfuel for energy.

One of the primary motivators behind Senegal's butanisation programme (see box 2) was its alarming rate of deforestation, which in turn was thought to contribute to the acceleration of desertification. Since then, the rate at which woodfuel has been extracted has slowed markedly. The Senegal Ministry of Energy estimates the annual saving of firewood and charcoal to be 70,000 tonnes and 90,000 tonnes, respectively—which represents 15% of current demand for those fuels (Sokona et al. 2003).

The benefits of reducing the rate of deforestation are many and are felt on local and global scales. The benefits include the retention of important ecosystem services such as carbon sequestration, preservation of biodiversity, prevention of soil depletion and desertification, and the production of important resources (e.g. timber). The Millennium Development Goals directly address the issue of deforestation, and cite the proportion of forested land as an indicator by which to evaluate environmental sustainability (UN 2008).

Climate change mitigation

The predominance of woodfuel in household cooking is related to global climate change through two primary mechanisms: 1) to the extent that biomass for woodfuel is being harvested at an unsustainable rate (i.e. the rate of extraction exceeds the rate of replenishment) the capacity of the biosphere to remove carbon dioxide from the atmosphere is reduced; and 2) because the combustion of woodfuel in household cooking is incomplete, some of the carbon in the woodfuel is released in forms other than carbon dioxide, which may have a greater effect on climate. Most of the literature exploring the effects of the use of woodfuel has focused on the second mechanism, but a brief discussion of the first is warranted.

The rapid rate of deforestation in sub-Saharan Africa supports the claim that woodfuel is being harvested unsustainably. Because of deforestation, the amount of carbon that can be stored in the biosphere is continually decreasing, which results in a net increase of carbon dioxide in the atmosphere. In the most ideal biomass fuel cycle (one in which combustion is completed so that all the carbon is converted to carbon dioxide), if the biomass is harvested sustainably, emissions will be exactly offset by the uptake in carbon through the growth of forests. When the sustainability condition is not met, the rate at which carbon dioxide is emitted exceeds the ability of the forests to remove it from the atmosphere, resulting in increased atmospheric concentrations of carbon dioxide.

However, even if biomass were harvested sustainably, woodfuel would not be carbon neutral due to its incomplete combustion—the idealised fuel cycle in which all the carbon is converted to carbon dioxide is not a realistic model. Instead, due to incomplete combustion, carbon is released in other forms, including methane (CH4), nitrous oxide (N2O), carbon monoxide (CO) and non-methane hydrocarbons (NMHC). These compounds are referred to as products of incomplete combustion (PIC) and have a much greater potential impact on climate change. According to the IPCC Fourth Assessment Report (2007), the 100-year global warming potential of methane and nitrous oxide are 25 and 298 times that of carbon, respectively. Because of the incomplete combustion of woodfuel, between 10 and 20% of the carbon released is in the form of PIC (Smith et al. 2000a). This number, the molar ratio of PIC emitted to total carbon emitted, is defined by researchers as the k-factor of a fuel, and it varies based on the technology used with the fuel. Alternative cooking fuels typically have much lower k-factors than woodfuel (see table 2.3.).

Carbon output in sub-Saharan Africa could be significantly reduced by a shift to clean cooking fuels. Aside from their low k-factor, fossil fuels have several other advantages over woodfuel: a higher energy density, a higher nominal combustion efficiency, and a higher heat-transfer efficiency. These factors offset their higher carbon density, as both LPG and kerosene produce less carbon per unit of useful energy than woodfuel. At the same time, because the k-factor is lower, even less of the carbon is released as PIC. Given the current unsustainable pattern of woodfuel extraction, a transition to petroleum-based fuels would reduce net carbon emissions. Emissions scenarios based on this shift predict a decrease in cumulative emissions by 2050 of 1–10% (this projection is based on a combined use of kerosene and LPG to meet household cooking needs) (Bailis et al. 2005). It is, however, worth noting that if woodfuel were used in a sustainable manner and with higher efficiency, the carbon emissions would be of comparable magnitude to—and generally less than—that of petroleum-based fuels.

Biogas and ethanol offer the greatest potential for reduction of carbon output, as both can be burned close to completion and produced sustainably. Assuming sustainable production, carbon output of biogas in household cooking would be approximately one hundred times less than woodfuel when used unsustainably (Smith et al. 2000a). This is because the k-factor of biogas is so low that almost all of the carbon is released as carbon dioxide—emissions that are offset by carbon uptake due to the sustainable production of fuel. Because ethanol has not yet reached the market, little work has been done to measure its carbon output. However, one study conducted by the Biomass Technology Group as part of the MGI confirmed that ethanol gel-fuel has the lowest carbon dioxide output per unit of useful energy of any of the clean cooking fuels (Utria 2004). Because of its low k-factor and high combustion efficiency, it is likely that the use of ethanol would significantly decrease carbon emissions if it were produced efficiently and sustainably.

Table 2.3. The K-factor of various cooking fuels

Fuel	k-factor
Woodfuel	0.1–0.2
Kerosene (wick stove)	0.051
Kerosene (pressure stove)	0.022
LPG	0.0231
Biogas	0.00562

Source: Smith et al., 2000a

Reduction of indoor air pollution

The woodfuel that most of Africa's households use for cooking is a major source of indoor air pollution. The inefficient and incomplete combustion of woodfuel releases a number of hazardous pollutants, including carbon monoxide, sulfur and nitrogen oxides and particulate matter. In many households, poor ventilation exacerbates the effects of these pollutants, and women and children are often exposed to them at significant levels for between three and seven hours each day (Bruce et al. 2002). Such prolonged exposure to indoor air pollution has been implicated in the increased incidence of a number of respiratory diseases in developing nations.

The causal relationship between high concentrations of particulate matter and acute respiratory infection (ARI) has been established in a number of studies and is thoroughly reviewed in Smith et al. (2000b). Accounting for an estimated 10% of disease-related deaths in Africa (Bruce et al. 2002), ARI poses a major threat to women and children in developing nations. Children are particularly susceptible to contracting acute lower respiratory infections (ALRI)—a specific type of ARI—which is the leading global cause of death for children younger than five (Bruce et al. 2002). A recent study by Ezzati and Kammen (2001) that monitored 55 rural Kenyan households that relied primarily on firewood and charcoal has measured the exposure–response relationship between the incidence of ARI and the indoor concentration of particulate matter, which is a concave curve that increases with exposure. The potential to reduce exposure—and, by proxy, ARI—is significant: a follow-up study (Ezzati and Kammen 2002) found that a complete transition to charcoal would reduce the incidence of ARI by up to 65%. Clean cooking fuels offer the potential for even greater reductions. Gas burning stoves emit up to 50 times fewer pollutants than biomass burning stoves (Smith et al. 2000b): as a result, the associated incidence of ARI would be expected to drop considerably.

Several other diseases have been attributed to exposure to indoor air pollution from solid biomass fuels. Smoke produced by firewood combustion deposits carbon in the lungs and is known to cause chronic bronchitis, emphysema, and chronic obstructive pulmonary disease. Several studies have also linked childhood exposure to the smoke with asthma, though others have concluded that there is no association.

If the patterns of energy use for household cooking do not change, it is estimated that diseases attributable to indoor air pollution will cause 9.8 million premature deaths by 2030 (Bailis et al. 2005). However, the same study predicts that a transition to petroleum-based cooking fuels could delay between 1.3 and 3.7 million of these deaths, depending on the rate at which the transition to clean fuel occurs. Many of the lives saved would be those of women and children because of their disproportionate exposure. Such health improvements are highly prioritised in the Millennium Development Goals, which include a target of a two-thirds reduction in child mortality between 1990 and 2015 (UN 2008). At the same time, the issue of improving indoor air quality has important implications for gender equality, another subject addressed in the MDGs. Because the task of household cooking is almost exclusively borne by women, they are often at the greatest risk of contracting diseases related to indoor air pollution. Thus, fuel switching offers women the chance of better health—and with it, the opportunity to work towards development goals.

Socio-economic mobility

In rural communities that rely almost exclusively on solid biomass for cooking fuel, the burden of firewood collection falls primarily on women and, to a lesser extent, young girls. Women gather firewood on foot, often walking long distances with heavy loads; the International Energy Agency (IEA 2006) reports that the average load of firewood in sub-Saharan Africa weighs 20kg. The task of collecting firewood has become an increasing burden in recent years as a result of deforestation, which in many areas has necessitated travel over greater distances to collect wood.

The amount of time spent and distance travelled to collect firewood varies from region to region, but most studies have found that women spend a significant part of their day collecting firewood. A survey of 30 households near Lake Malawi found a mean distance to a viable firewood source of 2.1km, resulting in a mean trip length of 241 minutes, averaging 63 minutes travel time a day (Biran et al. 2004). The results of a study of three villages in northern Kenya suggest that women in the region spend an average of 70 minutes per day collecting firewood (McPeak 2002). In Tanzania, the roundtrip distance for firewood collection varies from just over 1km to 10.5km (IEA 2002).

Time spent collecting firewood represents considerable opportunity costs for women and has perpetuated gender inequality in the developing world. Because many women in rural communities spend so much time collecting firewood, they sacrifice valuable opportunities for their advancement through education or income-generating activities. This is one cause of the low literacy rate among rural women in sub-Saharan Africa compared with men.

Clean cooking fuel is purchased in markets, so its use would mean that women would not lose opportunities as a result of firewood collection. By relieving women of this burden, a transition to clean cooking fuels would help to close the gender gap in the developing world and allow women to devote more time to education and income generation, both of which are vital indicators in the MDGs (UN 2008).

Long-term sustainability

As well as the benefits discussed above, biofuels such as biogas and ethanol offer the prospect of long-term sustainability in household energy consumption. Current patterns of household energy use are unsustainable, as the demand for woodfuel is degrading and/or depleting forest resources in many areas. A transition to clean fossil fuels provides a temporary solution, but fossil fuels cannot be used indefinitely for household cooking. Biofuels produced using agricultural and organic feedstocks could serve as a long-term solution. A transition to such fuels could provide many regions in sub-Saharan Africa with a more sustainable and secure system for household energy production and consumption.

At the same time, by replacing other cooking fuels with sustainably produced biofuels African nations can become more energy self-sufficient. By circumventing the need to import and subsidise costly petroleum products to meet demand, these countries can avoid the fluctuations of the unstable global petroleum market. Meeting energy needs through domestically produced cooking fuel will thus provide an impetus for national economic development.

3. MARKET BARRIERS TO CLEAN COOKING FUEL TRANSITION

Despite the many advantages that clean cooking fuel has over traditional fuel its use remains limited in sub-Saharan Africa. The present failure of clean fuel to achieve widespread dissemination in households is a result of a combination of economic, political and social factors. These market barriers present considerable obstacles for policymakers, non-governmental organisations (NGOs) and other organisations in their efforts to provide African nations with modern energy services.

3.1 Price competitiveness of fuel

One of the major barriers to the use of clean cooking fuel is its cost to the individual, which in many regions can be significantly higher than the cost of traditional fuel. For clean cooking fuels to attain widespread use in sub-Saharan Africa, they must be offered to the public at a price that competes with traditional fuels. Of course, the price of different fuels varies to a great extent between urban and rural areas and across national borders due to transportation costs, availability of resources, national policy, and market-driven demand. Yet where direct and significant economic incentives to encourage demand for clean cooking fuel have not been implemented, there is a clear pattern in which traditional options are much cheaper and are more widely used than clean cooking fuel.

A household's fuel expenditure depends not only on the unit price of the fuel but also on its energy density and the efficiency of the stove that is used to burn it. With these parameters, it is possible to determine a fuel's cost per unit of useful energy in order to compare household expenditure on different fuels. There have been a number of such analyses, both single and multi-country, that have attempted to measure the fuel costs of household cooking. This paper reviews seven studies that explore the costs of household cooking in sixteen countries: Benin, Burkina Faso, Côte d'Ivoire, Ethiopia, Guinea Bissau, Kenya, Malawi, Mali, Mozambique, Niger, Nigeria, Senegal, South Africa, Togo, Tanzania, and Zimbabwe (Anozie et al. 2004; Bailis 2004; Ghanadan 2004; Kassa 2007; Sanga et al. 2005; Utria 2004; Visser 2006). Senegal, Ethiopia, and Tanzania each appeared in two of the studies, making a total of 19 samples.

This paper compares the average monthly costs of the various fuels based on a monthly energy demand of 320 megajoules. This corresponds to 2.5 meals per person per day (Utria 2004). Ethanol and gelfuel market prices are projected figures whereas the remaining fuels use market-based prices. When only commercially available fuels are examined, clear trends emerge. LPG has a higher monthly cost than charcoal in seventeen of the nineteen samples; in fifteen of the samples, traditional woodfuel offers the lowest monthly cost. Despite its inefficiency and heat loss, woodfuel tends to offer much cheaper energy for households than modern options, especially without price interventions.

The extent to which the price of ethanol will limit its use as a fuel is uncertain as it is not yet commercially available in most locations. One notable exception is in Addis Ababa, where Project Gaia has begun marketing ethanol so that it is competitive with subsidised kerosene (Kassa 2007). Elsewhere, where ethanol production is still in development, projections for market prices vary considerably. There are a number of factors (e.g. the cost of feedstock and other input, the scale of production) that must be taken into account in price projections. The price of ethanol depends in large part on the feedstock: up to one half of the cost of ethanol production is accounted for by the price of the raw materials used (Visser 2006). One study that reviews the efforts of the Millennium Gelfuel Initiative envisions ethanol being offered at a price that is competitive with traditional fuels in all the countries that it examines (Ethiopia, Malawi, Mozambique, Senegal, South Africa, and Zimbabwe) (Utria 2004). Gelfuel, while slightly more expensive, would still cost households less than LPG and kerosene, with a comparable price to charcoal. At the other end of the spectrum, a study of ethanol production in several countries in Western African concludes that ethanol's high market price would discourage its use as a cooking fuel. This study concludes that ethanol could not compete with LPG in the fuel market (Visser 2006).

Thus, it remains uncertain if ethanol will be competitive when it is made commercially available. Should prices be low enough to encourage its use, as predicted by the MGI, a major barrier will be avoided and ethanol could replace a substantial amount of woodfuel use, in which case it would be up to the supply side to keep pace with demand. However, it is quite possible that the price will be comparable to that of LPG and that ethanol will face a similar disadvantage in the fuel market.

The low price of charcoal and firewood results from the fact that both of these fuels are derived from a natural resource that can be tapped with little or no direct cost to producers or consumers. In other words, where forest-based resources are neither priced nor regulated, people may be able to extract resources at only the cost of their own labour. With a few notable exceptions, the price of modern commercial cooking fuel is significantly higher than traditional fuel due to the processes required to produce and supply them to urban markets.

As long as the price of clean cooking fuel remains uncompetitive with traditional fuel it will be difficult for it to gain widespread use. However, there is evidence that where cost-effective alternatives to traditional fuel have been offered, they have gained a significant share of the market. The Government of Kenya, for example, removed all taxes on kerosene. Though not classified as a clean fuel, it is an improvement on woodfuel. Without tax the price of kerosene in Kenya is close enough to that of charcoal to offer a competitive alternative. As a result, many consumers in Kenya's cities switched to kerosene, which is now used in 56% of urban households. At the same time, the government policy has retarded a further shift towards clean cooking fuels by maintaining high levels of taxation on LPG, the price of which is well above all other options (Bailis 2004). Not surprisingly, use of LPG as a household cooking fuel is minimal in Kenya.

High taxation of petroleum-based products to raise government revenue is a common policy in sub-Saharan Africa. Because these taxes inflate the price of modern fuel, they often act as a barrier to transition. In Tanzania, for instance, 60% of the price of LPG is accounted for by taxes and distribution charges (Sanga et al. 2005), meaning that the price of LPG in urban markets is high enough to discourage even wealthy consumers. As a result the number of households in Tanzania that use LPG is negligible. Nonetheless, even if the taxes were repealed the cost of LPG would still probably exceed that of charcoal. It would therefore be difficult for LPG to compete in Tanzania's urban markets without a government subsidy.

While clean cooking fuel is relatively expensive in most sub-Saharan nations, Senegal's fuel market serves as an interesting exception. Due to government intervention in the "butanisation programme" (see box 2), which began in the 1970s, LPG is currently sold in urban markets at a price comparable to charcoal. Clearly, consumption of LPG in Senegal reflects its affordability: the proportion of Senegal's urban households reliant on LPG is greater than 70% (ANSD 2006). The case of Senegal provides strong evidence that government intervention can facilitate a switch to cleaner fuels. The programme's goal—to increase household use of LPG as a cooking fuel—was achieved through a direct government subsidy for LPG.

Despite the success of Senegal's butanisation programme, fuel subsidies as an incentive for fuel switching do not provide a simple solution to the problem

Box 2: Butanisation in Senegal

The goal of Senegal's butanisation programme, which was first implemented in the 1970s was to introduce LPG in place of traditional biomass fuels, which were being extracted at an alarming rate.

The programme began in 1974 with the introduction of the Blip Banekh, an LPG-compatible stove. Despite the fact that the stove and all required cookware were exempt from import duties, the programme initially failed to prompt large-scale use of LPG. As a result, in 1976 the Senegal Government opted for the implementation of a direct fuel subsidy on 2.75kg (and later 6kg) LPG fuel cylinders, funded by taxes on other petroleum products. By offering discounts on smaller units of fuel, the government hoped to provide an adequate incentive to encourage fuel switching. The success of Senegal's fuel subsidy can hardly be overstated: annual domestic consumption of LPG rose from 3,000 tons in 1974 to 100,000 tons in 2000, almost all of which is sold in the smaller cylinders designed for household use. Annual growth in consumption during this period was between 10 and 12%. In 1998, the government began to reduce the subsidy by 20% per year with the goal of eliminating it altogether by 2002.

Since the subsidy's elimination consumption of LPG in Senegal has continued to expand, though at a slower pace (by 2005 annual consumption was 140,000 tons), as the private sector has taken over the market. Due to competition between firms, LPG prices remain affordable for most households, and it is now the primary cooking fuel in 71% of urban households. In the capital city of Dakar over 90% of households use LPG for cooking (ANSD 2006; Sarr and Dafrallah 2006; Sokona et al. 2003).

of price competitiveness. The primary beneficiaries of such subsidies tend to be wealthy and middle class urban households. The desired effect of the subsidy is often lost on the urban poor, who, with little disposable income, find it more affordable to purchase woodfuel on a day-to-day basis (Kebede and Dube 2004). Poor households tend to prefer fuel that can be purchased in small, discrete quantities (e.g. charcoal, firewood) to that which requires the purchase of a larger unit of fuel (e.g. a tank of LPG) (Alfstad et al. 2003). This purchasing pattern complicates the discussion of economic issues: in the long term, poor households might spend more money by purchasing traditional fuels each day instead of purchasing larger quantities of clean cooking fuels.

Fuel subsidies can even have a negative effect on the urban poor. A study of kerosene subsidies in several African nations found that the urban poor would benefit from their removal, because they continue to purchase traditional fuels which are taxed to fund the kerosene subsidy (Kebede and Dube 2004). Thus, before any subsidy is introduced there should be careful consideration of how all stakeholders might be affected. Nonetheless, Senegal's success with subsidies still provides a promising example of how such a policy can change fuel consumption patterns.

In comparison, price incentives have been markedly less successful in rural areas, where the patterns of fuel use are significantly different from urban settings. In Senegal close to 90% of the rural population still depends on woodfuel despite the LPG subsidy (ANSD 2006). Of course, there are two factors at play here: the price of different fuels and their availability in remote rural areas (the latter is discussed in section 3.3). In rural sub-Saharan Africa the difference in price between traditional and clean cooking fuel is more exaggerated than in urban areas: many households collect firewood for use in the home at no immediate cost, and even in rural markets the price of wood is significantly less than in urban areas.

However, this does not reflect the social and external costs of woodfuel use, which households generally do not consider. The first of these is the opportunity cost associated with firewood collection. Several efforts have been made to calculate proxy prices for rural firewood based on the employment opportunities lost to those who collect it (Nyang 1999). The social cost is greater still: it includes negative health effects due to indoor air pollution as well as external costs associated with climate change, deforestation and other environmental issues. As long as firewood is regarded as a "free" fuel because its true social cost is not recognised, it will be difficult for any clean cooking fuel, no matter how cheap, to gain widespread use in rural communities. Thus, the artificially low price of woodfuel remains a major obstacle in the transition to clean cooking fuel.

3.2 Technological issues

In the wake of Senegal's success with LPG subsidies, several other Western African countries have implemented similar programmes in an attempt to encourage the use of clean cooking fuels. In addition to a subsidy on LPG, Burkina Faso has introduced forest taxes and levies in an effort to drive up the market price of firewood, which is by a long way the main fuel of choice in both rural and urban settings. However, the effectiveness of these policies in shifting fuel consumption patterns has been slight in comparison to Senegal. In the capital of Burkina Faso, Ouagadougou, 13% of households have made the transition to LPG, but over 70% still rely on firewood (Ouedraogo 2005). The failure of a larger scale transition points to other market barriers and can, in part, be attributed to the capital costs associated with fuel switching, as households must make significant investments in stoves compatible with modern fuels.

The main reason for the hesitance to adopt new stoves is the large investment required. With a large fraction of households in sub-Saharan Africa living on less than a dollar a day, the price of stoves compatible with clean cooking fuel is prohibitive for many households. In Ouagadougou, the equipment required for cooking with LPG costs almost nine times as much as a 12-kg supply of the fuel itself (Ouedraogo 2005). Because the initial outlay is so high, if a household does not see immediate fuel savings it is unlikely to make the investment.

There have been several recent studies that have analysed the possibility of disseminating stoves compatible with gelfuel. There are a number of models currently being tested in the field. The SuperBlu Stove, which has been tested in Malawi, is projected to cost around 10USD (Robinson 2006). Other models developed as part of the Millennium Gelfuel Initiative are expected to have prices of between 2 to 20USD (Utria 2004). Although this seems a low figure it is still a big investment for poor families. In the area of Malawi where the Bluwave stove was tested, the purchase of a stove would consume more than a quarter of average monthly income (Robinson 2006). Clearly such an investment is likely to deter a transition to clean cooking fuel.

In light of the size of the initial investment, how to disseminate stoves more widely is a major question. However, while high capital cost is a deterrent, programmes that have offered subsidised stoves to households for free or at a minimal cost have been received with little enthusiasm. In such programmes, the direct subsidies created an undervaluation of the stoves and the users did not make the effort to operate it properly or maintain it to ensure its durability. This resulted in low usage rate; end users did not value that which was freely given (Barnes et al. 1994). Many dissemination efforts have succeeded by pricing the stove at a self-sustaining level in a market where the socio-economic benefits of its use are recognised. The user is thus encouraged to purchase, and more importantly use, this stove for its financial value and also for its social benefits (e.g. in terms of health and opportunity cost).

The success of Senegal's butanisation programme suggests that it is possible to achieve widespread dissemination of advanced stoves in spite of their prices. With the introduction of a specialised LPG stove in 1974, the government removed all taxes on imported equipment associated with the stove. Nevertheless, the price remained above the level that many households could afford. In 1976, the government reinstated taxes on the imported equipment but introduced heavy subsidies on LPG, offering a clear economic incentive to switch. Consumers were willing to make a significant initial investment in the knowledge that it would be offset by savings in fuel due to the subsidy. (Sokona et al. 2003). Senegal's butanisation programme thus indicates that the price of fuel has an important effect on the willingness of a household to make an initial investment in a stove.

For many poor households, though, the potential for future savings on the price of fuel may not be enough to encourage investment in a stove. Because such households have a limited disposable income, savings in the distant future will not prompt a large investment today, and fuel choices are often made on the basis of first costs instead of "lifecycle" costs. Therefore, a big investment in a stove can still deter fuel switching even if fuel is heavily subsidised.

The capital cost of a stove, however, is not the only obstacle to the adoption of stoves compatible with clean cooking fuels. The successes and failures of numerous projects in the 1980s and 1990s to introduce more efficient biomass stoves in various regions of sub-Saharan Africa show that other factors determine whether a stove will be adopted. In particular, finding a design that meets the needs of users plays a critical role, as consumers are at times hesitant to adopt a new and foreign technology. This is especially important for the emergent ethanol-fuel technology for which new stove designs are being rapidly developed. The assumption that consumers have a singular preference for higher efficiency stoves is misguided; efficiency does not guarantee public acceptance. Stoves that are designed and tested in laboratories without field-testing have often been poorly received (Barnes et al. 1994).

Socio-cultural preferences also affect the acceptance of stoves. Often, the new technology introduced for cooking with clean fuel requires specialised utensils and allows households little flexibility for use of pots and pans. The women responsible for cooking often have particular preferences for pots and pans depending on the food being cooked, and modern stoves are often incompatible with traditional kitchen practices. Thus, the purchase of a new stove would require the adoption of new cooking habits, a change that many women are hesitant to make (Vermeulen 2001).

There are several possible ways to overcome these obstacles. Many recently developed stoves—specifically gelfuel stoves—have been or are being tested in the field and revised to meet the need of users before being introduced into the market. By revising design based on input from potential users, an ideal stove design compatible with user preferences can be achieved. Most designs for gelfuel stoves have undergone such rigorous field-testing. Both the SuperBlu stove and Millenium Gelfuel Initiative models have performed well in comparison with traditional stoves in field tests. As early as 2001 the Programme for Biomass Energy Conservation (ProBEC) was testing a stove in communities in Zimbabwe and reported that it performed well compared to traditional stoves, gaining the approval of users (Mhazo 2001).

Collaboration with local artisans and mobilisation of the local economy in the design phase has also helped recent stove programmes to succeed (Barnes et al. 2004). In many early efforts to disseminate improved biomass stoves in the 1980s, stoves were designed in government laboratories in such a manner that they were not adapted to consumer needs. When local artisans were brought into the design process, stove dissemination programmes were considerably more successful. Through such collaboration production is integrated into the local economy ensuring a compatibility with consumer needs as well as providing a direct stimulus to local industry. If future efforts to distribute stoves for clean cooking fuel are to succeed, such factors should be considered in the design.

3.3 Lack of infrastructure

One of the major impediments to the distribution of clean cooking fuels is sub-Saharan Africa's underdeveloped infrastructure. This is mainly a problem in rural areas, where the lack of an extensive distribution network complicates efforts to offer modern alternatives to traditional fuel. In urban areas, commercial fuels such as LPG are a success because it is simple to distribute fuel in areas of high population density. Furthermore, economies of scale are possible because of high demand in a localised area. In Senegal, for instance, as part of the butanisation programme fuel is dispensed from distribution centres in 2.75-kg and 6-kg canisters. In rural settings distribution becomes a major obstacle: in addition to low population density (and therefore low demand), transport infrastructure—roads in particular—are very poorly developed in rural sub-Saharan Africa.

The quality of existing infrastructure is also poor: half of all roads in rural areas are in need of "substantial rehabilitation", and only 10% are paved (Mwabu et al. 2004). Roads are so inadequate that in many rural communities even if fuels were supplied, transportation costs would be so high that they would be all but unaffordable. Furthermore, the dependability of supply of traditional fuels deters consumers from inadequate or unreliable supplies of alternative fuels. It is not surprising that most efforts to increase use of clean cooking fuel have focused on stakeholders in urban settings, where shortened supply chains lead to ease of access. The fact that over 90% of households in rural areas depend on traditional fuel for energy reveals the severity of the problem. Because the overwhelming majority of people in sub-Saharan Africa who lack access to modern energy services live in rural areas, it is imperative that the rural energy crisis is addressed.

Aside from improving regional infrastructure, one solution could be the development of small-scale local energy resources. Here, biogas digesters and micro-distilleries for ethanol might prove successful. If biogas were widely adopted, the need to establish extensive distribution systems would be bypassed. One study in rural Tanzania found that low cost biodigesters could provide up to 50% of cooking energy needs and that the initial investment could be recouped in 9 to 18 months (Rutamu 1999).

3.4. Lack of information

Another issue that complicates the shift to clean cooking fuels in sub-Saharan Africa is poor information flow between producers, consumers and intermediary organisations. Just as underdeveloped physical infrastructure prevents the distribution of fuel, poor information infrastructure has many adverse effects on the trade in fuel. Limited information flow acts as a barrier to fuel switching in several respects: first, since there is limited knowledge of specific patterns of household energy-use across sub-Saharan Africa, it is difficult to assess market demand and the potential for clean cooking fuel programmes in different areas; and second, consumers have limited access to information about the alternatives to traditional fuels and the accompanying benefits.There is also a lack of detailed information on household energy, which makes it difficult to determine the commercial viability of different types of fuel. Comprehensive energy surveys have not been conducted in many areas and it is often left to private organisations to try to fill the information gap. Government censuses have been inconsistent and often confuse the specific nature of household energy consumption.

At the same time, consumers have little access to information about their options. There is a lack of awareness among the public on a number of levels: first, many consumers are not aware of the available alternatives and do not have a clear understanding of what their purchasing options are. Second, those consumers who know their options are often ignorant of the effects of their consumption choices. Because they do not understand the consequences of their use of traditional fuel—specifically, the health and environmental effects—they continue to use it in spite of the benefits of a transition to clean alternatives. Because many people have received little education that would help inform their choice of fuel, encouraging a shift to clean alternatives is a difficult task. However, it is likely that better awareness would increase consumers' willingness to make the change. Thus, public education would play an important role in encouraging a transition to clean cooking fuels.

3.5. Socio-cultural issues

In addition to the factors discussed above—the most significant barriers to fuel switching—there are a number of minor social and cultural issues that reinforce the dependence on traditional fuels. Nearly all sub-Saharan African societies are characterised by patriarchy: generally, men are in control of the meaningful economic decisions in each household. Because it is women who are most often responsible for duties associated with household cooking, there is a minor conflict of interest, as household cooking is not a priority among men. Because of poor communication between men and women on these issues, women, who bear the brunt of the costs associated with cooking, have little input in a household's fuel choice. If women were included in the decision-making process for household economics, and assuming they have the required understanding of the costs and benefits, it is likely that clean cooking fuel would be much more widely used.

Cultural tradition also plays a role in the rejection of clean cooking fuel. The traditional methods of cooking with firewood are so deeply ingrained in many local cultures that modernisation has little appeal, even when the potential savings are recognised (Vermeulen 2001). The incompatibility of household cookware with improved stoves also illustrates how tradition can hinder the process of fuel switching.

4. A POLICY FRAMEWORK FOR CLEAN COOKING FUELS

An analysis of market barriers to clean cooking fuels is a useful starting point in the creation of a broad policy framework to encourage fuel switching, and points the way to practical solutions to the problems associated with household cooking. Any solution to sub-Saharan Africa's household energy crisis will require the direct attention and involvement of national governments. Strengthening the institutional framework that controls the market for energy services at the national level is a prerequisite for progress. The first task, as described in Goldemberg et al. (2004), should be the creation of a national clean cooking fuel bureau (CCFB) charged with collecting and analyzing relevant data and making informed policy recommendations specific to national circumstances. Based on the above analysis of market barriers, some of the most important considerations for such an agency are enumerated below, describing potential strategies to overcome the obstacles.

Because there are clear differences between the barriers encountered in urban and rural communities with regards to fuel switching, national policy on clean cooking fuel should reflect these differences. The total cost of conversion to clean cooking fuel is likely to be much lower for households in an urban setting. Therefore policymakers should first "pick the low-hanging fruit" through policies that encourage urban households to adopt clean cooking fuels.

Box 3: Biogas in Africa

Biogas systems have been installed as early as the 1950's in Kenya and South Africa, and presently, are used in several sub-African countries and in numerous locations such as commercial farms, health institutions, using a variety of inputs. However, the most common are household systems operating with domestic and animal waste.

Despite the demonstrated benefits for household use, biogas has not been widely adopted in sub-Saharan Africa, partly because the prerequisites for biogas generation are often not met. In Uganda, for example, this is attributed to location-specific problems (e.g. too few animals to supply a system; organic material depleted by nomadic grazing; inadequate water supply, etc.).

In many cases, growth in biogas use is constrained by the initial plant costs for individual or community projects. Lack of knowledge, maintenance and operation requirements, and an unwillingness to pay for cooking fuel has limited dissemination of the technology in Tanzania. Many of the biogas models in the Africa that were built were intended for small community-based demonstration projects with the expectation that the initial support would naturally lead to replication. However, it did not include specific future commercialisation plans, which led to programme failure after the subsidies were discontinued.

Nepal's Biogas Support Program (BSP) is an example of a successful biogas experience. Over 120 000 biogas plants have been installed, resulting in improved indoor air and sanitation condition. Nepal's free market conditions and standardisation of technology that has lead to improved quality are cited as prerequisites, demonstrating that national programmes can succeed with the right incentives.

Modelled on the successes of the Nepalese programme, a group of 27 African partners launched "Biogas for Better Life: An African Initiative" with the vision to develop market-driven partnerships to facilitate the growth of biogas programmes in Africa, with a specific focus on markets with the greatest potential and primary users of biogas—women. When the technology is demand driven, there exists an opportunity for both governments and entrepreneurs to develop a feasible, commercial biogas programme appropriate for the local setting (Rutamu 1999, WHO 2006, Biogas for Better Life 2007, Abbey 2005).

Because of the comparative ease with which modern energy services can be provided to urban households—coupled with the pace of urban population growth—it makes sense to initiate the transition to clean cooking fuels in urban areas. The issue of urban energy use is expected to become increasingly important, as the average rate of urban population growth in most sub-Saharan countries is close to double the national rate (Karekezi and Majoro 2002). The increase in demand that will inevitably accompany rapid population expansion underscores the importance of enabling access to modern energy services for this demographic, as doing so can be achieved at the lowest cost and with the greatest success. Over time, policies can be formulated to address the needs of peri-urban consumers, with the ultimate goal of reaching rural communities. Of course, much like the issue of subsidies benefiting primarily the upper classes, the urban focus raises questions of equity. While it is more feasible to promote commercial clean fuels in urban areas, alternative solutions—namely, small-scale sustainable development programmes that produce fuels such as biogas—can be implemented in rural areas to meet the need for modern energy services.

4.1 Implementation of economic incentives

If clean cooking fuels are to gain widespread use, consumers must have an incentive to switch. The current market price of fuel and stoves is, for the most part, high enough to discourage this transition, so government intervention through economic incentives is an important strategy. In countries such as Tanzania, a major part of the price of LPG is a petroleum tax—reconsidering tax policy on clean fuel is a major first step towards encouraging transition.

Governments can be even more proactive: through the introduction of targeted financial instruments—particularly taxes and subsidies—governments can increase the competitiveness of clean cooking fuel. A subsidy on clean fuel offers a direct incentive for uptake, and Senegal's butanisation programme has shown that such a policy can successfully increase the competitiveness of clean fuel. A properly allocated subsidy on stoves themselves is another option: a lower capital investment would encourage the adoption of clean cooking fuels in urban households, although it should be high enough to support commercialisation.

However, as suggested earlier, there are a number of issues that must be addressed when formulating an optimal subsidy on cooking fuels—specifically, issues related to equity and implementation. The beneficiaries of broad energy subsidies are most often wealthy urban consumers, while the consumption patterns of the lower classes often remain unchanged (Kebede and Dube 2004). Such subsidies often encourage fuel switching in those households that would have switched anyway. In such cases the impact of the subsidy is minimal since it mainly affects wealthy households and does little to alleviate the problems of poor families—a recurring theme in the Millennium Development Goals.

An optimal policy should target subsidies to lower income families so that they affect a broader demographic range and prompt more widespread fuel switching. Subsidies that target the fixed costs of fuel switching (e.g. investment in a new stove) offer such a potential, as it is often the barrier of the capital cost that discourages fuel switching among the urban poor. One such option, proposed by Karekezi and Majoro (2002), is a "cross" subsidy through which the price of technologies such as stoves and storage tanks is included in the purchase of fuel. Such a measure would effectively eliminate the barrier of high capital cost for poor households while also forcing wealthier households to pay more for their fuel. Another policy, which has proven successful in helping Brazil increase household use of LPG, is to target subsidies to the poor by offering a rebate to qualifying households (Goldemberg et al. 2006). In Brazil's case, up to 60% of the price of LPG can be recouped through such subsidies, making it an attractive option for poor households. Determining which mechanism would be of most benefit would be the responsibility of the CCFB. Nonetheless it is clear that, given careful consideration, such financial instruments can facilitate fuel switching among wealthy and poor households alike.

4.2 Cooperation and establishment of partnerships

What is also clear given the global nature of the household energy crisis, as described by the GCCFI (Goldemberg et al. 2004), is that national clean cooking fuel initiatives would benefit from the involvement of international agencies, industrialised countries and the private sector. A number of partnerships between national governments and international development agencies have emerged in recent years. The UN Development Programme (UNDP) and the German sustainable development organisation GTZ are providing assistance to the East African Community in its goal of providing access to modern cooking technology by

2015 for half the population that currently rely on biomass fuels (GTZ, UNDP 2005). Other nations in Southern Africa (Lesotho, Malawi, Mozambique, Namibia, South Africa, Tanzania, Zambia and Zimbabwe) have collaborated on the Programme for Basic Energy and Conservation in Southern Africa (ProBec), with the support of GTZ, to reduce dependence on biomass fuels (GTZ 2005). 27 African partners have launched the "Biogas for Better Life: an African Initiative" to facilitate the growth of biogas programmes. (Box 3).

The ongoing help of development agencies will play an important role in the transition to clean cooking fuels. National clean cooking fuel initiatives are likely to attract further investment from industrialised countries and private corporations under the umbrella of Official Development Assistance (ODA) and Clean Development Mechanisms (CDMs) (Goldemberg et al. 2004). Similarly, the private sector can play an important role. Ethiopia's Project Gaia provides evidence that businesses can benefit from getting involved in the issue of promoting clean cooking fuels.

4.3 Public outreach and education

While national policies that provide incentives for clean cooking fuel will play an important role in encouraging fuel switching, market barriers are social as well as economic, and the direct involvement of household consumers is required to overcome these social barriers. Governments have a great opportunity to promote fuel switching through the formation of partnerships with institutions and organisations that work directly with household consumers. There are several ways in which the public interest in clean cooking fuels can be mobilised.

Historically, stove dissemination programmes that have involved local communities in design and distribution have proven the most successful. By consulting local artisans and testing stoves in real household situations the uptake of new technologies has been greatly improved. Recent programmes that have followed this pattern, such as Project Gaia and SuperBlu, have seen their efforts reflected in the popularity of their stoves (Robinson 2006, Stokes and Ebbeson 2005). It is also vital that people should be properly trained to use the technology: simply distributing improved stoves will not be enough to ensure successful transition. Assisting the public during the introduction of improved energy services will foster better understanding and wider acceptance.

Another way to mobilise public interest is to improve education on issues around household cooking, especially among women. Lack of awareness of the costs and benefits associated with different fuels confounds consumer preferences, so it is important that consumers have full information regarding their choices. It is especially important that women be involved in the education process—because they are directly disadvantaged by use of traditional fuel for cooking, they stand to benefit the most from a transition to clean cooking fuel. This might be achieved through local campaigns or the organisation of groups that address these issues at a community level. Improvements in public education will hopefully bring to light the gravity of the issues.

4.4 Rural sustainable development

The ultimate goal of clean cooking fuel initiatives should be to provide access to modern energy services to urban and rural households alike. But because extending transport infrastructure to link urban and rural communities will take considerable time and investment, this is an unrealistic aim in the short-term, and alternative measures must also be taken. In particular, there is great potential to meet the energy needs of rural communities through the sustainable development of local fuel production systems, and national governments can encourage the use of these systems by collaborating with sustainable development agencies. This would help to satisfy the energy needs of rural communities as well as promote rural enterprise.

There are several ways in which this might be achieved. Biogas digesters are currently too expensive for many rural households (Murphy 2001), but if private investment were used to fund digester dissemination programmes, biogas could offer an attractive short-term solution to the rural energy crisis. Furthermore, as biogas programmes continued to expand, economies of scale would make these technologies accessible to an increasing number of households (See box 3). Another option is to introduce low-cost digesters made of plastic. Several designs are in development and would offer a cheaper alternative to standard digesters (Rutamu 1999). For many farmers, digesters would also have the side benefit of producing sludge fertilisers.

Of course, disseminating biogas technology is only one step in a successful programme. Ultimately, biogas initiatives are likely to fail unless they provide "hardware plus software implementation packages" (Reddy 2002), whereby the introduction of biogas technologies is accompanied by public education, training, and appropriate outside management. It is vital that not only biogas but all such initiatives recognise the need for a combination of "hardware" and "software" in facilitating the transition to clean cooking fuels—at all scales and income levels.

With the necessary improvements in stove combustion technology, the Jatropha System touted by Reinhard Henning offers another model for sustainable development, particularly in East Africa because of the plant's geographic distribution. This system offers a range of benefits to communities and has been found to be economically feasible in rural areas (as long as the seeds are collected and the oil is extracted locally and not purchased in the market) (Henning 2004b).

Because much of the population lives in a rural setting, sustainable development should be a priority for governments in sub-Saharan Africa. Transition to clean fuel in urban areas will benefit only a small fraction of the population in the region, and extending those benefits to rural communities will prove a challenge. In the meantime, governments should pursue policies to develop sustainable systems to meet rural energy needs. By coupling household energy with other development themes, sustainable development efforts can potentially generate synergistic and cost-effective approaches to the energy crisis, offering efficient and immediate solutions. Eventually, the short-term strategies described above would ideally give way to long-term solutions in which rural households have access to comparable energy services to urban households.

5. CONCLUSIONS

Research literature has identified a number of demand-side market barriers to the household use of clean cooking fuels. The combination of these factors—which are social, economic and political—has contributed to the continued dependence on primitive biomass fuels in the majority of households in sub-Saharan Africa.

While the socioeconomic market barriers to clean cooking fuels limit demand considerably, an active government can adopt a range of strategies to overcome these barriers. At the national level, governments must strengthen the institutional framework that governs household energy services to enable informed policy to be identified and implemented. National clean cooking fuel initiatives must offer both short- and long-term strategies for addressing the household energy crisis in sub-Saharan Africa.

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