The Quest for Fire: Hazards of a Daily Struggle

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Ever since humans first nursed embers into flames with a pile of sticks, biomass fuels have played a key part in our survival. Biofuels delivered light, heat, and a means to cook food that was otherwise eaten raw. But that first whiff of smoke also signaled the arrival of a new set of health problems, for lungs were not meant to breathe soot, nor eyes to absorb smoke. Today, some 1 million years after humans learned to use fire, biofuels remain the principal fuel for heating and cooking for approximately one-third of the people on the planet, mostly in developing countries, according to the World Resources Institute. Biofuels are even enjoying a revival in the industrialized world, where they are seen as a less expensive and less polluting form of energy than fossil fuels. Yet severe health problems persist with burning traditional biofuels, and these problems particularly impact women and children. What are the promises and pitfalls of biofuels? And can they be used without sacrificing human health and harming the environment?

Biomass and People

The term "biomass" refers to living or recently living matter, plant or animal. Traditionally, biofuels have included wood, charcoal, crop wastes, and animal dung. Biomass can also be converted into liquid fuels, such as methanol and ethanol (derived from wood and crops, respectively), and into gaseous products, such as methane (derived from decomposing animal and vegetable matter). When properly managed, biofuels are a renewable form of energy, whereas fossil fuels, such as coal, oil, and natural gas, are not.

Because biofuels are typically collected by end users from fields and forests rather than sold on the open market, exact figures on the number of biofuel users or the amount of material burned are hard to come by. Biofuels account for more than one-half of all energy use in many developing countries and for as much as 95% of all energy use in some of the poorest nations. The use of biofuels had been on a downward trend since about 1900, but may have slowed or even reversed among the poor in developing countries with the rising price of petroleum products and electricity.

The reason for the persistent popularity of biofuels is simple--they are cheap, available in many forms, accessible to many, often freely collected, and simple to use. Little or no processing is required to burn them other than collecting them off the ground and cutting them to size. The devices required to burn biofuels are simple; a three-stone hearth or a row of bricks arranged in a U-shaped pattern will suffice. Due to cultural preference, concerns about fluctuating availability and price, or a decision to spend income on other things, even people who can afford to switch to cleaner, more efficient fuels, such as electricity, kerosene, and natural gas, sometimes stick with biomass.

At the same time, biofuels give off relatively little energy compared with other fuels, and they are often dirty and time-consuming to collect. But even more distressing are the direct effects that collecting and burning biofuels have on human health,

particularly that of women and children. Anoja Wickramasinghe, a professor and head of the Department of Geography at the University of Peradeniya in Sri Lanka, has researched and written extensively on gender issues related to the use of wood for fuel. Wickramasinghe notes that in Sri Lanka, as elsewhere in the developing world, women bear the main responsibility for gathering, carrying, and using wood for fuel in the home. She finds that this "biofuel cycle" has become a major source of difficulty, stress, and physical discomfort for women.

Wickramasinghe divides the biofuel cycle into three spheres--procurement, carrying, and combustion--each having its own health problems. Procurement involves women venturing out from their homes to collect wood. As populations expand and woodlots around inhabited areas are depleted, women have to travel farther and farther to find adequate amounts of wood. Through her survey of 720 households in Sri Lanka, published in the December 2001 issue of *ENERGIA News*, Wickramasinghe found that, in addition to being exposed to sun and rain, women gathering wood incur cuts, bruises, sprains, fractures, skin irritation, allergic reactions, insect and snake bites, and other injuries. Approximately 68% of the households in Wickramasinghe's survey reported spending 2-3 hours, excluding travel time, collecting one load of wood, and that this activity is often repeated three times a week. The time spent gathering wood takes away from time available for other important tasks, such as breastfeeding of infants. A similar study in Cambodia, published in the same issue of *ENERGIA News*, revealed that women there are also exposed to malaria and landmine injuries in the gathering of wood.

Transporting fuelwood to the home is typically done by headloading. Approximately 80% of the respondents in Wickramasinghe's survey mentioned headloading as one of the most exhausting tasks in the biofuel cycle. Fatigue, headaches, and pain in the joints and chest were among the problems reported. Suffering is particularly severe among the elderly. "The headloading of wood several times a week over a period of more than thirty years, without having long breaks other than during late stages of pregnancy and immediately after child delivery, has weakened the joints, affected backs, and also weakened the resistance to infection," Wickramasinghe says.

The third, and perhaps most damaging, sphere is the combustion cycle. Throughout much of the developing world, cooking is done on primitive stoves in small rooms that frequently lack adequate ventilation. In Wickramasinghe's survey, 60% of households used a three-stone hearth or a U-shaped mud-plastered hearth known as a *chulha*. Only 28% of kitchens had chimneys, and only 32% had windows for ventilation. Under these circumstances, exposure to indoor air pollutants is unavoidable.

Many of the substances in biomass smoke can damage human health. These include particulate matter, carbon monoxide, nitrous oxides, formaldehyde, and polycyclic organic matter, including carcinogens such as benzo[*a*]pyrene. Particles less than 10 microns in diameter (PM_{10}), and particularly those less than 2.5 microns in diameter ($PM_{2.5}$), can penetrate deeply into the lungs and appear to have the greatest potential for damaging human health by contributing to respiratory ailments such as acute lower respiratory infection (ALRI).

Women's work. The cycle of gathering, carrying, and burning biofuels exposes women and children around the world to myriad health problems including exposure to hazards such as land mines, orthopedic problems, exhaustion, and respiratory and eye illnesses from wood smoke.
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Studies from Africa, Asia, and the Americas have shown that indoor levels of air pollution from combustion of biofuels are very high, often well in excess of modern health standards. Health effects are determined not just by pollutant levels, but also by the amount of time spent breathing polluted air, especially in close proximity to the stove. The U.S. Environmental Protection Agency maintains standard 24-hour averages for PM_{10} and $PM_{2.5}$ of 150 $\mu g/m^3$ and 65 $\mu g/m^3$, respectively. In developing countries where biofuels are used for cooking, the mean 24-hour levels of PM_{10} are typically in the 300-3,000 $\mu g/m^3$ range, and may reach 30,000 $\mu g/m^3$ or more during periods of cooking. The agency's 8-hour standard for carbon monoxide is 9 ppm. The

mean 24-hour levels in homes using biofuels in developing countries is in the range of 2-50 ppm, with values of 10-500 ppm reported during cooking.

Not surprisingly, numerous studies in developing countries reveal a strong association between household use of biofuels and a variety of health problems. In the June 2000 issue of *Thorax*, Kirk Smith, a professor of environmental health sciences at the University of California at Berkeley, Nigel Bruce, a senior lecturer in public health at the University of Liverpool, and colleagues reviewed studies in developing countries that have reported on the association between indoor air pollution and ALRI. They wrote, "The studies of indoor air pollution from household biomass fuels are reasonably consistent and, as a group, show a strong significant increase in risk for exposed young children compared with those living in households using cleaner fuels or being otherwise less exposed. Not all studies were able to adjust for confounders, but most of those that did so found that strong and significant risks remained."

More recently, Daniel Kammen, director of the Renewable and Appropriate Energy Laboratory at Berkeley, and his then-doctoral student Majid Ezzati developed the first exposure-response study, published in the 25 August 2001 issue of *The Lancet*, of the relationship between taking steps to reduce smoke exposure through fuel and stove switching, and reducing illness rates. This continuous risk relationship is key for evaluating a range of interventions that may provide large and small reductions in exposure.

The burden of ALRI falls particularly heavily on women, who do most of the cooking, and on infants and children, who spend a great deal of time near their mothers and are highly susceptible to ALRI. ALRI, the single most important cause of mortality in children under age 5, accounts for around 2 million deaths annually in this age group, according to the World Health Organization's *World Health Report 2000*. Analysis of data from India's 1992-1993 National Family Health Survey has shown that the prevalence of acute respiratory infection (ARI) in children under age 3 is more than 50% higher for households using biofuels than for those using cleaner fuels. Ezzati and Kammen's August 25 *Lancet* study, which looked at more than 400 people in rural Kenya, found that women who regularly participate in cooking activities are twice as likely as any of the men to be diagnosed with ARI or ALRI.

Numerous studies have reported on the association between exposure to biomass smoke and chronic bronchitis or chronic obstructive pulmonary disease. Cigarette smoking, which is prevalent among men in the developing world, is known to be a major factor in these illnesses. However, studies conducted in Nepal, Pakistan, and the Ladakh region of India, and revealed equally high incidence of these illnesses among women, few of whom smoke in these areas. And a study in New Guinea, where neither men nor women smoke frequently, reported patients with chronic lung disease in communities heavily exposed to indoor biomass smoke.

No association has been reported between lung cancer and exposure to wood smoke. However, Bruce and colleagues state in a paper published in volume 78, number 9 (2000) of the *Bulletin of the World Health Organization* that it would be unwise to conclude that biomass smoke does not increase the risk of lung cancer. "In

some homes, cooking for three hours a day exposes women to similar amounts of benzo[*a*]pyrene as smoking two packs of cigarettes a day," the authors write. They further write that exposure to all the carcinogens in wood smoke through cooking with traditional biomass stoves may be equivalent to smoking several packs of cigarettes per day.

One study, conducted in Guatemala by Bruce and colleagues Erick Boy and Hernán Delgado and reported in the January 2002 issue of *EHP*, analyzed the birth weight of babies born to women using wood for fuel. That study found that birth weight was 63 g lower for babies born in households using wood versus those using cleaner fuels. This result is consistent with a meta-analysis of the effects of environmental tobacco smoke, and with several outdoor air pollution studies published by the California Environmental Protection Agency in 1997.

Anyone who has been exposed to wood smoke knows that it irritates the eyes. There is some evidence that exposure to biomass smoke may also cause cataracts. A hospital-based case-control study in Delhi, published in the May 1989 issue of *Archives of Ophthalmology*, found that the use of liquid petroleum gas was associated with a lower risk of cortical, nuclear, and mixed cataracts, compared with the use of cow dung. An analysis of over 100,000 people in India showed significantly increased odds for reported partial or complete blindness among persons using mainly biofuels, compared with other fuels.

Researchers point out that, until recently, studies on indoor air pollution and health effects had suffered from a lack of detailed and systematic exposure information, had been strictly observational (with no intervention studies), had frequently dealt inadequately with confounding variables such as malnutrition, low birth weight, and housing type, and had poor outcome measures (diagnosis of illness). To remedy this situation, the NIEHS has funded what is perhaps the first randomized intervention trial in the rural highlands of western Guatemala to attempt to directly measure the change in incidence of ALRI and other diseases after the installation of stoves with chimneys in households using open fires for cooking and heating [see "New Stoves for Better Children's Health?" p. A33 this issue].

Despite the shortcomings of the research, studies strongly suggest that exposure to biomass smoke is a major health hazard in the developing world. In the 2 November 2002 issue of *The Lancet*, Ezzati and colleagues list it as a leading cause of burden of disease in all high-mortality developing regions and cite it as the cause of 2.6% of the global burden of disease, based on the literature available.

Biomass and the Planet

Although the planet has survived through some 1 million years of biomass collection and burning by humans, evidence suggests that the practice is damaging to the environment. Of particular concern is the collection and burning of massive amounts of wood. The United Nations Food and Agriculture Organization (FAO) estimates that about 63% of all wood harvested is burned as fuel. Five countries--Brazil, China, India, Indonesia, and Nigeria--account for about half of the firewood and charcoal produced and consumed each year. Though data are scarce, the FAO estimates that

fuelwood consumption rose by nearly 80% between 1961 and 1998, slightly trailing world population growth of 92% over that period. Demand for fuelwood is driven primarily by commercial enterprises and by growing numbers of rural poor, who depend on wood for their cooking and heating needs.

What effect does this consumption have on the world's forests? Twenty years ago, conventional wisdom held that growing fuelwood collection would lead to widespread deforestation. A 1979 Nepalese forecast, for example, predicted that all accessible forests in the country would disappear by 1990. However, actual forest loss has been about one-half the predicted amount, an error resulting from the mistaken assumption that forests were the sole source of firewood, according to Emily Matthews, a senior associate at the World Resources Institute, writing in the institute's 2000 report *Pilot Analysis of Global Ecosystems (PAGE): Forest Ecosystems*.

Based on its latest surveys, the FAO does not regard fuelwood collection to be an important cause of deforestation at the global level. Regional studies indicate that as much as two-thirds of fuelwood worldwide comes from nonforest sources, including tree plantations, roadside verges, backyards, residues from logging and wood industries, construction waste, and waste packaging.

That said, officials do not always agree on the role of fuelwood consumption in deforestation. Matthews writes in *Forest Ecosystems*, "Rising demand for fuelwood and charcoal is causing a halo of deforestation around many cities, towns, and roads. Anecdotal evidence exists of closed forests being affected, notably in India, Sri Lanka, and Thailand." In reality, says Wickramasinghe, in Sri Lanka the natural forests and forest plantations contribute only about 10% of the national fuelwood requirements.

Use of biofuels for cooking and heating can be a major contributor to air pollution on both a local and regional scale. This is especially true in China and India, where large numbers of people cook with primitive stoves. Most cooking with biofuels is done in simple devices at relatively low temperatures, which results in incomplete combustion and a high output of pollutants. During combustion, carbon in biofuels is converted to suspended solids and gases, including carbon dioxide, carbon monoxide, and volatile organic compounds. In analyzing greenhouse gases and other air pollutants from woodstoves in China, Jim Zhang and colleagues noted in the 2 August 2000 issue of *Atmospheric Environment* that total emissions per unit of delivered energy were substantially greater from burning solid fuels than from burning liquid or gaseous fuels.

Biomass advocates contend that if biofuels are harvested in a renewable form (that is, from a site that is replanted or allowed to regenerate), then there is no net contribution to global warming, as the carbon released in burning is replaced through photosynthesis in the growing biomass. However, Smith and colleagues pointed out in several papers in volume 26 (1993) of *Chemosphere* that burning of biomass releases greenhouses gases other than carbon dioxide (methane, nitrous oxides, carbon monoxide) and, thus, can be a net contributor to global warming even when the fuel is grown renewably.

Black carbon (soot), created in part from household burning of biofuels, is another pollutant that can have major impacts on the environment. In the 27 September 2002 issue of *Science*, Surabi Menon and James Hansen of the National Aeronautic and Space Administration's Goddard Institute for Space Studies indicate that black carbon may have been indirectly responsible for floods and droughts that killed more than 1,000 people in China last year alone. Black carbon can affect regional climate by absorbing sunlight and heating the air, thereby altering large-scale atmospheric circulation and the hydrologic cycle. Using the Goddard Institute climate computer model and aerosol data from ground stations in China, Menon and Hansen conducted four sets of computer simulations to monitor the effects of black carbon on the hydrologic cycle over China and India. In each of the four scenarios, the increased amounts of soot created a clear tendency toward the flooding scenario that has been occurring in southern China and the increasing drought over northern China that has persisted over the last several years.

"If our interpretation is correct," Hansen says, "then reducing the amount of black carbon, or soot, may help diminish the intensity of floods in the south and droughts in the northern areas of China, in addition to having human health benefits."

On a Path toward Improvement

Using less fuelwood and other biomass and allowing women time to work at other things, including making money, would improve the health of the millions of people who use biofuels, reduce deforestation, and better the economies of affected households. Toward these goals, international development and public health organizations, including the World Bank, have sought to promote improved biomass stoves as a replacement for the traditional open fire or primitive stove. Since the 1970s, several hundred of these programs have been launched in more than 50 countries. These programs range from local initiatives targeting several hundred homes to national programs such as China's, which has reached nearly 200 million homes.

These programs have met with mixed success. Many of the woodstoves installed failed to achieve the efficiencies in the field that they did under laboratory conditions. Some were poorly designed or manufactured, or inappropriate for the target population. One example is a project in Kenya, where some "improved" stoves had a small firebox requiring that wood be cut into short pieces--something the local women had neither the time nor tools to accomplish. Some stoves were too expensive for local people to afford. At the same time, stoves that were given away for free were often perceived as worthless by the recipients. Some programs required trained technicians to custom-build and install stoves.

These programs were often unsustainable, whereas those involving stoves mass-produced by local artisans were more often a success. In China, for example, the woodstove program was initially slowed by a custom-built approach but has since been improved by a move toward mass-production.

"Reliably achieving high fuel efficiency and low emission with low-cost devices that meet local cooking needs has turned out to be a much more challenging technical

goal than originally thought," writes Douglas Barnes, a senior energy specialist with the World Bank, in the 1994 report *What Makes People Cook with Improved Biomass Stoves? A Comparative International Review of Stove Programs*. With time, however, sponsoring agencies have learned to better tailor the design, manufacture, and distribution of stoves to meet local needs. One program cited as a model of success involved the installation of improved stoves in rural households in western Kenya. This program enrolled local women in the construction and marketing of a chimneyless ceramic stove that is cheap, relatively durable, and more fuel-efficient than the traditional *chulha*.

Have these programs actually reduced participants' exposure to pollutants and yielded health benefits? In a November 2002 *EHP* article on the health impacts of exposure to indoor air pollution, Ezzati and Kammen say there has been little research in the field documenting the health effects of improved stoves. They do cite research showing significant reductions in average pollution concentrations for Guatemalan households installing improved stoves. These benefits persisted over the eight-month period of monitoring under normal conditions of use. And a study published in the 5 June 2002 issue of the *Journal of the National Cancer Institute* used innovative designs in the form of retrospective exposure data to illustrate the long-term benefits of exposure reduction. Other research shows that all stoves exhibit a wide variability of emissions, based on how they are used. Thus, education on how to use stoves properly appears to be as important as the type of stove used.

"Technological innovation cannot be separated from human behavior because the performance and sustainability of household energy technologies largely depend on the behavior of people who use them," Ezzati says. Ezzati is critical of the "technical fix" approach of the past, in which technology design was almost exclusively based on laboratory engineering criteria and implemented without much consultation with or consideration of the users. He supports an approach that focuses on incorporating behavioral and social factors in the design of technological interventions. Behavioral changes that might lead to reduced exposure include keeping children away from stoves in use, providing proper ventilation for the duration of burning, and not leaving fires to burn for extended periods of time.

Analyzing the improved stove program in rural Kenya, Ezzati estimates that a combination of technology and behavior-based interventions can result in a 35-95% reduction in exposure to PM_{10} compared to the use of traditional open fires. That, in turn, can lead to a reduction in exposure-related disease. In particular, these interventions could reduce diagnosis of ARI by 24-64% and of ALRI by 21-44% for children under age 5, according to Kammen and Ezzati's November 2002 *EHP* paper.

By all accounts, biomass will continue to be an important household fuel in the developing world. Many people will switch to cleaner fuels such as electricity and kerosene when they can afford to, but prices for these fuels are still too high and distribution systems for modern fuels inadequate to allow for a wholesale switch. In the meantime, programs that provide improved stoves, combined with education on how to use them in a healthful manner, will provide a valuable bridge to the use of cleaner fuels.

"The challenge for health and energy policies in developing countries is to increase access to clean energy, especially for poor households, while avoiding its negative global and local effects," Ezzati says. If harvested sustainably and used efficiently, biofuels can have minimal ecological and global environmental impacts, he says.