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Household Energy Solutions in Developing Countries.

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Household Energy Solutions in Developing Countries

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Abbreviations

ALRI	acute lower respiratory infection
AQG	air quality guideline
CBA	cost-benefit analysis
CEA	cost-effectiveness analysis
CER	cost-effectiveness ratio
COPD	chronic obstructive pulmonary disease
DHS	Demographic and Health Survey
GTZ	Deutsche Gesellschaft für Technische Zusammenarbeit (German Federal Agency for International Development)
IEA	International Energy Agency
PM	particulate matter, usually defined by aerodynamic diameter in microns, for example, PM10 (10 microns in diameter), or PM2.5 (2.5 microns in diameter)
WHO	World Health Organization

Introduction

Indoor air pollution (IAP) from solid household fuel use is associated with a substantial global health burden, and addressing this is a public health priority. In considering solutions, one of the most important factors influencing options for change and methods of delivery is the close relationship between reliance on traditional fuels and poverty (Figure 1).

This relationship operates in both directions. On the one hand, poor households do not have the financial resources and income security required to switch to more efficient, cleaner fuels and energy technologies. At the same time, the consequences of using traditional fuels – which include impacts on health, women's time and opportunities for income generation – add to the constraints on families attempting to escape from poverty.

For these reasons, poverty is a key underlying issue in any consideration of household energy solution for developing countries. However, since improving access to cleaner and more efficient household energy will make direct contributions to both health improvement and poverty reduction, it is important not to rely on economic growth and other poverty reduction measures as the primary means of improving energy choices for poor households. This is similar to household interventions for clean water and sanitation, which serve to assist poor families' health and their prospects for improving their condition in other ways. Effective strategies for accelerating the transition to clean household energy are required as a matter of urgency.

This article considers the range of interventions and policies available to achieve this transition, and reviews their effectiveness and efficiency, along with experience from projects and programs over the past 30 years.

What Benefits Can Household Energy Interventions Deliver?

A critical issue in considering appropriate household energy solutions is to identify the potential benefits. Although reducing IAP is the priority, there is growing recognition that other consequences of household energy use in developing countries are also important. These are summarized in Table 1, and lead to a range of objectives that inform the design and promotion of household energy interventions (Box 1).

The extent to which all of these objectives are relevant in any given setting will vary, but this represents a starting point. As this article is concerned primarily with health impacts, the following sections will focus on reducing pollution and return to the other benefits in discussion of economic analysis.

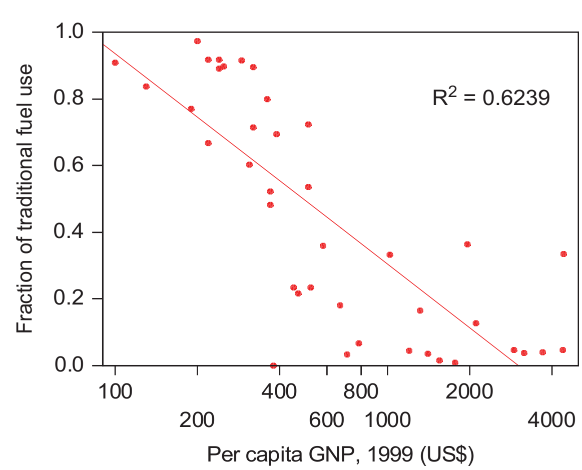

Figure 1 The relationship between per capita GNP and fraction of the population using traditional fuels. *Source*: Smith KR, Mehta S, Feuz M (2004) Indoor air pollution from household use of solid fuels. In: Ezzati M (ed.) *Comparative Quantification of Health Risks: Global and Regional Burden of Disease Attributable to Selected Major Risk Factors*. Geneva: World Health Organization.

Table 1 The diverse impacts of household energy illustrate the wide range of potential benefits from interventions

Area of impact	*Mechanism*	*Specific impacts*
Health	Exposure to high levels of indoor air pollution (products of incomplete combustion)	Available evidence strong for childhood ALRI, and COPD and lung cancer (coal use) in adults. Tentative evidence for increased risk of lung cancer with biomass, upper aerodigestive tract cancer, TB, low birthweight, stillbirth, cataract, asthma, and cardiovascular disease.
	Increased risk of burns and scalds due to open nature of fires, and location (often) on floor	Young children suffer burns from falling into open fires, picking up hot fuel. Cooks at risk of clothes igniting, especially in countries such as India where long drapes worn. Scalds to children from knocking over pots that are on stoves at floor level. Clothes, bedding, and house fires from knocking over candles and simple kerosene lamps, which are very common in the absence of electricity.[a]
	Poisoning	Where kerosene (paraffin) is used as a household fuel, this is frequently stored in soft drink bottles, and poisoning of young children who drink the fuel is common.
	Injuries and animal bites during fuel collection	Most collection of fuel is carried out by women, and school-age children are often involved. Although not well studied and quantified, there is sufficient evidence that injuries (from falling with heavy loads) and animal bites (snakes, etc.) are quite common. Women may also have increased risk of uterine prolapse. In some areas, particularly of political instability, women may be at risk of physical threats, assault, and rape.
Environment	Local environmental impacts from pressure on forest resources and use of animal dung	The use of fuel wood can place pressure on forest resources, although the extent of this usually depends on other pressures including timber requirements for building and land clearance for agriculture. The use of dung for fuel diverts this from being used to increase soil fertility.
	Global environmental impacts from CO_2 and other products of incomplete combustion	The low combustion efficiency, around 10–20%, of most solid fuel stoves in developing countries results in substantial global warming emissions. These include methane, the warming effect of which is more than 20 times that of CO_2, and black carbon that has an effect around 700 times that of CO_2.[b]
Use of time	Time spent collecting fuel	Where households collect fuel, the time spent varies considerably but is not infrequently (on average) 1–2 h per day, and can be considerably more as fuel resources become scarce.
	Time spent cooking	Inefficient stove combustion and design may result in more time spent cooking.
Household activities	Income generation	Energy is important for income generation in a variety of ways, including, for example, fuel for drying foods (e.g., fish) or preparing cooked food to sell, and the provision of adequate lighting to carry out handcrafts in homes with poor natural lighting or in the evenings.
	School work	Inadequate lighting at home is a barrier to school children who have homework, or other household members who wish to study further.
Gender issues	Disproportionate impact on women	Since the role of women generally includes responsibility for procuring household fuel and carrying out cooking, it is women who bear most of the burden on health and other aspects of their lives described here. Furthermore, women often have less control of resources (including land use) and decision-making, which means that they have little control over measures that could improve these conditions. For this reason, many community-based intervention programs often attempt to involve women in the development process, and help them make decisions about appropriate technology and other changes to the home and kitchen, how these should be financed, and so forth.

[a] The International Energy Agency (IEA) estimates that more than 1.5 billion people still do not have access to electricity for lighting.

[b] The global warming emissions from inefficient stoves has led to initiatives to promote the dual benefits of interventions, namely (1) short-term health and related benefits to households and (2) longer-term climate change benefits. This offers the potential for financial support from developed countries through official and voluntary carbon offset programs.

Box 1 Range of Objectives for Household Energy Interventions (See Text for Further Discussion)

- Reduced levels of IAP and human exposure: the question of how much (and to what level) IAP exposure needs to be reduced is considered in the section on 'Impacts of interventions on health outcomes'.
- Increased fuel efficiency, including both efficiency in combustion and efficiency of transfer of heat for cooking tasks and space heating (where required).
- Reduced time spent in collecting fuel and in using inefficient stoves, particularly involving the time of women and school-aged children.
- Reduced stress on the local environment in respect of forest cover, erosion, and soil fertility.
- Increased opportunities for income generation.
- Contribution to an overall improvement in the quality of the home environment, in particular the working environment and conditions for women.
- Reduced global warming emissions, with potential for linking implementation of interventions to the Clean Development Mechanism.

What Reductions in IAP Are Required?

Studies from many developing countries have shown that levels of IAP in homes using solid fuels are well in excess of World Health Organization (WHO) air quality guidelines (AQGs). These AQGs apply to both outdoor and indoor environments, and should serve as the longer-term objective of policy to maximize risk reduction in all populations, urban and rural, rich and poor.

In practice, however, it is proving very difficult to achieve such low pollution levels (e.g., annual average of $20\,\mu g\,m^{-3}$ PM_{10}, particulate matter 10) in most developing country homes, and will remain so for some time for the following reasons: (1) it is not currently possible to obtain very low emissions with low-cost solid fuel stoves, (2) the International Energy Agency (IEA) estimates that the absolute number of people depending on biomass fuels will increase to 2.6 billion by 2030, and (3) there are contributions to personal exposure from the outdoor environment, which include vented household solid fuel emissions. The question then is, how much health benefit can be obtained from a partial reduction in IAP levels and exposure, for example, a 50% reduction in 24 h kitchen PM_{10} from 500 to $250\,\mu g\,m^{-3}$?

Studies from Kenya and Guatemala have provided information to help answer this question for child pneumonia. More details are provided in the section 'Impacts of interventions on health outcomes,' but the conclusion is that technologies currently available in developing countries can deliver a useful reduction in childhood pneumonia, even though post-intervention pollutant concentrations still exceed WHO AQGs.

Approaches to Delivering Improved Household Energy in Developing Countries

Improving access of households to cleaner and more efficient energy requires both *interventions* and *enabling policy*. These two aspects will now be considered, and then evidence on how effective these are in practice will be reviewed.

Interventions

Interventions for reducing IAP can be grouped under three headings: those acting on the source of pollution, those improving the living environment, and those modifying user behaviors (**Table 2**).

Switching from wood, dung, or charcoal to more efficient modern fuels, such as kerosene, LPG, biogas, and ethanol, brings about the largest reductions in IAP. In many poor rural communities, however, access to these alternatives is limited and biomass remains the most practical fuel. Here, improved stoves – provided they are adequately designed, installed, and maintained – can also reduce IAP considerably. Stove location, housing construction, and better ventilation are also partial remedies. Changing behaviors can also contribute: drying fuel wood improves combustion and lowers emissions, using pot lids cuts cooking time, and exposure of young children can be reduced by keeping them away from polluted kitchens (if this is safe). Such changes are unlikely to reduce IAP as much as cleaner fuel or a well-functioning chimney stove, but are important supporting measures.

Solar cookers offer zero emissions and a free, inexhaustible source of energy, and can be effective in settings with high solar irradiance. Experience with solar cookers has, however, been mixed. Although their use is relatively widespread in Tibet and on the Altiplano of South America, where virtually no other clean fuel alternatives are available, user acceptability (e.g., ability to prepare local dishes and concern about theft) and cost have prevented adoption in many other places. Another promising approach is advanced combustion stoves that achieve low emissions even using raw biomass in the form of wood or crop residues. For example, one such technology, semi-gasifier stoves, emits levels of pollution almost as low as for LPG when operating well. Although extremely promising, most such stoves are sensitive

Table 2 Interventions for reducing exposure to IAP

Source of pollution	*Living environment*	*User behaviors*
Improved cooking devices	*Improved ventilation*	*Reduced exposure through operation of source*
• Improved biomass stoves without flues • Improved stoves with flues attached	• Hoods, fireplaces, and chimneys built into the structure of the house • Windows, ventilation holes, for example, in roof, which may have cowls to assist extraction	• Fuel drying • Use of pot lids to conserve heat • Good maintenance of stoves and chimneys and other appliances
Alternative fuel–cooker combinations	*Kitchen design and placement of the stove*	*Reductions by avoiding smoke*
• Briquettes and pellets • Kerosene • Charcoal • Liquefied petroleum gas • Biogas, producer gas • Solar cookers (thermal) • Other low-smoke fuels • Electricity	• Kitchen separate from house reduces exposure of family (less so for cook) • Stove at waist height to reduce direct exposure of cook leaning over fire	• Keeping children away from smoke, for example, in another room (if available and safe to do so)
Reduced need for the fire		
• Insulated fireless cooker (haybox) • Efficient housing design and construction • Solar water heating		

Source: Modified from Ballard-Tremeer G, and Mathee A (2000) Review of interventions to reduce the exposure of women and young children to indoor air pollution in developing countries. In von Schirnding Y, et al. (2002) Addressing the impact of household energy and indoor air pollution on the health of the poor: Implications for policy action and intervention measures. WHO/HDE/HID/02.9. Geneva: WHO.

to fuel quality, including size and moisture, and relatively few studies have been done on their field performance over time in rural households. One way to increase performance reliability is to include a small electric blower, which stabilizes the combustion and uses tiny amounts of electricity, what could be called 'hybrid' stoves. A small rechargeable battery can be incorporated to ensure functioning in areas of unreliable power supply. Another approach is briquetting or pelletizing of biomass, which greatly improves stove performance but requires creating a new small industry in rural areas.

Enabling Policy

Poor households face many barriers to adoption of interventions, and enabling policy is needed as much as changes in technology, fuels, and behaviors. These barriers arise because energy and associated technologies are commodities, and the people concerned are poor, and many are very poor. The poorer the community, the more complete and entrenched the reliance on traditional fuels and stoves. Furthermore, as with many other aspects of environmental health, implementation differs from health care since interventions and policy are directed at issues that include energy supply and markets, environmental improvement, housing, education, agriculture, gender, and development. Thus, although major benefits may accrue to the health system, action is taken mainly through other sectors, resulting in a lack of clarity about roles and funding.

The fuels and devices used for cooking, heating, and lighting are products and services and as such are just one of a number procured by households to meet everyday needs and compete for the limited resources available. For many, energy is obtained without monetary expenditure by collecting wood, twigs, dung, and crop residues and using stoves made from earth or stones. For others, varying amounts of their daily energy needs together with stoves and other technologies are purchased in markets that are influenced by local, national, and international factors – most notably in recent years, the price of oil. This has increased the cost of two important cleaner fuels, kerosene and LPG, forcing people down the energy ladder onto greater reliance on biomass. Although households collecting all of their fuel are outside formal markets, experience is showing that effective, sustainable interventions will require engagement with markets for energy supply and products.

Policy should therefore generate demand through a number of routes, including by regulation (e.g., on standards for stove manufacture, or air quality, where possible), by raising awareness of the health and other benefits among communities and professional groups, and also by facilitating greater engagement of poor households in markets for products appropriate to their needs, culture, and circumstances. Policy instruments that can support this approach are summarized in Table 3.

Effectiveness of Interventions

The assessment of intervention effectiveness requires consideration not only whether the intervention delivers on IAP reduction and other objectives identified earlier in text, but also whether it is acceptable to users, is maintained, and remains in everyday use. It is useful to distinguish *efficacy* (what an intervention delivers in ideal circumstances) from *effectiveness* (what it does in realistic situations) and *efficiency* (whether it does so cost-effectively). Here, effectiveness and efficiency is the focus, with the main emphasis on the reduction of IAP and resulting health impacts. Two approaches can be taken in respect of health improvements. The first assesses impact on ambient air pollution in and around the home, and ideally also on personal exposure. The second approach involves assessing the impact on specific health outcomes.

Impact of Interventions on Household Pollution and Personal Exposure

In East Africa, cheap improved ceramic (pottery) stoves without flues, burning either wood or charcoal, are popular and can reduce kitchen pollution by improving combustion, although recent work suggests such reductions are small. Charcoal emits considerably less particulate matter (PM), and stoves such as the Kenyan Jiko have been shown to yield particulate levels in the region of 10% of those from wood fires. Newer flueless wood stoves with improved combustion such as the *Rocket* are being introduced and evaluated in a number of African countries.

Improved stoves with flues have been promoted extensively in several Asian countries, although many were found to be in poor condition after a few years. Some studies from India have shown variable and sometimes modest or minimal reductions in pollution. For example, *Laxmi* chimney stoves in homes located in Maharashtra, India, resulted in a 24% reduction in $PM_{2.5}$ and a 39% reduction in CO, whereas a *sukhad* chimney stove in the Bundelkhand region of India reduced kitchen concentrations of $PM_{2.5}$ and CO by 44% and 70%, respectively. Studies from Nepal have shown reductions of approximately two-thirds, although high baseline levels mean that homes with stoves still recorded total PM values of 1000–3000 $\mu g\,m^{-3}$ during cooking.

Similar experience with flued stoves has been reported from Latin America. *Plancha* stoves in Guatemala (made of cement blocks, with a metal plate and flue) can reduce PM by 60–70%, and by as much as 90% when well maintained. Typical 24 h PM levels (PM_{10}, $PM_{3.5}$, and $PM_{2.5}$ have been reported) with open fires of 1000–2000 $\mu g\,m^{-3}$ have been reduced to 300–500 $\mu g\,m^{-3}$, and in some cases less than 100 $\mu g\,m^{-3}$. A Mexican intervention study assessing the *patsari* flued stove in Michoacán state found a 67% reduction in $PM_{2.5}$ and a 66% reduction in CO.

IAP reductions studied in three provinces of China found 24 h kitchen PM_4 of 268 $\mu g\,m^{-3}$ for all traditional stove types and 152 $\mu g\,m^{-3}$ for all improved stove types. Although a significant reduction, most homes were still above the Chinese national IAP air quality standard of 150 $\mu g\,m^{-3}$ PM_{10}. Evaluation was complicated by multiplicity of fuel types in regular use, changes within and between seasons, and multiple stove type use (improved and traditional) for various purposes.

Recent work developing hoods with flues for highly polluted Kenyan Maasai homes reported reductions in 24 h mean $PM_{3.5}$ of 75% from more than 4300 $\mu g\,m^{-3}$ to approximately 1000 $\mu g\,m^{-3}$. Households may also opt for combinations of changes: in west Kenya, hood and flues used with ceramic stoves (for better combustion), hayboxes (insulated chambers that slow-cook hot food without fuel), and improved ventilation reduced kitchen levels of CO (used as a proxy for PM) by approximately 70%.

Where studied, personal exposure has been found to reduce proportionately less than area pollution. Thus, in the Kenyan Maasai study, a 75% reduction in 24 h mean kitchen $PM_{3.5}$ and CO was associated with a 35% reduction in women's mean 24 h CO exposure. Similar proportionate reductions were found for women and children using wood stoves in Guatemala. A study of personal particulate exposure in Guatemalan children <15 months of age reported mean 10 to 12 h $PM_{2.5}$ levels of 279 $\mu g\,m^{-3}$ for open fires and 170 $\mu g\,m^{-3}$ for *plancha* stoves, a 40% difference.

Impact of Cleaner Fuels

Kerosene and LPG can deliver much lower pollution, although for practical and cost reasons may not fully substitute for solid fuel. For example, a study in rural Guatemala comparing LPG with open fires and *plancha* chimney stoves found that LPG-using households typically also used an open fire for space heating and cooking with large pots. Consequently, the *plancha* homes had the lowest pollution. Other studies from India have shown that kerosene and LPG users had much lower kitchen pollution, reflecting different cooking and space-heating requirements. In rural Tamil Nadu, 2 h (meal time) kitchen respirable PM (PM_{resp}) levels of 76 $\mu g\,m^{-3}$ (kerosene) and 101 $\mu g\,m^{-3}$ (LPG) contrasted with 1500–2000 $\mu g\,m^{-3}$ for wood and animal dung. Personal (cook)

Table 3 Policy instruments for promoting implementation of effective household energy interventions

Policy instruments	*Examples*	*Applications*
1. Information, education, and communication	Schools	Learning about household energy, health, and development integrated in school curricula, particularly in countries where these topics are a priority for health and economic development.
	Media	Local and national radio, television, and newspapers can be used to raise awareness and disseminate information on technologies and opportunities to support implementation, such as promotions and microcredit. These media can be directed at a range of audiences, including decision makers, professionals, and the public where radio is widely used.
	Community education	Opportunities such as adult literacy programs can be used to raise awareness and share experience of interventions, and innovative methods used, for example, theatre.
	Professional education	Raising awareness about the impacts of solid fuels and IAP on health and development is required for all sectors and professional groups with a part to play. This includes identification of their roles, joint working, and the steps each group can take to contribute effectively.
2. Taxes and subsidies	Tax on fuels and appliances	Reduced tax on fuels and appliances may promote development of distribution networks and uptake, and can be seen as efficient if there is evidence of health, education, and economic benefits.
	Subsidy on fuels and appliances	General (e.g., national) subsidy on fuels such as kerosene has been used in an effort to promote use by poor households. Subsidies have been found to be inefficient instruments, however, often benefiting the better-off rather than the poor. Time-limited subsidy on specific products (e.g., clean fuel appliances and connection to grid) may be a useful method for promoting initial uptake, generating demand, and thereby providing market conditions for lower prices and more consistent quality. Climate change co-benefits can provide a source of funding through formal or voluntary carbon offset schemes.
3. Regulation and legislation	Air quality standards (AQS)	Although some developing countries have AQS for urban air, only China currently has a standard for indoor air quality (150 $\mu g\, m^{-3}$ PM_{10}). Routine air pollution monitoring and enforcement of AQGs for homes is not practical in most settings, but standards based on information about fuel and stove type (obtained through surveys such as the DHS, Demographic and Health Survey) can be used as an indicator of disease risk.
	Design standards for appliances	These can be applied to safety (prevention of burns, gas leaks, and explosions), venting of emissions, and fuel efficiency. Although such standards may be difficult to enforce in an informal economy, these could become valuable with mass production and a greater involvement of the private sector.
4. Direct expenditures	Public program provision of appliances	Large-scale public provision of appliances, such as improved stoves or clean fuel appliances, has generally been found to be unsuitable. Some form of targeted provision or partial subsidy where households have made informed choices and commit to cost sharing may be useful to stimulate demand and act in favor of equity.
	Funding of finance schemes	Experience has shown that credit is most likely to be made available, and adopted, for energy applications that contribute directly to productive, income-generating activities (such as food processing for sale). Meeting everyday cooking and space-heating needs is seen as a lower priority. Good opportunities may exist where biomass fuel is purchased and where cost saving combines with other valued benefits, such as increased prestige and cleaner kitchens. Support for such schemes, mainly in the form of raising awareness, skills training in managing funds, and seed funding (the main source of funds being from users), may be cost-effective.
5. Research and development	Surveys	Surveys of fuel and appliance use, knowledge of risks to health, willingness to pay for interventions, knowledge of and confidence in credit schemes, and so forth are important for planning interventions.
	Development and evaluation of interventions	Evaluation of interventions should be conducted in a range of settings, where possible using harmonized methods that allow local flexibility but permit comparison with other types of interventions and other locations.
	Studies of health impacts	Stronger and better-quantified evidence of the effects on health of reducing IAP, which includes exposure measurement, is required for key outcomes such as ALRI, but also for other health outcomes for which evidence is currently tentative.
	Research capacity development	Capacity for carrying out a wide range of research, from national and local surveys, monitoring, and evaluation of interventions through to more complex health studies, requires strengthening in those countries where the problems associated with household energy and IAP are most pressing.

24 h exposure to PM_{resp} was 132 $\mu g\,m^{-3}$ with kerosene and 1300–1500 $\mu g\,m^{-3}$ for wood and dung.

For most developing country homes, electricity – even if it were available – would be too expensive to use as a cooking or heating fuel. South Africa is one of the few countries with a large biomass and coal-using populations that has invested in rural electrification sufficient to support cooking. A study comparing nonelectrified and electrified villages in the North West province found 3.6 years after grid connection that 44% of electrified homes had never used an electric cooker. Only 27% of electrified homes cooked primarily with electricity, the remainder using a mix of electricity, kerosene, and solid fuels. Despite mixed fuel use, households cooking with electricity had significantly lower 24 h mean PM_{resp} and CO levels and significantly lower mean 24 h CO exposure for children aged <18 months.

Impacts of Interventions on Health Outcomes

Few intervention-based studies of impact on the most important health outcomes (child pneumonia, COPD, and lung cancer) have been published. For child pneumonia, two studies are of particular interest. The first was conducted in rural Kenya and, although an observational design, provides information on the relationship between child acute lower respiratory infection (ALRI) and a range of exposure associated with the use of traditional wood stoves, improved stoves, and charcoal. Some 93 infants living in 55 households were studied, and personal exposure and ALRI incidence were assessed. ALRI incidence increased at a higher rate for PM_{10} exposure levels below 2000 $\mu g\,m^{-3}$ than for levels above 2000 $\mu g\,m^{-3}$, suggesting that the exposure–response relationship is not linear but levels off at concentrations of approximately 2000 $\mu g\,m^{-3}$. The small numbers and high incidence of ALRI indicate that confirmation of these findings is required.

The second is currently the only completed randomized-controlled trial. A total of 534 homes in rural Guatemala either were randomized to receive an improved *plancha* chimney stove or continued to cook on an open fire. Child exposure was assessed using CO, previously shown to be an adequate proxy for PM in this setting. Preliminary results (reported in conference abstracts) show that the *plancha* reduced kitchen pollution by approximately 90% and child CO exposure by approximately 50%. ALRI incidence among children <18 months was determined through a combination of weekly home visits by fieldworkers and physician examination. The *plancha* resulted in a modest reduction in pneumonia incidence (whether assessed by fieldworker or physician) of approximately 10–20%, with larger reductions for more severe cases of approximately 30% with hypoxemia (low oxygen saturation).

For chronic obstructive pulmonary disease (COPD) and lung cancer, two cohort studies have reported the impact on these outcomes following introduction of improved stoves as part of the Chinese National Improved Stove Programme. For lung cancer, the adjusted hazard ratio for men using improved coal stoves compared with traditional open coal fires was 0.59 (95% CI: 0.49–0.71), and was 0.54 (95% CI: 0.44–0.65) for women. For COPD, in a similar type of study, use of improved stoves was associated with hazard ratios of 0.58 (95% CI: 0.49–0.70) in men and 0.75 (95% CI: 0.62–0.92) in women. The reduction in risk became unequivocal approximately 10 years after stove improvement.

Economic Evaluation of Household Energy Interventions

Economic analysis is playing an increasingly important role in decision-making for health. This article will first look at cost-effectiveness analysis (CEA), which identifies how much requires to be spent on an intervention to obtain a given unit of health gain. The second approach is cost–benefit analysis (CBA), which determines the monetary value of all intervention costs and benefits, and hence whether the investment in the intervention yields a net gain in economic terms. Because of the capacity of CBA to take into account a wide range of benefits, this method is usually considered more appropriate for economic evaluation of household energy interventions, and more emphasis is given to CBA here.

Cost-Effectiveness Analysis of Interventions at Regional Level

The analysis reported in this article is based on work by Mehta and Shahpar. This analysis examined both improved stove and clean fuel options, and combinations, with varying coverage:

- access to improved stoves (stoves with flues), with 50 and 95% coverage
- access to cleaner fuels (LPG or kerosene), with 50 and 95% coverage
- part of the population with access to cleaner fuels (50%) and part with improved stoves (45%)

Intervention costs included program costs, fixed costs (including stoves), and recurrent fuel costs. Savings from averted health-care costs were not included since many of these cases currently go untreated. Health impacts were estimated through the lowered risks associated with reduced IAP exposure, based on a previous meta-analysis. It was assumed that cleaner fuels remove exposure completely, whereas improved stoves reduce exposure and associated health effects by 75% (from the discussion in the section 'Effectiveness of interventions', this should be considered optimistic). Health outcomes included were ALRI and COPD, as these were responsible for nearly all of the 1.6 million deaths attributable to IAP. Future costs and health impacts were discounted at 3%, and the implementation period was 10 years. Results were expressed, for the five intervention scenarios with differing coverage, by WHO region, as cost-effectiveness ratios (CERs) in international dollars per healthy year gained (**Table 4**).

Cleaner fuels yielded the greatest gains in healthy years for all regions (not shown), but improved stoves also had a significant impact, with the largest total population health gains in sub-Saharan Africa and South Asia for all types of interventions, and in East Asia and Pacific (mainly China) for cleaner fuels. CERs in the two regions with the largest attributable burdens of disease (Africa and South East Asia) were most favorable for improved stoves, although in both regions kerosene was not far behind. In East Asia and Pacific, kerosene was most cost-effective, followed by improved stove/clean fuel combinations, and then LPG. Although these cost-effectiveness estimates vary considerably across regions, they do provide evidence that household energy interventions can be cost-effective. This is despite this CEA being restricted to direct health benefits and only outcomes with current strong evidence of risk. Inclusion of other health impacts of IAP and through other mechanisms (e.g., burns) can be expected to improve CERs.

Cost–Benefit Analysis

The WHO has recently published guidance on carrying out CBA for household energy interventions, and applied this to interventions at WHO regional level. The approach used and key results from the regional study, together with three community case studies using similar methods, are now reported.

In CBA, all main benefits are expressed in a common unit of monetary value. The assessment of costs has much in common with CEA. The key difference lies in the impacts included as benefits and the methods for valuing these.

Cost–Benefit Analysis at Global and Regional Levels

In the WHO study, costs and benefits were modeled under eight different intervention scenarios, covering three specific interventions: LPG, biofuel (ethanol), and a chimneyless stove based on the *Rocket* design. As in the CEA discussed earlier in text, cleaner fuels were assumed to remove exposure and attributable health impacts completely. A more conservative assumption was employed for the impact of improved stoves, where a reduction of 35% (and lower and upper values of 10 and 60% in sensitivity analysis) in personal exposure was used as a proxy for likely reductions in health outcomes. Two levels of population coverage were assumed, to reduce the population not served in 2005 by 50% or 100% by 2015. The 50% scenarios were further subdivided into one where all users of traditional fuels are targeted equally and a pro-poor alternative that first targets those with the most polluting and least efficient solid fuels in the following order: dung and agricultural residues, firewood, coal, and charcoal. The intervention period was 10 years, with future costs and impacts discounted at 3%. The costs and benefits included in the analysis are summarized in **Table 5**.

Results are shown initially as net present values (NPV) for three of the intervention scenarios, by WHO

Table 4 Cost-effectiveness ratios for household energy interventions, expressed as the costs in international dollars ($1) per healthy year (HY) gained, by intervention scenarios for selected WHO epidemiological subregions, 2002

Region	*WHO epidemiological subregion*[a]	*LPG*	*Kerosene*	*Improved stoves*	*LPG and improved stoves*	*Kerosene and improved stoves*
Africa	AFR-D	6270	1000	500	3750	840
	AFR-E	11 050	2000	730	6440	1530
The Americas	AMR-B	14 050	2410	–	16 330	8080
	AMR-D	7500	1180	5880	6770	3120
Eastern Mediterranean	EMR-B	24 200	16 200	–	–	–
	EMR-D	11 020	1800	7800	9780	4500
Europe	EUR-B	17 740	3010	–	19 870	9510
South and South East Asia	SEAR-B	15 120	2450	1180	8970	1950
	SEAR-D	7350	1380	610	4280	1040
Western Pacific	WPR-B	1410	260	32 240	1570	780

[a]See web link for the explanation of regions – included in ESD article, which is the source for this table (http://www.who.int/indoorair/interventions/iapcosteffectiv.pdf).

Note: Where a CER result is not shown, the region is already at or above the specified level of coverage for the intervention.

Table 5 WHO cost–benefit analysis study: Overview of costs and impacts, and time horizon of modeled impacts

Variable	*Immediate cost or impact*	*Delayed cost or impact*[a]
Intervention costs	Investment costs, such as stove purchase cost and cost of house alterations Recurrent costs, such as fuel costs and program costs	Not relevant
Health benefits and savings on health-care costs	Acute lower respiratory infection (ALRI)	Chronic obstructive pulmonary disease (COPD); lung cancer
Productivity gains due to reduced morbidity	Related to ALRI	Related to COPD and lung cancer among women and men above 30 years of age
Productivity gains due to reduced mortality	Not relevant	Related to ALRI for children
Time savings	Fuel collection time and cooking time	Not relevant
Environmental benefits	Local and global environmental benefits	Not relevant

[a]Future costs and impacts are discounted at 3% rate per year.

Table 6 Net present values (average annual value: millions US$) for three intervention scenarios at 50% coverage

Region	*WHO epidemiological subregion*	*Scenario I*		*Scenario II*		*Scenario III*	
		(LPG)		*(LPG pro-poor)*		*(Improved stove)*	
		Urban	*Rural*	*Urban*	*Rural*	*Urban*	*Rural*
Africa	AFR-D	2 440	2 240	1 740	2 120	3 000	2 180
	AFR-E	2 660	4 570	2 480	6 160	4 580	4 260
The Americas	AMR-B	560	4 410	530	4 580	13 030	7 920
	AMR-D	270	190	–10	600	2 010	520
Eastern Mediterranean	EMR-B	1 060	1 590	1 070	1 630	4 940	2 880
	EMR-D	500	870	430	870	3 110	2 150
Europe	EUR-B	470	690	450	680	3 960	450
	EUR-C	580	290	630	290	1 690	80
South and South East Asia	SEAR-B	380	2 510	–140	3 640	2 260	3 850
	SEAR-D	1 620	1 830	640	3 050	10 340	4 210
Western Pacific	WPR-B	43 510	4 040	49 460	6 530	56 610	4 850
World (non-A)		54 050	23 230	57 290	29 970	105 540	33 350
World total (non-A)		77 490[a]		97 430		138 920	

[a]This figure and the two others in this row are total value of urban and rural areas across the world.
Source: http://www.who.int/indoorair/publications/summary_household_energy_health_intervention.pdf.

epidemiological subregion, in Table 6. The NPV is the estimated total annual economic surplus – this is calculated by subtracting net present (discounted) costs from net present (discounted) economic benefits. Almost all cells in the table show positive NPVs, and most are substantial. The largest NPVs are seen overall for improved stoves and for all three scenarios in urban settings in the western Pacific subregion.

Benefit–cost ratios for the same three intervention scenarios are shown in Table 7. The majority either are greater than 1 (signifying the value of benefits exceeds costs) or have negative values that result from intervention cost savings exceeding the intervention costs, for example, where fuel costs are reduced through greater efficiency.

A striking conclusion is the dominance of time savings, although averted child and adult deaths were also important. This CBA shows that investments in household energy and health interventions can be highly cost beneficial and in some cases cost saving. Under the model assumptions, improved stoves led to the greatest overall benefit to society as reflected in the NPV (Table 6). This holds particularly true in urban settings where the majority of the population already pays for fuel. This finding is important in view of IEA projections to 2030, which indicate that biomass will remain the principal household fuel for the poor in South Asia and sub-Saharan Africa and that actual numbers of users will increase.

Table 7 Benefit–cost ratios for three intervention scenarios at 50% coverage (US$ return per US$1 invested)

Region	*WHO epidemiological subregion*	*Scenario I*		*Scenario II*		*Scenario III*	
		(LPG)		*(LPG pro-poor)*		*(Improved stove)*	
		Urban	*Rural*	*Urban*	*Rural*	*Urban*	*Rural*
Africa	AFR-D	26.5	3.7	3.3	3.2	Neg	Neg
	AFR-E	Neg	6.2	12.7	6.9	Neg	Neg
The Americas	AMR-B	14.3	3.8	6.9	3.7	Neg	Neg
	AMR-D	Neg	1.8	0.9	3.6	Neg	Neg
Eastern Mediterranean	EMR-B	4.9	4.2	4.9	4.3	136.1	89.9
	EMR-D	Neg	2.2	16.1	2.1	Neg	Neg
Europe	EUR-B	Neg	3.0	Neg	2.9	Neg	Neg
	EUR-C	Neg	3.4	Neg	3.1	Neg	Neg
South and South East Asia	SEAR-B	Neg	2.7	0.2	3.4	Neg	Neg
	SEAR-D	2.6	1.5	1.4	1.8	Neg	Neg
Western Pacific	WPR-B	27.0	21.2	68.5	14.6	Neg	Neg
World (non-A)		22.3	3.2	15.1	3.7	Neg	Neg
World total (non-A)		6.9[a]		6.7		Neg	

[a]This figure and the two others in this row are total value of urban and rural areas across the world.
Note: Neg, a negative benefit–cost ratio means that intervention cost savings exceed intervention costs.
Source: http://www.who.int/indoorair/publications/summary_household_energy_health_intervention.pdf.

Community-Based CBA Studies

The first study examined costs and benefits for 190 000 households using *Rocket* wood stoves and improved charcoal stoves, promoted by GTZ in Uganda. Benefits were similar to those described by WHO, and included fuel saved, time saved collecting fuel and cooking, savings of time (illness) and costs to households and the public health system, forestry, soil fertility, and greenhouse gases (CO_2 and methane). Health benefits were based on symptoms of respiratory and eye disease and burns combined with nonempirical estimates of reductions in health-care costs and time lost due to illness, but excluded mortality. Future costs and benefits were discounted at 10% and the intervention period was 10 years. The overall program NPV was 57 million euro, with a benefit–cost ratio of 25. Consistent with the WHO study, benefits were dominated by fuel saving (including time collecting fuel) at 51.9%, with time saved cooking providing 14.3% and health benefits 7.4%.

The second community study was based on smaller-scale community interventions carried out by Practical Action (an international NGO) in highland Nepal (addition of a LPG, hood and flue, and improved stove with grate and wall insulation), Kassala in Sudan (facilitated access to financing for LPG fuel and stoves), and periurban communities around Kisumu, Kenya (improved wood stoves, LPG, hoods and flues, hayboxes, and improved ventilation). CBA was undertaken from a household perspective, drawing on WHO guidelines. A 10% discount rate was used with a 10-year intervention period. Results showed net economic benefit in all countries, with average household NPVs (in UK pounds) of 19, 634, and 149 for Nepal, Kenya, and Sudan, respectively. Again, time and fuel costs were the main contributors, although for Nepal fuel cost savings were not relevant as all fuel was collected from the forest.

The third study reports on a CBA of biogas carried out by Winrock International for all of sub-Saharan Africa as well as country-level analyses for Uganda, Rwanda, and Ethiopia. The proposed interventions would deliver integrated household biogas, latrine, and hygiene facilities, and include a subsidy of approximately 30% of the biogas unit cost. The analysis utilized data from country-level feasibility studies, other secondary sources, and limited primary data collection. Both household and societal perspectives were used, the latter including the value of time savings associated with fuel wood collection, cooking, access to a latrine, a range of health-related benefits, and environmental benefits due to reduction in greenhouse gas emissions and deforestation. Benefit–cost ratio estimates were favorable, ranging from 1.2 to 1.3 for the household and from 4.5 to 6.8 for the societal perspective.

Experience with the Implementation of Household Energy Programs

The past 20–30 years have seen many, diverse programs on household energy, from small and medium-scale NGO and community-led initiatives to ambitious national programs, the largest of which achieved installation of perhaps 200 million improved stoves in rural China. It is important to note, however, that none of these large programs in the past were designed specifically to achieve low pollution exposures. Experience with a number of smaller-scale initiatives has also been reported recently, some of which do focus on air pollution, and several larger initiatives focusing on air pollution are now underway (see the section 'Relevant Websites' for links to current programs). Evaluation efforts are currently being promoted and more reports should be available in the next few years.

Among the large-scale initiatives, evaluations are available and summarized here for the Indian National Programme of Improved Cook Stoves (NPIC), the Chinese National Improved Stoves Program, and LPG promotion.

India

The NPIC was established in 1983 with goals of conserving fuel, reducing smoke emissions and improving health, reducing deforestation, limiting the drudgery of women and children, and reducing cooking time and improving employment opportunities for the rural poor.

Although the Ministry of Non-Conventional Energy Sources was responsible for planning, setting targets, and approving stove designs, state-level agencies relayed this information to local government agencies or NGOs. A technical backup unit (TBU) in each state trained rural women or unemployed youths to become self-employed workers to construct and install stoves. Many also conducted laboratory research to develop and test stoves.

Between 1983 and 2000, the program distributed more than 33 million improved stoves, but despite extensive efforts these now account for less than 7% of all stoves. Among those that have been adopted, poor quality and lack of maintenance have resulted in a lifespan of two years at most and typically much less. Evaluation identified several problems:

- Most states placed inadequate emphasis on commercialization, now seen as crucial for effective and sustainable uptake.
- There was insufficient interaction with users, self-employed workers, and NGOs, so that designs did not meet household needs and there was very poor acceptance of user training.
- Quality control, monitoring, and evaluation for installation and maintenance of the stove and its appropriate use were lacking.
- Most stoves used inexpensive materials with low durability, leading to poor performance and short lifetimes.
- High levels of subsidy (approximately 50% of stove cost) were found to reduce household motivation to use and maintain the stove.

There were some more successfully managed locations that focused on technical assistance, research and development, marketing, and information dissemination. Recently, the government of India decentralized the program and transferred all implementation responsibility to state level. Since 2000, the NPIC promotes only durable cement stoves with chimneys that have a minimum lifespan of five years. The introduction of these stoves will make adhesion to technical specifications and quality control easier.

China

Implementation of the Chinese national program differed substantially from that of India, but operated over the same period. Although rural Chinese populations are poor, they do have greater effective purchasing power than in many developing countries, allowing the majority of consumers to purchase stoves at close to full cost. Among the key features of the Chinese program reported to have contributed to its success are decentralization of administration, a commercialization strategy that provided subsidies to rural energy enterprise development, and quality control through the central production of critical components (such as combustion chamber parts) and engaging local technical institutions in modifying national stove designs to local needs. National-level stove competitions generated public and media interest, a bidding process among counties for contracts allowing the best-placed counties to proceed first; financial payments were provided to counties only after completion of an independent review of their achievements. No large flows of funds came from the center as the major financial contributions were provided by local governments. The Chinese program shifted norms: most biomass stoves now available on the market have flues and other technical features that classify them as improved.

In 2002, an independent study was undertaken to evaluate (1) implementation methods used to promote improved stoves, (2) commercial stove production and marketing organizations that were created, and (3) impacts of the program on households, including health, stove performance, socioeconomic factors, and monitoring of indoor air quality. The first two objectives were assessed through a facility survey of 108 institutions at all levels. The third objective was assessed through a household survey of nearly 4000 households in Zhejiang, Hubei, and Shaanxi provinces. Overall, several important conclusions emerged. First, the impact of an improved stove program on IAP and health may be limited in settings where a wide range of combinations of different fuel and stove types are used. Second, given the importance of space heating, making available an improved biomass stove for cooking may not be a sufficient strategy to reduce IAP: there is a need to promote improved coal stoves that are increasingly common among rural Chinese households. Third, even among households using improved stoves (as noted in the section

Box 2 Key Lessons Learned in the Promotion of New Markets for LPG in Developing Countries

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

Source: Based on McDade S (2004) Fueling development: The role of LPG in poverty reduction and growth. *Energy for Sustainable Development* 8: 74–81.

'Effectiveness of interventions'), PM_4 and CO levels were still found to exceed Chinese national indoor air standards (and were substantially higher than WHO AQGs). Overall, this study showed that, in general, the improved stoves were reducing IAP concentrations, but the use of fuels and stoves was complex, and the actual levels of IAP and reductions were quite variable, and consequently it has not been easy to report a single figure (e.g., % reduction in PM) on the impact of the stoves.

Promotion of LPG

Experience in the promotion of LPG has also been reported, for example, from the Indian Deepam Scheme and from the LPG Rural Energy Challenge. This latter initiative, developed by UNDP and the World LPG Association in 2002, is promoting the development of new, viable markets for LPG in developing countries. Key elements include the development of partnerships in countries; regulatory environments that facilitate LPG business development and product delivery; the reduction in barriers, for example, the introduction of smaller (more affordable) gas bottles; and greater government and consumer awareness of costs and benefits. Key lessons emerging from experience with the promotion of LPG markets are shown in Box 2.

Conclusions, and Research and Development Agenda

Experience shows that household energy interventions, in particular improved solid fuel stoves and cleaner fuels, can deliver substantial IAP reductions although there are important cautions. Large (or indeed any) reductions in IAP should not be assumed, and furthermore, large reductions have been more difficult to achieve with solid fuel interventions than with cleaner fuels. Even well-functioning improved stoves show postintervention levels well in excess of WHO AQGs. Personal exposure is generally not reduced proportionately as much as ambient pollution for any given intervention.

Although intervention-based evidence of impact on health outcomes is still limited, there are indications that the degree of exposure reduction achieved with well-functioning improved stoves can result in important reductions in incidence of child pneumonia, COPD, and (where coal is used) lung cancer.

Economic analyses have shown that interventions can be cost-effective. CBA studies have reported favorable results, despite variations in settings, interventions, data sources, and assumptions. Improved stoves have yielded the most favorable economic results thus far. Time and fuel savings were most important, compared to health, even more so where averted mortality was not included among the benefits. The findings strengthen the case for interventions and for promoting awareness of the time and fuel savings in addition to health benefits.

Experience from intervention programs has identified a number of key pointers for success, including generation of demand, attention to the needs of users, local commercialization and targeted financial assistance and credit, careful engineering with robust materials, and evaluation with associated feedback. Local initiatives will usually have little impact unless there is national policy that encourages the coordinated contributions of a range of actors, including government (energy, health, housing, and other ministries), business, NGOs, and community groups.

Given that solid fuels are expected to be the main household cooking energy source for more than 3 billion people up to and beyond 2030, research is needed on improving combustion efficiency (to reduce emissions and save fuel), heat transfer, and ventilation of stoves. For example, technology such as biomass gasification and pelletization may have considerable potential, but development and evaluation for wider use are still required. Just as with outdoor air pollution sources, chimneys are not the long-term answer, but rather ways to greatly reduce emissions at the source. At present, it seems low-combustion stoves, such as the hybrid stoves, show much promise, although more experience is needed. The research agenda for clean fuel is concerned mainly with policy on how access can be rapidly and substantially improved for poor households. In addition, innovations in clean fuels such as biogas, ethanol, and plant oils also need development and evaluation.

An exciting potential for co-benefits for both health and climate protection is being explored in a number of stove projects around the world. By taking advantage of either official or voluntary carbon offset programs, resources from developed countries are being tapped for this purpose. This could potentially provide substantial resources for research and dissemination on advanced household energy technologies with both low greenhouse and low health-damaging emissions.

The key priorities for implementation in respect of health outcome research are to extend the intervention-based evidence on health impacts required to strengthen advocacy efforts, together with further description of the exposure–response relationship for childhood pneumonia to define medium and longer-term targets for exposure reduction. This should draw on new data from a variety of settings and span a wider range of exposure than is currently available. Exposure–response data for other health outcomes is desirable, but has lower priority.

Economic evaluation is at an early stage, and there is a need for more empirical evidence on costs and the full range of benefits associated with various interventions across a range of settings. It is also important to determine the direct impact of household energy interventions on poverty reduction and the pathways by which this is mediated, both at the household/community level as well as at the macroeconomic level for countries.

In conclusion, work on household energy solutions for developing countries is at a critical stage. There is a strong and growing case for action. Improved technologies and cleaner fuels are already available or require relatively modest investment for innovation. Growing efforts to find ways to reduce global warming emissions that also assist poor countries provide another opportunity. Improvements in household energy will contribute directly to achieving the Millennium Development Goals, particularly child mortality reduction (Goal 4) and extreme poverty reduction (Goal 1). The principal challenge is to achieve a rapid but sustainable increase in access to cleaner, more efficient household energy among the 3 billion people in the world whose development prospects are held back by practices that affluent nations have long since left behind. This will require wider awareness of the problem, increased political commitment, and careful deployment of substantially greater financial resources than are currently allocated to this critical aspect of development.

See also: Indoor Air Pollution Attributed to Solid Fuel Use for Heating and Cooking and Cancer Risk, Solid Fuel: Health Effects, Solid Fuel Use: Health Effect.

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Relevant Websites

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